MONOCULAR SIMULTANEOUS LOCALIZATION AND MAPPING SYSTEM FOR A WHEELED MOBILE ROBOT

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INTRODUCTION

The present work describes the implementation of a monocular SLAM system applied to a wheeled mobile robot moving in an indoor environment. The implemented visual SLAM makes use of the latest techniques for undelayed landmark initialization which are required given the partial observability of bearing only SLAM. Presented results show the performance of the implementation mainly for robot pose estimation, from which a highly accurate result in robot orientation estimation can be observed.

MONOCULAR VISUAL SLAM

EKF-SLAM

Discrete-time dynamic system for EKF based SLAM

$$\mathbf{x}_k = \boldsymbol{f}(\mathbf{x}_{k-1}, \mathbf{u}_{k-1}) + \mathbf{w}_k, \qquad \mathbf{w}_k \sim \mathcal{N}(\mathbf{0}, \mathbf{Q}_k), \tag{1}$$

$$\mathbf{z}_k = \boldsymbol{h}(\mathbf{x}_k) + \mathbf{v}_k, \qquad \mathbf{v}_k \sim \mathcal{N}(\mathbf{0}, \mathbf{R}_k) \tag{2}$$

where $\mathbf{x}_k$ is the unobserved system state, $\mathbf{u}_k$ is the known control action, $\mathbf{z}_k$ is the observation. The process equation (1) is the odometric motion model, and the observation equation (2) is the sensor model which projects map landmark to the sensor space.
The state vector is composed of the robot state given by its pose (position and orientation) $\mathbf{x}_R$, and the map state $\mathbf{x}_M$, i.e.

$$\mathbf{x} = \begin{bmatrix} \mathbf{x}_R \\ \mathbf{x}_M \end{bmatrix}, \quad \text{where} \quad \mathbf{x}_R = \begin{bmatrix} x_r \\ y_r \\ \theta_r \end{bmatrix} \quad \text{and} \quad \mathbf{x}_M = \begin{bmatrix} \mathbf{x}_1 \\ \vdots \\ \mathbf{x}_N \end{bmatrix},$$

with $\mathbf{x}_i, i = 1, \ldots, N$ are the map landmark positions.

Landmark parametrization

Map landmarks are 3D points represented by either Euclidean $\mathbf{x}_{\text{EU}}$ or Inverse depth $\mathbf{x}_{\text{ID},i}$ parametrizations (also known as Anchored Modified Polar Point) [1]. The measurement function (2) projects these points to image points $\underline{\mathbf{m}}_i$ in the image plane, using the pin-hole camera model.

- Euclidean representation:

$$\mathbf{x}_{\text{EU}} = \begin{bmatrix} X & Y & Z \end{bmatrix}^T \in \mathbb{R}^3,$$
$$\underline{\mathbf{m}} = \mathbf{K}\mathbf{R}_W^C(\mathbf{x}_{\text{EU}} - \mathbf{t}_C^W) \in \mathbb{P}^2.$$

- Inverse Depth Parametrization (IDP)[2]:

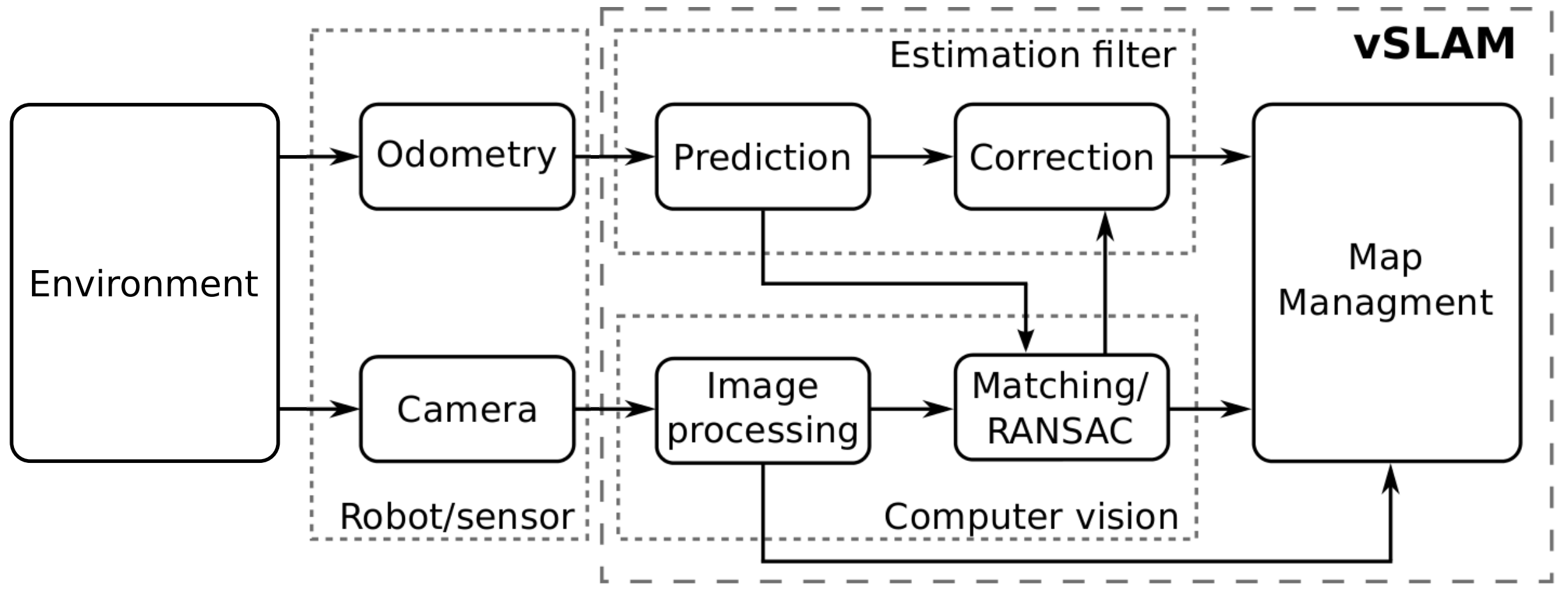
$$\mathbf{x}_{\text{ID}} = \begin{bmatrix} x_0 & y_0 & z_0 & \gamma & \phi & \rho \end{bmatrix}^T \in \mathbb{R}^6,$$
$$\underline{\mathbf{m}} = \mathbf{K}\mathbf{R}_W^C\left(\rho(\mathbf{t}_0 - \mathbf{t}_C^W) + \mathbf{d}(\gamma, \phi)\right) \in \mathbb{P}^2.$$

The Inverse Depth Parametrization allows to initialize map features immediately when new image points are detected, in a process known as Undelayed Landmark Initialization (ULI).

IMPLEMENTATION

The aim of the current implementation is to be applied to an indoor wheeled mobile robot carrying a single camera. This implementation is an adaptation of [3].

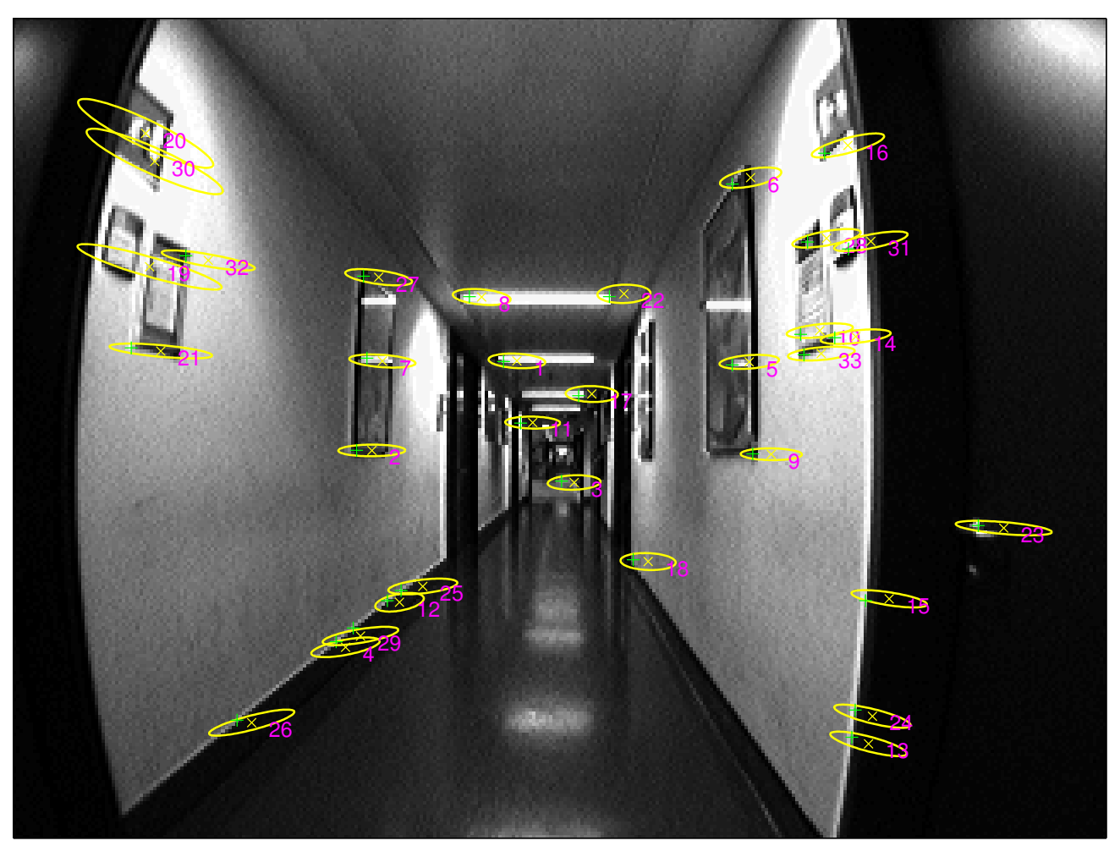
Monocular visual SLAM system


Estimation filter
vSLAM
Environment
Odometry
Prediction
Correction
Map Managment
Camera
Image processing
Matching/ RANSAC
Robot/sensor
Computer vision

The implemented monocular SLAM includes:

- ULI process by means of the IDP (with IDP to EU conversion),
- 1-Point RANSAC algorithm for data association,
- FAST image point detector and patch correlation (NCC) for matching.

Measurement prediction and matching



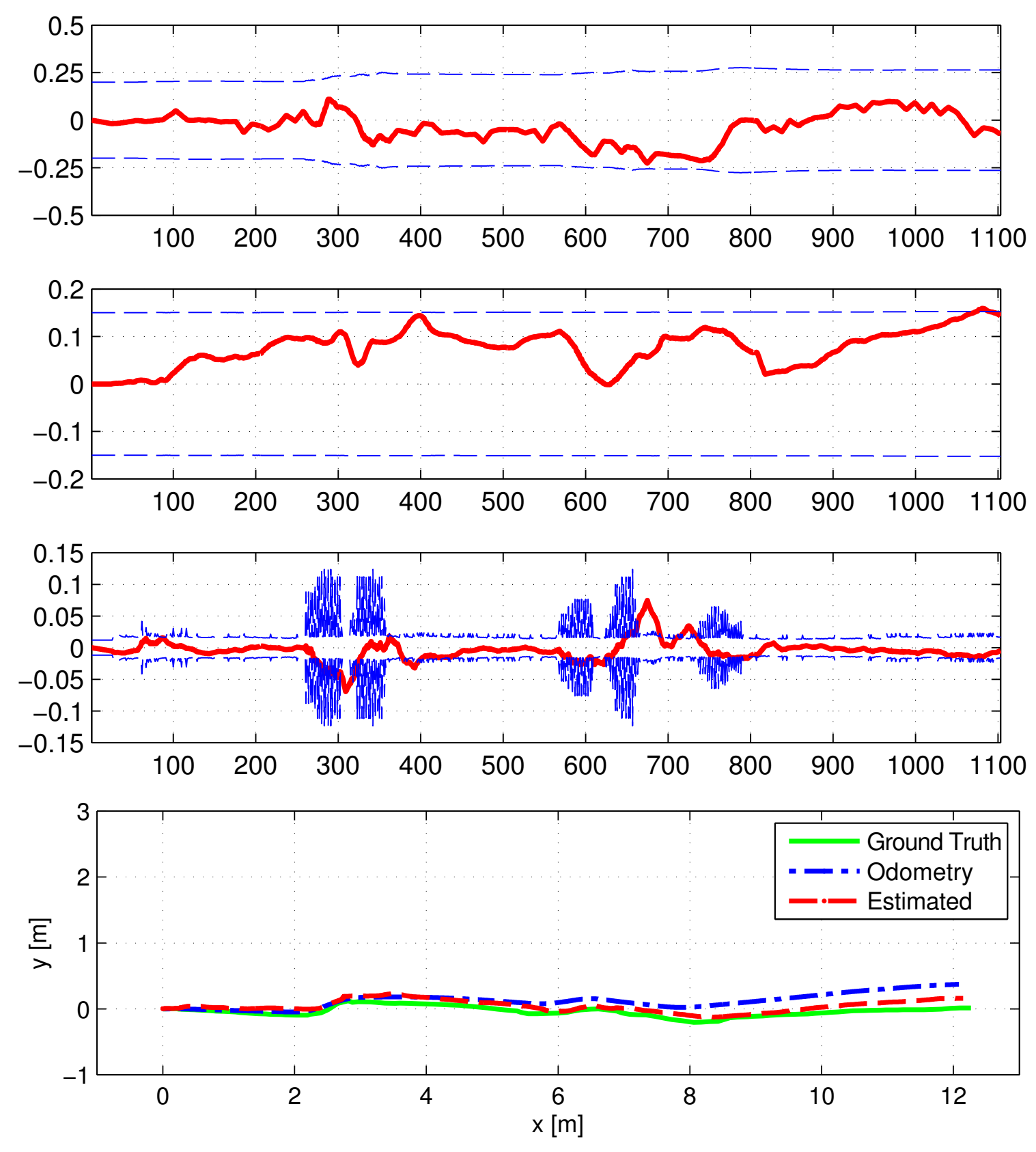
Matching process: bounding box and patches

RESULTS

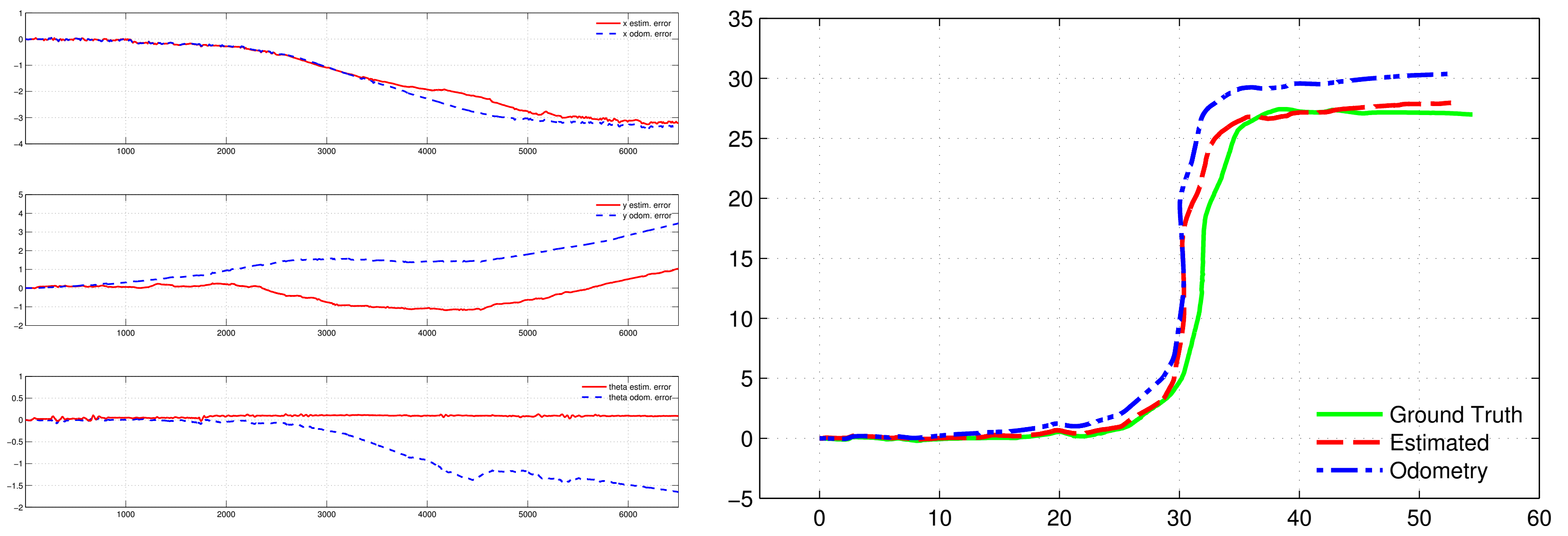
The algorithm evaluation is performed using the RAWSEEDS dataset. This includes an image sequence from a camera of 320×240 pixels, odometry and the robot pose Ground Truth (GT).

Results 1. The robot moves forward along a corridor in a path of length of 12m.

- Robot pose estimation error (red solid line) together with the uncertainties in the estimation given by $\pm 3\sigma$ bounds (blue dashed line).
- Robot path estimated by the SLAM, the GT and the odometry data.



Results 2. The robot moves along a corridor and an open area, of total length of approx. 70m. Robot pose error in (x_r, y_r, θ_r) given by odometry (blue dashed line) and SLAM estimation (red solid line).



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[3] J. Civera, O. G. Grasa, A. J. Davison, and J. M. M. Montiel, "1-point ransac for extended kalman filtering: Application to real-time structure from motion and visual odometry," *J. Field Robotics*, vol. 27, no. 5, pp. 609–631, 2010.

CONCLUSIONS

The results demonstrate that a monocular visual system can be used in robotic SLAM for robot pose estimation, even though it is not able to perceive scene depth and its limited field of view. They also show, as theory suggests, that a monocular vision system acts as a very precise orientation sensor, mainly due to the use of inverse depth parametrization for undelayed landmark initialization.