Final Presentation Master Thesis

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Outline

Dense SLAM with B-Splines
Motivation

Picture of Sparse SLAM Picture of Dense SLAM

Project Goal and Methodology

Project Goals

Create framework for surface reconstruction and localization using moving stereo camera based on moving monocular camera case.

Added functionalities

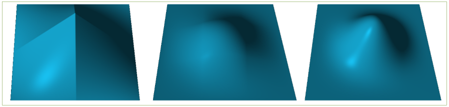
- Create spline surface reprensentation from static stereo camera.
- Localize new stereo camera position using obtained map.

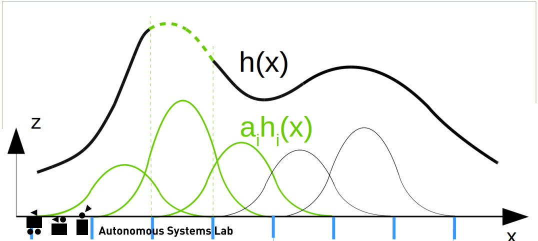
Methodology

- Simulation environment `ROS`with `rviz`for pointcloud and `opencv`for image handling.
- Implementation of optimization algorithm using `Eigen`'s sparse matrix solvers.
- Localization method using photometric errors only and generic rotation representation

B-Splines for surface representation
Theoretical Concepts

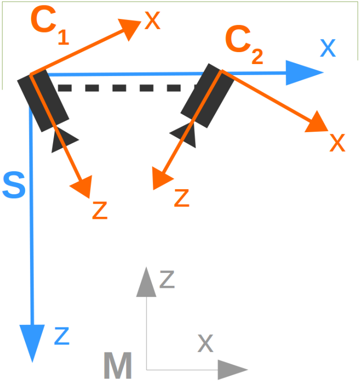
Splines: piecewise polynomial function of degree $<d$.
B(asis)-Splines: Specific choice of finite-support splines calculated by *Cox de Boor* recursion formula (support $s = d + 1$).





$$h(x_j) = \sum_{i=0}^{M} a_i h_i(x_j)$$
$$= \sum_{i=k}^{k+s} a_i h_i(x_j), \text{ for } j = 1 \dots N$$

Camera setup
Theoretical Concepts



Camera poses described by ${}_M\boldsymbol{r}_{MC_k}$ and $\boldsymbol{C}_{C_kM}$ for $k = 1, 2$ or

$$\boldsymbol{\xi}_{C_k} := \left[{}_M\boldsymbol{r}_{MC_k}, \boldsymbol{\Phi}_{\boldsymbol{CM}}\right]^T$$

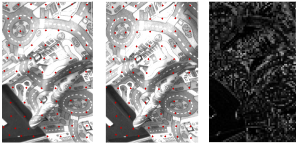
$$\boldsymbol{\xi}_{S} := \left[{}_M\boldsymbol{r}_{MS}, \boldsymbol{\Phi}_{\boldsymbol{SM}}\right]^T$$

with $\boldsymbol{\Phi}_{\boldsymbol{CM}}, \boldsymbol{\Phi}_{\boldsymbol{SM}} \in \mathbb{R}^3$ [?]

If stereo rotation matrices $\boldsymbol{R}_k := \boldsymbol{C}_{SC}$ and baseline $T_x := {}_S\boldsymbol{r}_{C_1C_2}$ are known, one pose of $\{\boldsymbol{\xi}_{C_1}, \boldsymbol{\xi}_{C_2}, \boldsymbol{\xi}_S\}$ is sufficient for all poses to be defined.

Photometric errors for mapping

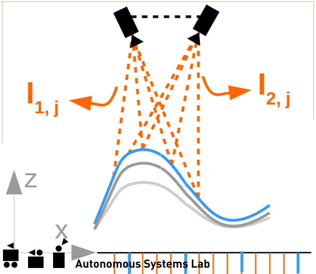
Theoretical Concepts



Photometric error of grid point x_j, y_j:

$$r_j = I_1(\boldsymbol{u}_{j,1}) - I_2(\boldsymbol{u}_{j,2}) \ ,$$

with I_1, I_2 interpolated intensities at the locations $\boldsymbol{u}_{j,k}$ in camera $k = 1$ and $k = 2$.



$$\boldsymbol{u}_{j,k} = \boldsymbol{K}_k D_k(\boldsymbol{T}_k({}_M\boldsymbol{r}_{MX_j}))$$

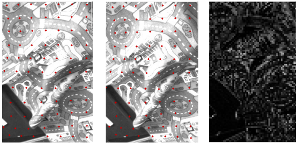
$$\boldsymbol{T}_k({}_M\boldsymbol{r}_{MX_j}) = \pi({}_{C_k}\boldsymbol{r}_{C_k X_j})$$

$$= \pi(\boldsymbol{C}_{C_k M}({}_M\boldsymbol{r}_{MX_j} - {}_M\boldsymbol{r}_{MC_k}))$$

3D point given by spline map:

$${}_M\boldsymbol{r}_{MX_j} = \begin{bmatrix} x_j & y_j & h(x_j, y_j) \end{bmatrix}^T$$

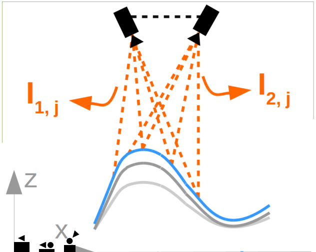
Photometric errors for mapping
Theoretical Concepts



The analytical Jacobian

$$\boldsymbol{J}_r(\boldsymbol{a}) = \frac{\partial \boldsymbol{r}(\boldsymbol{a})}{\partial \boldsymbol{a}} \in \mathbb{R}^{NxM}$$

is obtained by the chain rule:



$$\boldsymbol{J}_r(\boldsymbol{a}) = (\boldsymbol{J}_{pixel,1}\boldsymbol{J}_{camera,1}({}_M\boldsymbol{r}_{MX_j}) - \boldsymbol{J}_{pixel,2}\boldsymbol{J}_{camera,2}({}_M\boldsymbol{r}_{MX_j}))\boldsymbol{J}_{splines} \ ,$$

with

$$\boldsymbol{J}_{pixel,k} = \frac{\partial I_k(\boldsymbol{u}_k)}{\partial \tilde{\boldsymbol{u}}_k}, \quad \boldsymbol{J}_{camera,k}({}_M\boldsymbol{r}_{MX_j}) = \frac{\partial \tilde{\boldsymbol{u}}_k}{\partial {}_M\boldsymbol{r}_{MX_j}}$$

Optimization problem for mapping

Theoretical Concepts

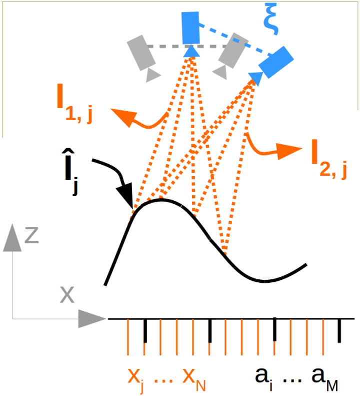
$$\hat{\boldsymbol{a}} = \underset{\boldsymbol{a}\in\mathbb{R}^M}{\arg\min}\ f(\boldsymbol{a})$$
$$= \underset{\boldsymbol{a}\in\mathbb{R}^M}{\arg\min}\ \frac{1}{2}(\sum_{j=0}^{N} w_j r_j(\boldsymbol{a})^2 + \beta \boldsymbol{a}^T \boldsymbol{B}\boldsymbol{a} + \gamma \boldsymbol{a}^T \boldsymbol{G}\boldsymbol{a})\ ,$$

with

- bending and gradient energy regularization terms and
- weight representing the average visibility of point j.

Photometric errors for localization

Theoretical Concepts

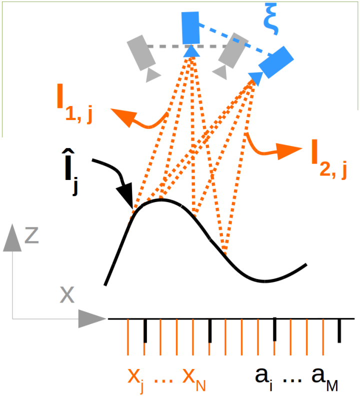


Photometric error of grid point x_j, y_j:

$$r_{j,1} = I_1(\boldsymbol{u}_{j,1}) - \hat{I}(x_j, y_j)$$
$$r_{j,2} = I_2(\boldsymbol{u}_{j,1}) - \hat{I}(x_j, y_j) \;,$$

with I_1, I_2 interpolated intensities at pixels $\boldsymbol{u}_{j,k}$ in camera $k = 1$ and $k = 2$ and $\hat{I}(x_j, y_j)$ the estimated intensity from previous step.

Photometric errors for localization
Theoretical Concepts



The analytical Jacobian

$$J_r(\xi) = \frac{\partial r(\xi)}{\partial \xi} \in \mathbb{R}^{Nx6}$$

is obtained by the chain rule:

$$J_r(\xi) = J_{pixel} J_{camera}(\xi)$$

with

$$J_{pixel} = \frac{\partial I(u)}{\partial \tilde{u}}, \quad J_{camera}(\xi) = \frac{\partial \tilde{u}}{\partial \xi}$$

Optimization problem for localization

Theoretical Concepts

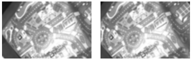
$$\hat{\boldsymbol{\xi}} = \underset{\hat{\boldsymbol{\xi}} \in \mathbb{R}^6}{\arg\min} \; \frac{1}{2} \sum_{j=0}^{N} r_j(\boldsymbol{\xi})^2$$

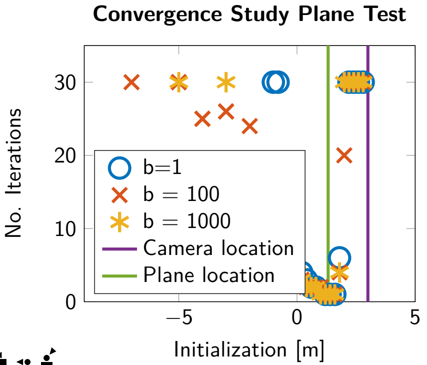
Datasets and parameters

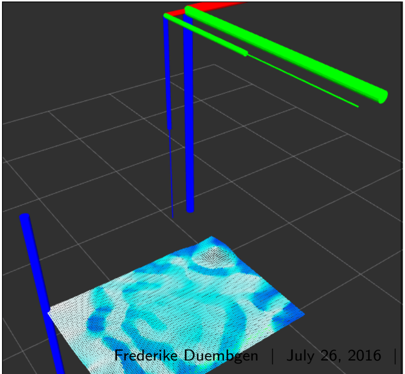
Results Mapping

Dataset	Plane test	Middlebury [?]	Inhouse
Ground truth	analytical	structured light	pattern matching
Images	rectified	rectified	non rectified
Calibration	+++	++	+
Mapping	yes	yes	yes
Localization	yes	no	no
Spline resolution	20 x 20	75 x 100	
Map dimensions	0.9 x 1.2	1.5 x 2.0	
Map resolution	90 x 120		

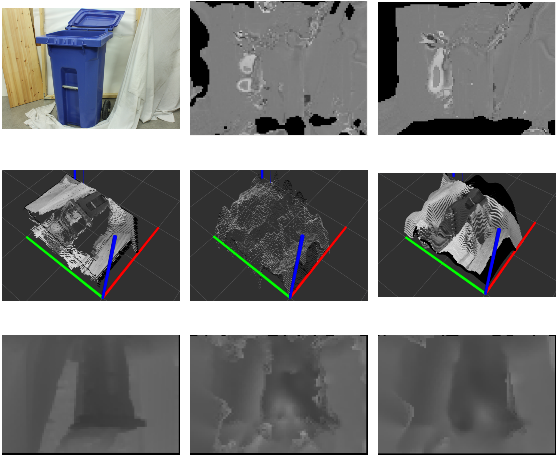
Plane test case
Mapping







Middlebury dataset
Mapping



Inhouse dataset

Mapping

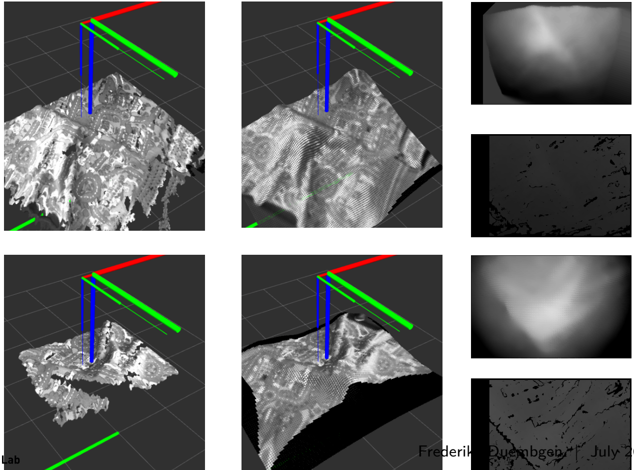
Parameters: $\beta = 10$ $\gamma = 100e3$ $d = 100$

Parameters:

$\beta = 10$

$\gamma = 1e6$

$d = 100$



Plane test case
Localization

Achievements

Localization

Suggestions For Future Work
Localization