

Universal Online Kinematic Parameters Calibration for Mobile Robots

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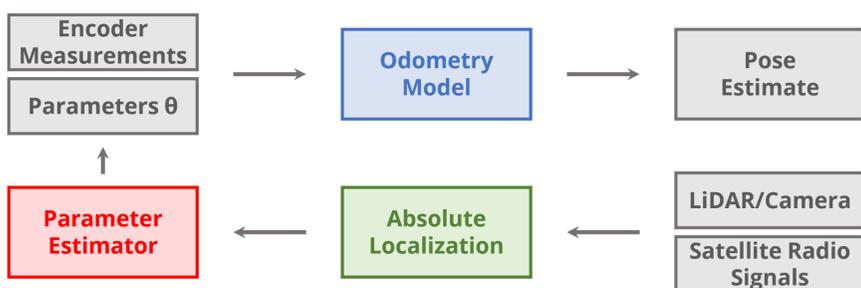
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CALIBRATION PROBLEM

Accurate robot odometry depends on correct kinematic parameters (wheel diameters, wheelbase, steering geometry). In practice, nominal parameter values deviate due to manufacturing tolerances, wear, and structural deformation, leading to systematic pose drift. Existing calibration approaches fall into three main groups. **Geometric methods (offline)** rely on predefined calibration trajectories [1]. **EKF-based methods (online)** estimate pose and parameters simultaneously but are sensitive to covariance initialization and noise modelling [2]. **Optimization methods (offline)** estimate parameters minimizing the error between predicted and measured robot motion but can be computationally intensive [3]. **All existing approaches are platform-specific.**

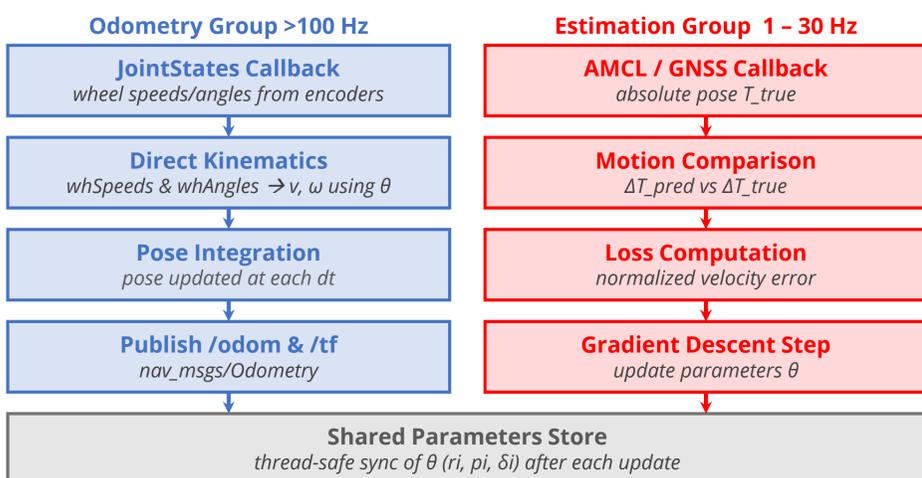
PROPOSED SOLUTION

A gradient-based estimator operates in parallel with an odometry model and continuously updates kinematic parameters using feedback from absolute localization. The correction runs online during normal robot operation, requiring no dedicated calibration trajectories or interruption of the system.

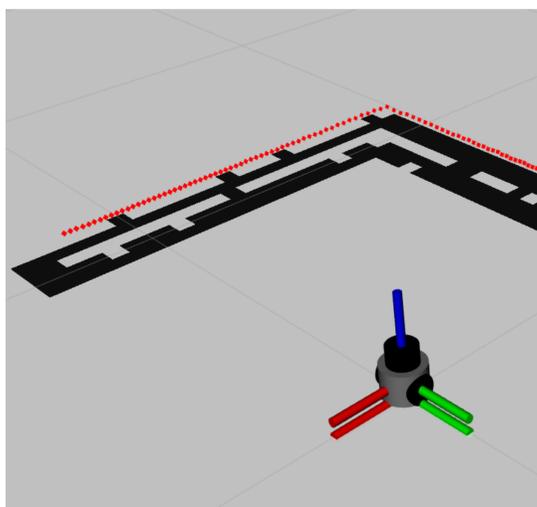


SOFTWARE ARCHITECTURE

Two mutually exclusive callback groups run in parallel via `MultithreadedExecutor`, ensuring parameter estimation never blocks odometry output.



EXPERIMENTAL SETUP



Simulator:
Gazebo Ignition + Rviz
Real physics

Platform:
Differential Drive
2-wheels, non-steerable

Localization
AMCL (Adaptive Monte Carlo)
1 - 10 Hz pose updates

Ground Truth
Gazebo TF

Estimated Parameters
Left & right wheel radii

REFERENCES

- [1] Borenstein J., Feng L., "Measurement and correction of systematic odometry errors in mobile robots," IEEE Transactions on Robotics and Automation, 869-880 (1996), doi:10.1109/70.544770.
- [2] Martinelli A., Tomatis N., Siegwart R., "Simultaneous localization and odometry self calibration for mobile robot," Autonomous Robots 22(1), 75-85 (2007), doi:10.1007/s10514-006-9006-7.
- [3] Čaran B., Milić V., Švaco M., Jerbić B., "Odometry calibration and pose estimation of a 4WIS4WID mobile wall climbing robot," 2025 European Conference on Mobile Robots (ECMR), 1-8 (2025); doi:10.1109/ECMR65884.2025.11163129.

EXPERIMENTAL RESULTS & DISCUSSION

Online calibration reduces odometry error by 50.23%.

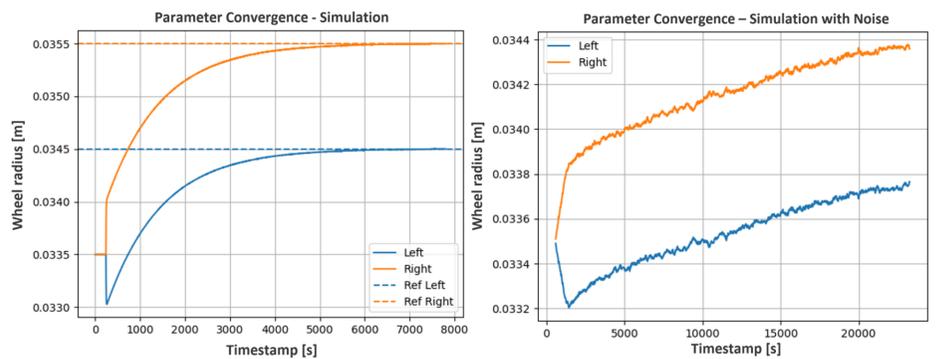


Fig.1 Parameter Convergence. Estimated wheel radii convergence under both conditions. Left: noise-free simulation - estimates convergence to known reference values (dashed). Right: simulation with noise and physics-based wheel deformation - slower but stable convergence.

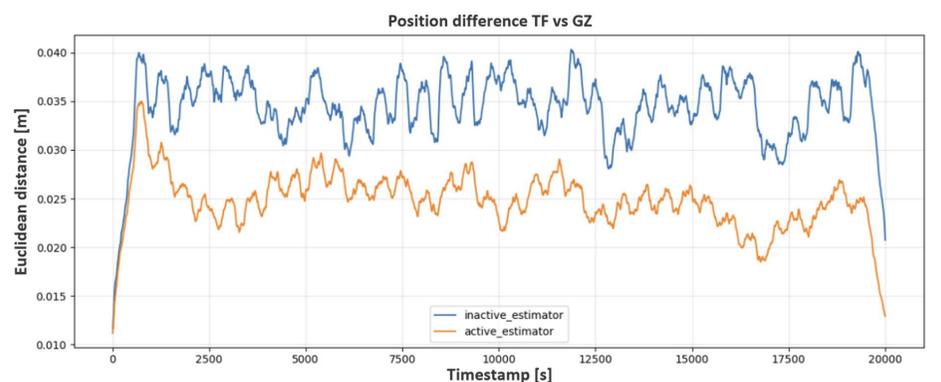


Fig.2 Position Error (TF vs Gazebo Ground Truth). The proposed estimator maintains lower position error than baseline odometry. Orange: odometry with active parameter estimation. Blue: baseline odometry without calibration. Error decreases as the parameters converge. Curves are smoothed using a moving average filter.

Convergence behaviour - in noise-free conditions, wheel radii converge to their reference values within ~6000 seconds (1 hour 40 minutes) of normal robot operation without requiring dedicated calibration manoeuvres.

Noise robustness - loss values are accumulated in a buffer and used collectively for each gradient descent update, averaging out noisy measurements. Stable convergence under noise is further supported by a reduced learning rate.

Non-Blocking operation - parameter estimation runs asynchronously while odometry continues at full encoder rate (> 100 Hz), ensuring no latency or interruption of the navigation system.

CONCLUSIONS

Plug-and-Play Deployment

Directly deployable in ROS 2 systems. The module estimates robot pose and continuously calibrates kinematic model parameters during normal operation.

Fully Autonomous Calibration

The framework performs continuous self-supervised parameter estimation without requiring manual calibration procedures.

Platform-Universal Formulation

A robot-agnostic kinematic formulation applicable across differential, tricycle, Ackermann, pseudo-omnidirectional MR platforms.

Continuous Adaptation

Kinematic parameters are continuously updated to compensate for wheel wear, load variations, and long-term structural changes.

FUTURE WORK

- Real world validation - evaluate the framework on physical mobile robot platforms.
- Extended kinematic model - estimate additional parameters such as contact-point positions and steering-axis offsets.
- Adaptive optimization - introduce adaptive learning-rate scheduling to improve convergence under high sensor noise.
- Sensor pose calibration - estimation of exteroceptive sensor position and heading for reliable localization references.



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