# Marker-based FastSLAM on the AlphaBot2

## Autonomous Systems Project 2023/2024


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# Presentation Overview

# AlphaBot2 Measurement Noise

# AlphaBot2 Measurement Noise

- AlphaBot2 implements a monocular **visual** SLAM.
- J. Wu and H. Zhang, “Camera Sensor Model for Visual SLAM,” Fourth Canadian Conference on Computer and Robot Vision (CRV ’07)

# AlphaBot2 Measurement Noise

## Covariance Matrix

*The covariance matrix in the measurement model is fundamental for SLAM as it provides a measure of the uncertainty associated with sensor measurements, allowing for* ***accurate state estimation****, and* ***robust mapping and localization****.*

# AlphaBot2 Measurement Noise
## Reprojection Error

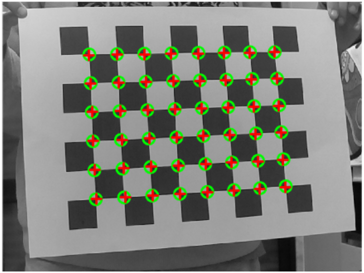

Figure: Reprojection error in calibration checkboard

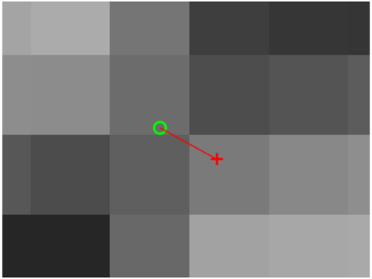

Figure: Reprojection error up close

- **Detection of 2D points in the image plane:** Identify the checkerboard corners in the 2D image plane.
- **Estimation of pose/transform:** Estimate the 3D transformation between the camera and the corners.
- **Projection of 3D points to the 2D image plane:** Project the real checkerboard corners coordinates obtained in the previous step on a 2D image plane.
- **Calculation of reprojection errors:** Compare the observed 2D coordinates with the projected 2D coordinates to compute the reprojection errors.

We proceed to calculate the measurement noise covariance matrix for a set of distances (50cm, 180cm, 270cm):

$$R = \frac{1}{N}\sum_{i=1}^{N}(X_i - \overline{X})(X_i - \overline{X})^T$$

# AlphaBot2 Measurement Noise
## Linear Regression

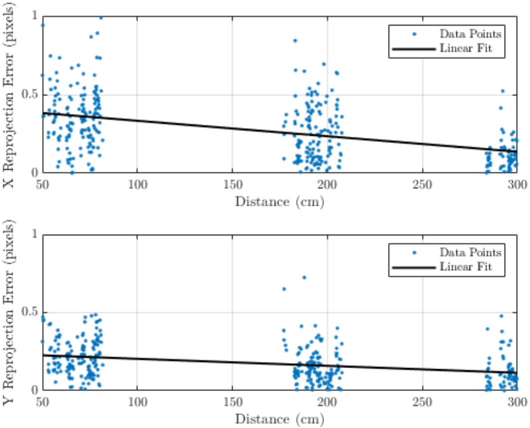


Figure: Reprojection errors when feature points are at various ranges

These findings align with the paper, confirming that increased distance leads to higher measurement uncertainty, despite improved relative precision in feature detection. **WHY?**

**Projection Geometry**:

- When features are farther from the camera, small errors in measured positions lead to smaller angular errors due to projection geometry.
- Reprojection errors in pixel coordinates decrease, leading to a lower standard deviation.
- 3D positions of feature points decrease with distance to the camera.

**Measurement Noise**:

- The measurement noise covariance matrix $R$ reflects increased uncertainty in feature positions as distance increases.
- Results in larger variance, directly related to squared errors.
- Individual measurements may have lower standard deviations, but overall variance increases due to error accumulation over distance.

In summary, the construction of the measurement noise matrix can be defined as (ignoring the small correlational coefficient)

$$v_t = N(0, R_{2\mathrm{D}})$$

where

$$R_{2\mathrm{D}} = \begin{pmatrix} (a \times range + b)^2 & 0 \\ 0 & (a \times range + b)^2 \end{pmatrix}.$$

How do we change this covariance matrix, which is in 2D pixel coordinates, to 3D world coordinates?

$$x = f_x \frac{X}{Z} + c_x, \quad y = f_y \frac{Y}{Z} + c_y \quad \Longrightarrow \quad R_{\text{2D}} = J_c R_{\text{3D}} J_c^T.$$

Optimization problem:

$$\text{argmin}_{R_{\text{3D}}} \left\| R_{\text{2D}} - J_c R_{\text{3D}} J_c^T \right\|_F^2.$$

# Project Structure

# Project Structure

## Primary References


- L. Joseph and A. Johny, *Robot Operating System (ROS) for Absolute Beginners*, Packt.
- L. Joseph and J. Cacace, *Mastering ROS for Robotics Programming*, Packt.

# Project Structure
## Active ROS Nodes

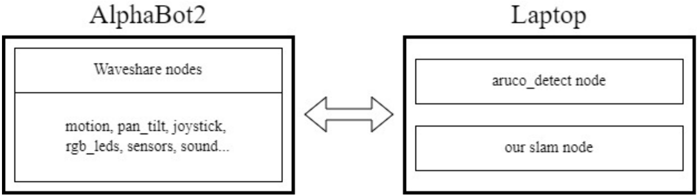


Figure: Separation of the ROS nodes layer

We are interested in:

- `/cmd_vel`, which will be the baseline for the motion model;
- `/fiducial_transforms`, which contains the ArUco's relative position and orientation to the robot.

# geometry_msgs/Twist Message

## File: geometry_msgs/Twist.msg

## Raw Message Definition

```
# This expresses velocity in free space broken into its linear and angular parts.
Vector3  linear
Vector3  angular
```

## Compact Message Definition

```
geometry_msgs/Vector3 linear
geometry_msgs/Vector3 angular
```

*autogenerated on Wed, 02 Mar 2022 00:06:53*

Figure: Message returned by the Waveshare's motion node

# Project Structure

## Message types

# fiducial_msgs/FiducialTransform Message

### File: fiducial_msgs/FiducialTransform.msg

### Raw Message Definition

```
# A camera to fiducial transform with supporting data
int32 fiducial_id
geometry_msgs/Transform transform
float64 image_error
float64 object_error
float64 fiducial_area
```

### Compact Message Definition

```
int32 fiducial_id
geometry_msgs/Transform transform
float64 image_error
float64 object_error
float64 fiducial_area
```

*autogenerated on Tue, 01 Jun 2021 03:03:26*

Figure: Message returned by the `aruco_detect` node

# Project Structure

## SLAM Node Structure

```
slam_node
├── package.xml
├── CMakeLists.txt
├── include
│   └── slam
│       ├── data_association.h
│       ├── particle_filter.h
│       └── slam.h
├── src
│   ├── data_association.cpp
│   ├── particle_filter.cpp
│   └── slam.cpp
└── launch
    └── slam.launch
```

# Other Work Developed

# Other Work Developed

- Expanded research on the data association topic.
  - Namely, joint compatibility branch and bound.

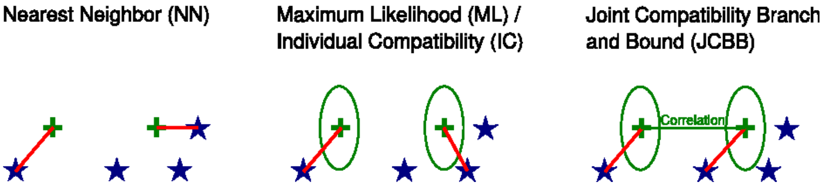


Figure: Data association types

# Questions

# Thank You!