1: Microsoft
2: WORMPEX AI RESEARCH LLC

gDLS*: Generalized Pose and Scale Estimation Given Scale and Gravity Priors

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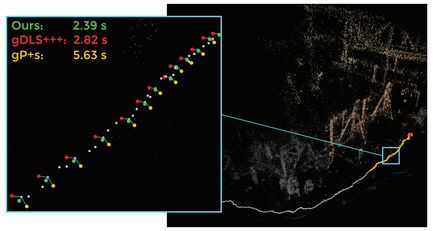
Problem

Fast and Accurate Pose and Scale Solvers for Aligning Two 3D Maps

	gP+s	gDLS	gDLS+++	UPnP	gDLS*
Generalized Camera	x	x	x	x	x
Geometric Optimality	x	x	x	x	x
Linear Complexity		x	x	x	x
Multiple Solutions	x	x	x	x	x
Similarity Transformation	x	x	x		x
Singularity-Free Rotation	x		x	x	x
Gravity Prior					x
Scale Prior					x



gDLS* uses scale and gravity priors to improve speed and accuracy

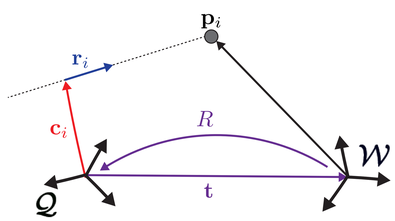
Method

*see paper for full derivation

gDLS Formulation

$$J_{gDLS} = J(R, \mathbf{t}, s, \boldsymbol{\alpha}) = \sum_{i=1}^{n} \|\alpha_i \mathbf{r}_i - (R\mathbf{p}_i + \mathbf{t} - s\mathbf{c}_i)$$

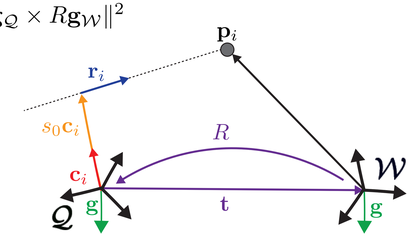
$\mathbf{p}_i$ - 3D point in $\mathcal{W}$
R - Rotation from $\mathcal{W}$ to $\mathcal{Q}$
$\mathbf{t}$ - Position of $\mathcal{W}$ from $\mathcal{Q}$
$\alpha_i \mathbf{r}_i + \mathbf{c}_i$ - Measurement of $\mathbf{p}_i$ from $\mathcal{Q}$



gDLS* Formulation: Adding Gravity and Scale Priors

$$J' = J_{gDLS} + J'_s + J'_g = J(R, \mathbf{t}, s, \boldsymbol{\alpha}) + \lambda_s (s_0 - s)^2 + \lambda_g \|\mathbf{g}_{\mathcal{Q}} \times R\mathbf{g}_{\mathcal{W}}\|^2$$

$\mathbf{g}$ - gravity direction prior
$\mathbf{c}_i$ - scale prior
λ_g - gravity prior weight
λ_s - scale prior weight



Computing the gDLS* Formulation in Closed Form

Computable Closed form solutions for each component

$$J_{gDLS} = \mathrm{vec}(R)^\intercal M_{\mathrm{gDLS}} \mathrm{vec}(R) + 2\mathbf{d}_{\mathrm{gDLS}}^\intercal \mathrm{vec}(R) + k_{\mathrm{gDLS}}$$
$$J'_s = \mathrm{vec}(R)^\intercal M_s \mathrm{vec}(R) + 2\mathbf{d}_s^\intercal \mathrm{vec}(R) + k_s$$
$$J'_g = \mathrm{vec}(R)^\intercal M_g \mathrm{vec}(R)$$

Combine gDLS and Prior Terms

$$M = M_{\mathrm{gDLS}} + M_s + M_g$$
$$\mathbf{d} = \mathbf{d}_{\mathrm{gDLS}} + \mathbf{d}_s$$
$$k = k_{\mathrm{gDLS}} + k_s$$

Simplified Computable Closed Form Solution

$$J' = \mathrm{vec}(R)^\intercal M \mathrm{vec}(R) + 2\mathbf{d}^\intercal \mathrm{vec}(R) + k$$

Synethetic Experiments

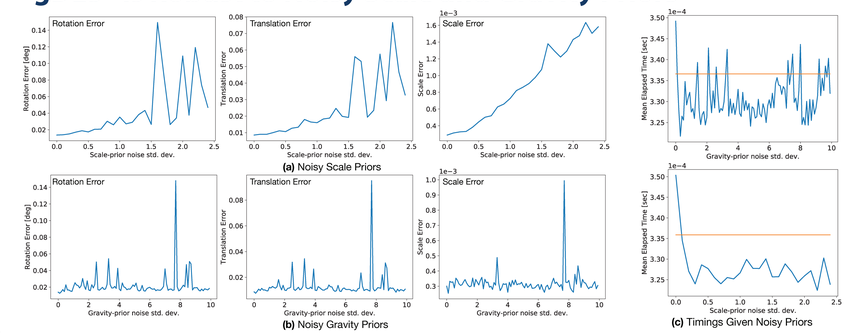
Experiment Setup

10 Randomly Positioned Cameras in [-10,10] x [-10,10] x [-10,10] cube

300 Randomly Positioned Points in [-5,5] x [-5,5] x [10,20] rectangular prism

1000 Trials: 3D points are transformed by the inverse of a random ground truth s[R | t]

gDLS* is Robust to Noisy Scale and Gravity Priors



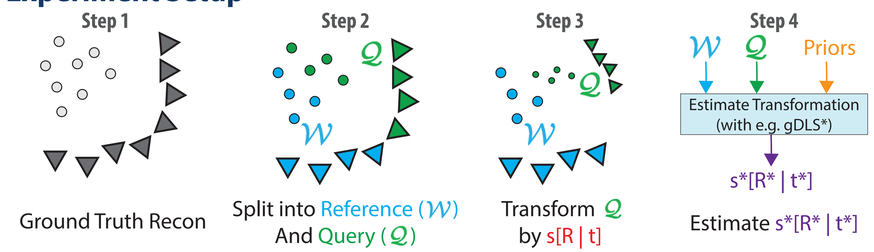
(a) Noisy Scale Priors
(b) Noisy Gravity Priors
(c) Timings Given Noisy Priors

Aligning Real SfM Reconstructions

Real World Datasets (Images, Gravity)

TUM RGBD Dataset KITTI Dataset

Experiment Setup



Ground Truth Recon
Split into Reference ($\mathcal{W}$) And Query ($\mathcal{Q}$)
Transform $\mathcal{Q}$ by s[R | t]
Estimate s*[R* | t*]

Scale and Gravity Priors Improve Solution Estimation Time

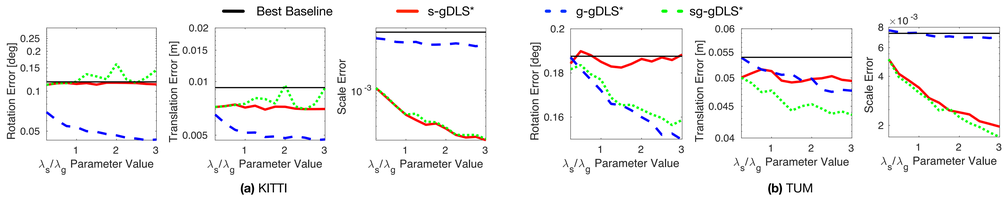
	Average Estimation Time (s)					
	gP+s	gDLS	gDLS+++	gDLS*-s	gDLS*-g	gDLS*-sg
TUM RGBD	8.48	12.03	4.52	5.93	**3.30**	4.79
KITTI	1.13	1.67	0.78	0.90	**0.57**	0.77
Total	4.81	6.85	2.65	3.41	**0.65**	2.78

Scale and Gravity Priors Improve Accuracy

	Average R_{error} [deg] (10^{-1})				Average t_{error} (10^{-2})				Average s_{error} (10^{-3})			
	gP+s	gDLS	gDLS+++	gDLS*	gP+s	gDLS	gDLS+++	gDLS*	gP+s	gDLS	gDLS+++	gDLS*
TUM RGBD	2.04	1.88	1.93	**1.54**	5.91	5.39	5.54	**4.29**	7.34	7.65	7.68	**1.93**
KITTI	1.27	1.18	1.25	**1.09**	0.98	0.93	0.99	**0.70**	7.22	6.94	7.11	**0.76**
Total	1.65	1.53	1.59	**1.32**	3.45	3.16	3.26	**2.50**	7.28	7.29	7.40	**1.34**

TUM RGBD: Fr1 Desk, Fr1 Room, Fr2 LargeNoLoop, Fr1 Desk2, Fr2 Pioneer SLAM, Fr2 Pioneer SLAM 2 KITTI: Drive 1, 9, 19, 22, 23, 29

Ablation: Both Priors Improve Accuracy and Speed When Used Individually or Together



(a) KITTI
(b) TUM