LAMBKIN Benchmark Report

Release 0.1.0-alpha

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ONE

OBJECTIVE

Compare Beluga AMCL *NDT* sensor model against a groundtruth signal for magazino datasets.

CHAPTER

TWO

METHODOLOGY

2.1 Dataset

For this report, Magazino datasets, published with the Cartographer Public Data set under Apache License v2.0, were chosen. As these datasets are distributed in rosbag format, equivalent datasets in rosbag2 format were recreated. As both localization systems need a map to work with, and a groundtruth is necessary for performance evaluation, offline mapping was conducted using Cartographer ROS.

2.2 NDT map

Maps where built by extracting aggregated raw pointcloud data, leveraging Cartographer's assets writer and then converted using *beluga_ros's* PLY to NDT conversion with a 30cm cell size.

2.3 Configuration

For this report, the following baseline configuration:

```
/**:
  ros__parameters:
    # Odometry motion model type.
    robot_model_type: nav2_amcl::DifferentialMotionModel
    # Expected process noise in odometry's rotation estimate from rotation.
    alpha1: 0.1
    # Expected process noise in odometry's rotation estimate from translation.
    alpha2: 0.05
    # Expected process noise in odometry's translation estimate from translation.
    alpha3: 0.1
    # Expected process noise in odometry's translation estimate from rotation.
    alpha4: 0.05
    # Expected process noise in odometry's strafe estimate from translation.
    alpha5: 0.1
    # The name of the coordinate frame published by the localization system.
    global_frame_id: map
    # The name of the coordinate frame published by the odometry system.
    odom_frame_id: odom
    # The name of the coordinate frame of the robot base.
    base_frame_id: base_link
    # The name of the topic where the map is published by the map server.
    map_topic: map
    # The name of the topic where scans are being published.
    scan_topic: scan_front
```

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```
    # The name of the topic where an initial pose can be published.
    # The particle filter will be reset using the provided pose with covariance.
    initial_pose_topic: initialpose
    # Maximum number of particles that will be used.
    max_particles: 2000
    # Minimum number of particles that will be used.
    min_particles: 500
    # Error allowed by KLD criteria.
    pf_err: 0.05
    # KLD criteria parameter.
    # Upper standard normal quantile for the probability that the error in the
    # estimated distribution is less than pf_err.
    pf_z: 3.0
    # Fast exponential filter constant, used to filter the average particles weights.
    # Random particles are added if the fast filter result is larger than the slow␣
↪filter result
    # allowing the particle filter to recover from a bad approximation.
    recovery_alpha_fast: 0.1
    # Slow exponential filter constant, used to filter the average particles weights.
    # Random particles are added if the fast filter result is larger than the slow␣
↪filter result
    # allowing the particle filter to recover from a bad approximation.
    recovery_alpha_slow: 0.001
    # Resample will happen after the amount of updates specified here happen.
    resample_interval: 1
    # Minimum angle difference from last resample for resampling to happen again.
    update_min_a: 0.1
    # Maximum angle difference from last resample for resampling to happen again.
    update_min_d: 0.08
    # Maximum range of the laser.
    laser_max_range: 25.0
    # Maximum number of beams to use in the sensor models. We set this reasonably␣
↪high so that we don't filter beams at all.
    max_beams: 10000
    # Whether to broadcast map to odom transform or not.
    tf_broadcast: false
    # Transform tolerance allowed.
    transform_tolerance: 1.0
    # Execution policy used to apply the motion update and importance weight steps.
    # Valid options: "seq", "par".
    execution_policy: seq
    # Whether to set initial pose based on parameters.
    # When enabled, particles will be initialized with the specified pose coordinates␣
↪and covariance.
    set_initial_pose: true
    # If false, AMCL will use the last known pose to initialize when a new map is␣
↪received.
    always_reset_initial_pose: false
    # Set this to true when you want to load only the first published map from map_
↪server and ignore subsequent ones.
    first_map_only: false
    # Initial pose x coordinate.
    initial_pose.x: 0.0
    # Initial pose y coordinate.
    initial_pose.y: 0.0
    # Initial pose yaw coordinate.
```

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```
    initial_pose.yaw: 0.0
    # Initial pose xx covariance.
    initial_pose.covariance_x: 0.25
    # Initial pose yy covariance.
    initial_pose.covariance_y: 0.25
    # Initial pose yawyaw covariance.
    initial_pose.covariance_yaw: 0.0685
    # Initial pose xy covariance.
    initial_pose.covariance_xy: 0.0
    # Initial pose xyaw covariance.
    initial_pose.covariance_xyaw: 0.0
    # Initial pose yyaw covariance.
    initial_pose.covariance_yyaw: 0.0
    # Scaling parameter for NDT cells amplitude.
    d1: 1.0
    # Scaling parameter for NDT cells covariance.
    d2: 0.6
    # Minimum likelihood for scores.
    minimum_likelihood: 0.01
```

was modified for each benchmark case in terms of:

- the number of particles, chosen from the {250, 500, 1000, 2000, 3000} set;
- the execution policy, to compare single-threaded and multi-threaded performance. Note this feature is only provided by Beluga AMCL.

so as to have a reasonably complete picture of how the localization systems performs.

2.4 Platform

- Hardware
  - CPU: AMD Ryzen 7 5800H with Radeon Graphics @ 4463.0 megahertz MHz x 8 cores (16 threads)
    - L1 instruction cache: 8 x 32 KB, 8-way set associative (64 sets), 64 byte lines, shared by 2 processors
    - L1 data cache: 8 x 32 KB, 8-way set associative (64 sets), 64 byte lines, shared by 2 processors
    - L2 unified cache: 8 x 512 KB (inclusive), 8-way set associative (1024 sets), 64 byte lines, shared by 2 processors
    - L3 unified cache: 16 MB (exclusive), 16-way set associative (16384 sets), 64 byte lines, shared by 16 processors
  - Memory: 20804.681728 MB
- Software
  - OS: Ubuntu 22.04.4 LTS
  - ROS:
    - Distribution: Humble Hawksbill
    - Packages:
      - `beluga_amcl` 2.0.1
      - `nav2_amcl` 1.1.14

2.5 Metrics

To characterize the localization performance of the system, this report uses:

- **APE**. The Absolute Pose Error is the difference between estimated and reference trajectories after alignment when taken as a whole. It is a measure of global accuracy and consistency.
- **RPE**. The Relative Pose Error is the difference between estimated and reference trajectories when compared in fixed time intervals. It is a measure of local accuracy and consistency.

To characterize the computational performance of both systems, this report uses:

- **CPU usage**. Usage is defined as the ratio between the time spent by an OS process, in both user and kernel space, and the total time elapsed.
- **RSS**. The Resident Set Size is the amount of physical memory allocated and held by an OS process.

These metrics are aggregated across multiple runs of each parameter variation to ensure statistical significance.

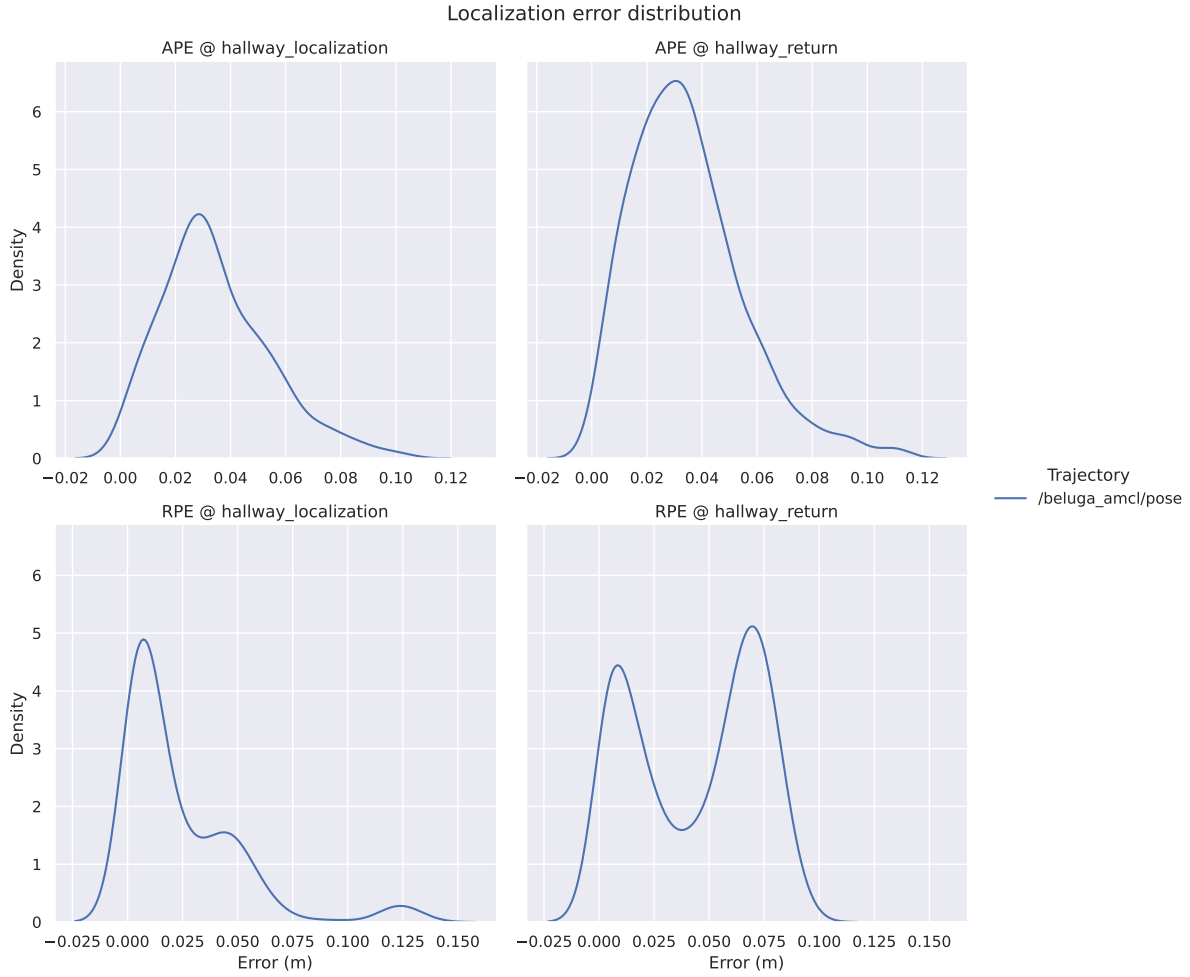
CHAPTER

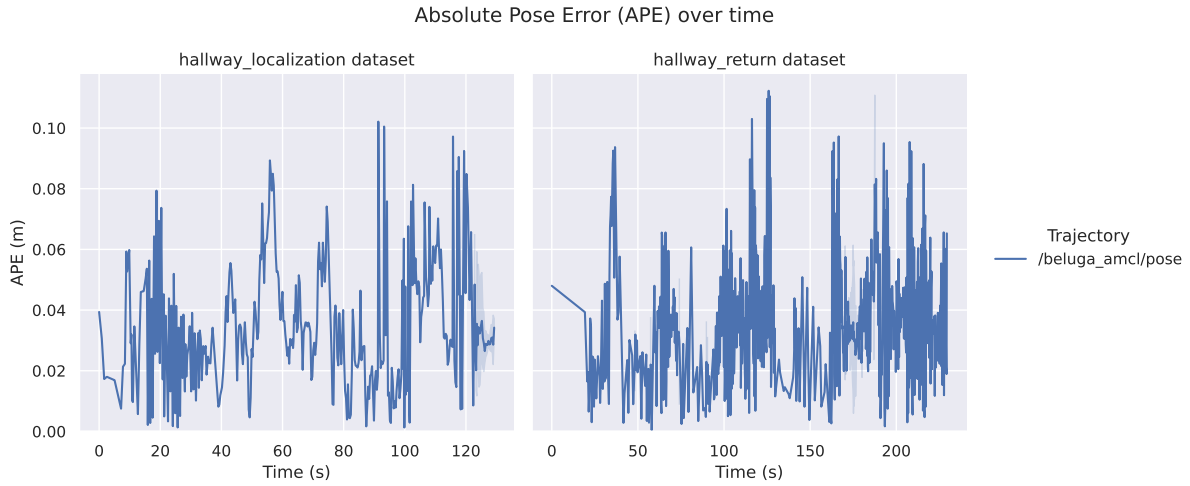
THREE

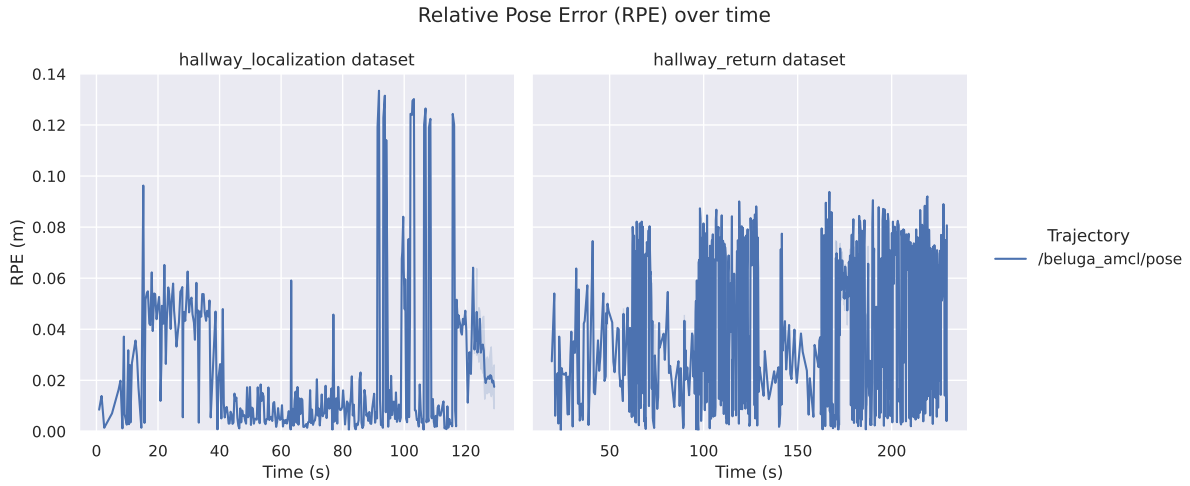
RESULTS

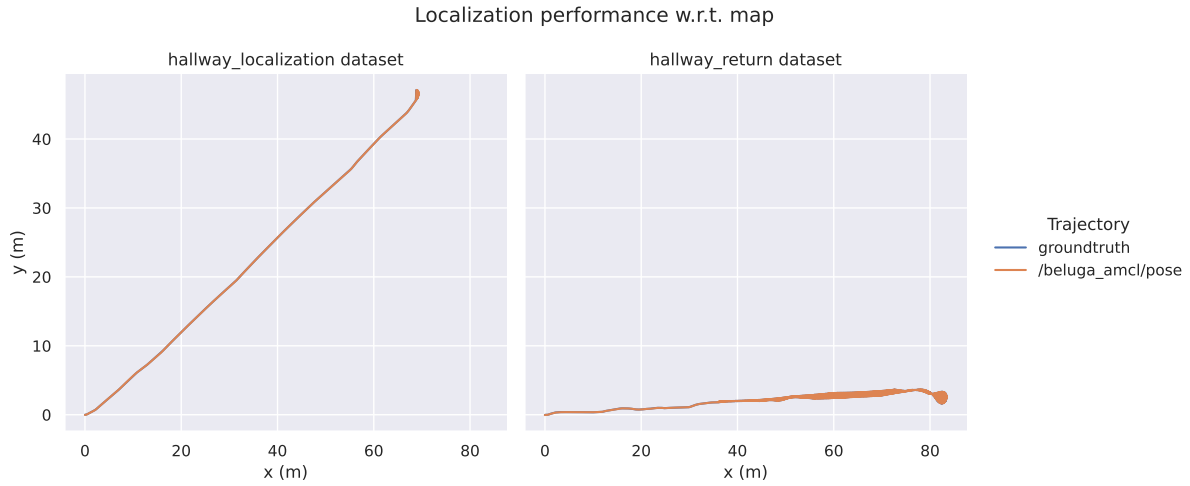
3.1 Nominal setup

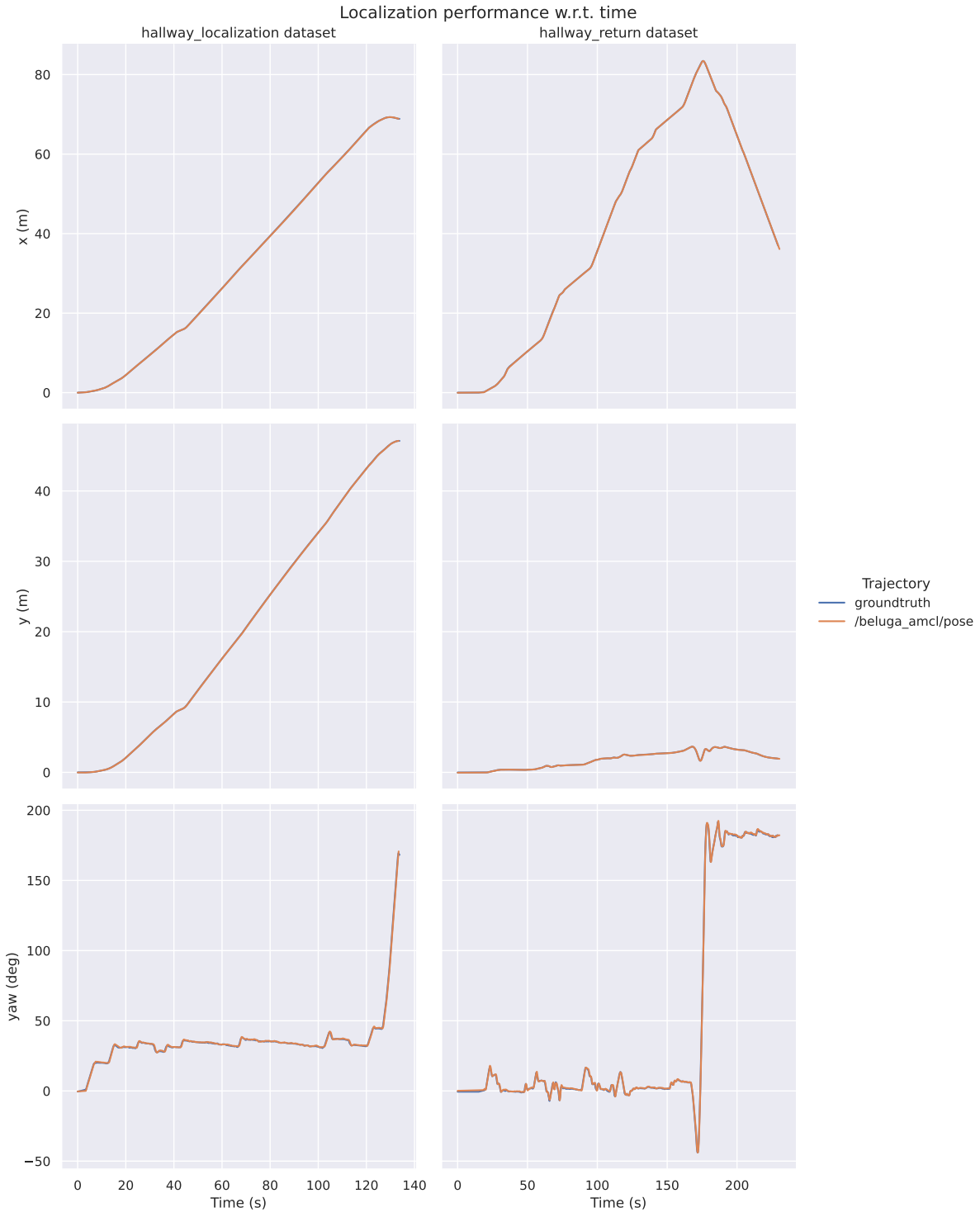
In the following, for a nominal setup this report assumes $N = 2000$ particles (fixed), and a sequential (i.e. single-threaded) execution policy.




Absolute Pose Error (APE) over time
hallway_localization dataset
hallway_return dataset
APE (m)
0.00
0.02
0.04
0.06
0.08
0.10
0 20 40 60 80 100 120
0 50 100 150 200
Time (s)
Time (s)
Trajectory
/beluga_amcl/pose

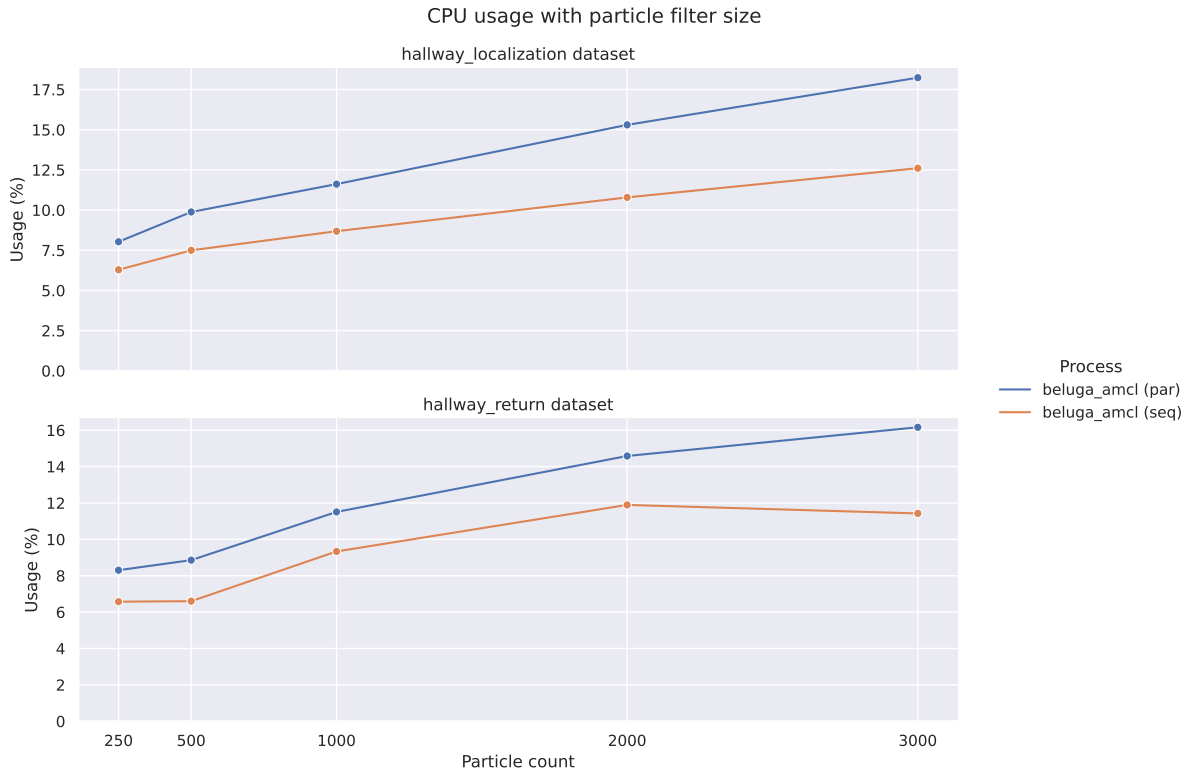

Relative Pose Error (RPE) over time
hallway_localization dataset
hallway_return dataset
RPE (m)
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0 20 40 60 80 100 120
50 100 150 200
Time (s)
Time (s)
Trajectory
/beluga_amcl/pose

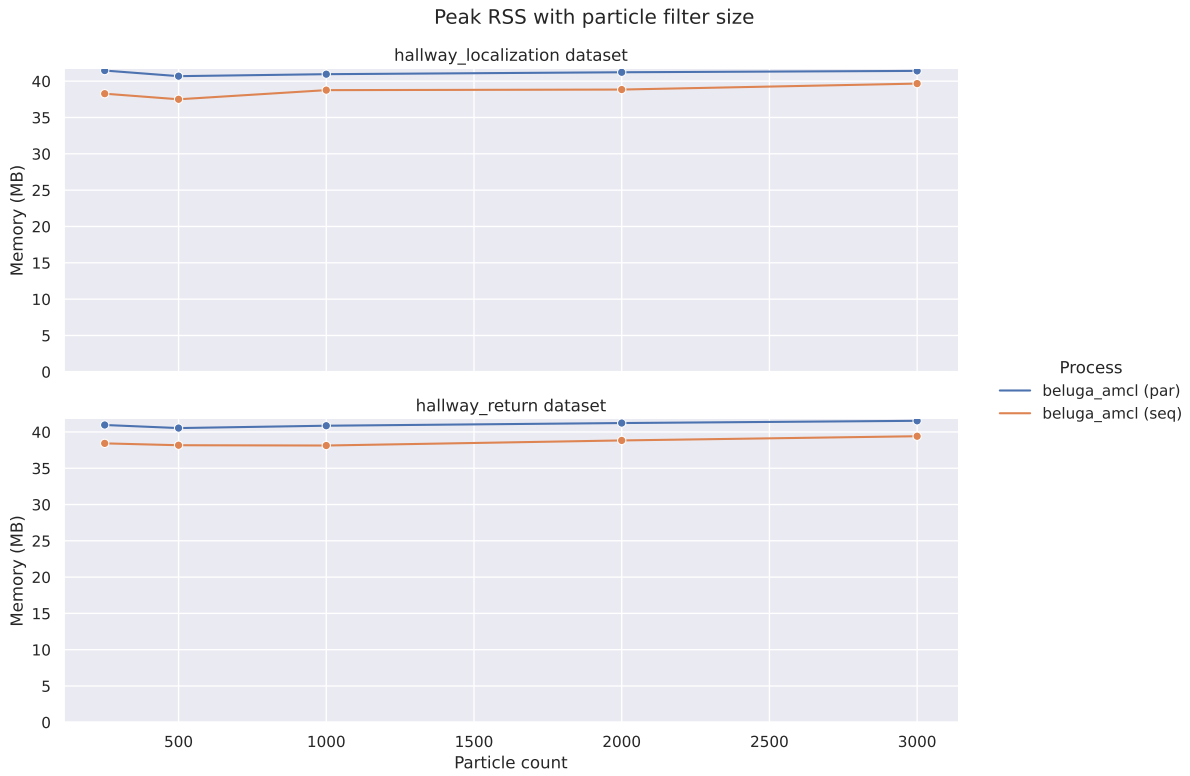

Localization performance w.r.t. map
hallway_localization dataset
hallway_return dataset
y (m)
0
10
20
30
40
0 20 40 60 80
0 20 40 60 80
x (m)
x (m)
Trajectory
groundtruth
/beluga_amcl/pose


Localization performance w.r.t. time
hallway_localization dataset
hallway_return dataset
x (m)
y (m)
yaw (deg)
Time (s)
Time (s)
Trajectory
groundtruth
/beluga_amcl/pose

3.2 Setup sweep

In the following, this report sweeps over parameterizations to compare the resulting performance. Error bars represent bootstrapped 95% confidence intervals.




Peak RSS with particle filter size
hallway_localization dataset
hallway_return dataset
Memory (MB)
Particle count
Process
beluga_amcl (par)
beluga_amcl (seq)