Extended Kalman Filter Report

Based off the original kalman filter submission that used gps+odometry data to do kalman prediction filtering
To gain an understanding of the individual effects of each measurment, additionally, the filter was executed with varying combinations of the inputs.

Method

Initially cloned from: `"git clone https://github.com/IgnacioCarlucho/B31YS_kalman_assignment_ROS1"`

The environment is called with: `"roslaunch rosbot_bringup fake_gps_random.launch"`

And the package containing the filter is ran with: `"roslaunch kalman_filter_assignment kalman_execution.launch student_name:=LukeEdgecombe"`

The behaviour is observed with: `"rosbag record -O kf_test /cmd_vel /fake_gps /odom1 /imu /kalman_estimate /odom"`

To make things easier to tune a seperate python file was added to introduce a series of configurable variables based on the noise assumptions

Configuration

- IC - Initial noise state assumption
- IMU_YAW - Imu angle in degree
- IMU_RATE - Imu rate in rad/s
- Q_DRIFT - xy drift in m/s (process noise for position)
- Q_YAW - angle deviation in degree/s (process noise for yaw)
- R_GPS - GPS position std dev in m (measurement noise)
- ODOM_XY - xy drift in cm
- ODOM_YAW - angle deviation in degrees

Initial state

IC = 0.5 IMU_YAW = 1.0 IMU_RATE = 0.02 Q_DRIFT = 0.05 Q_YAW = 2.0 R_GPS = 0.02 ODOM_XY = 0.20 ODOM_YAW = 5.0

Method

The config was verified visually by plotting the 2d motion of the robot along side the ground truth sensor.

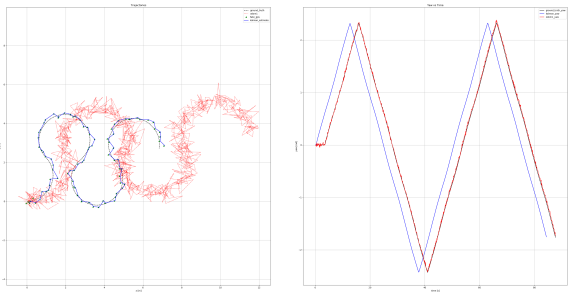
- After initial graph, close to ground truth but jagged
- V2 lead to smoother prediction but with strong deviation from ground truth
- V3 was erratic
- V4 was a satisfactory result

Table of changes

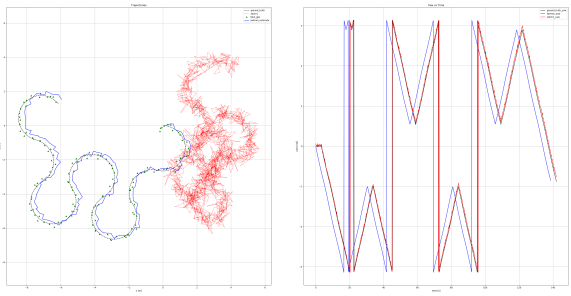
Measurement	V1	V2	V3	V4
IC	0.5	0.5	0.5	0.5
IMU_YAW	1.0	2.0	2.0	2.0
IMU_RATE	0.02	0.02	0.02	0.02
Q_DRIFT	0.05	0.02	0.04	0.04
Q_YAW	2.0	1.0	1.5	1.5
R_GPS	0.02	0.05	0.03	0.03
ODOM_XY	0.20	0.30	0.30	0.35
ODOM_YAW	5.0	8.0	8.0	9.0

Graphs of changes

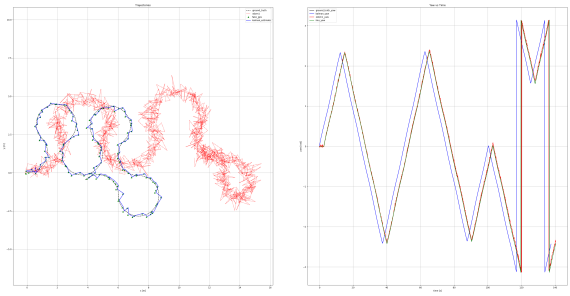
V1



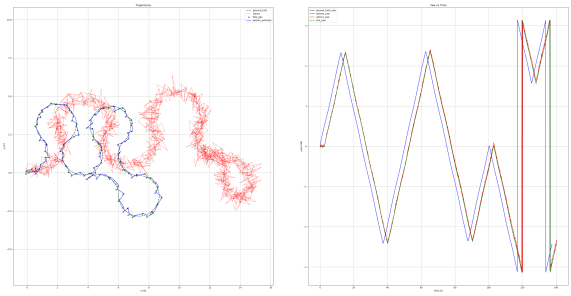
V2



V3



V4



Demonstration report

- Feedback from the report lead to a redesign on the code completely

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Extended Kalman Filter Redesign

Following demonstration feedback, the filter was completely redesigned to address fundamental architectural issues.

Key Issues Identified

1. **Incorrect prediction rate** - Original filter only ran prediction when GPS arrived (~1Hz), causing jagged output with large time steps
2. **Linear motion model** - Body-frame velocities were treated as world-frame, causing incorrect position integration
3. **Missing EKF Jacobian** - Covariance was not properly propagated for non-linear dynamics
4. **Improper process noise scaling** - Q matrix was constant instead of scaling with dt

Architectural Changes

The redesigned EKF now follows proper architecture:

- **Prediction** runs at odometry rate (~10Hz) for smooth estimates
- **GPS correction** applied only when GPS measurement arrives (~1Hz)
- **Non-linear motion model** properly transforms body-frame velocities to world frame:

"x' = x + (vx×cos(yaw) - vy×sin(yaw)) × dt" "y' = y + (vx×sin(yaw) + vy×cos(yaw)) × dt" "yaw' = yaw + omega × dt"

- **Jacobian computation** for covariance propagation:

"F = [[1, 0, (-vx×sin(yaw) - vy×cos(yaw))×dt], [0, 1, (vx×cos(yaw) - vy×sin(yaw))×dt], [0, 0, 1]]"

- **Joseph form** covariance update for numerical stability
- **Process noise scaled by dt** for consistent behaviour across different time steps

New Tuning Process

The redesigned filter required re-tuning with different parameter interpretations:

Measurement	VN1	VN2	VN3	VN4
IC	0.5	0.5	0.5	0.5
Q_DRIFT	0.04	0.1	0.05	0.05
Q_YAW	1.5	3.0	2.0	2.0
R_GPS	0.03	0.15	0.25	0.25
ODOM_XY	0.35	0.35	0.35	0.35
ODOM_YAW	9.0	9.0	9.0	9.0

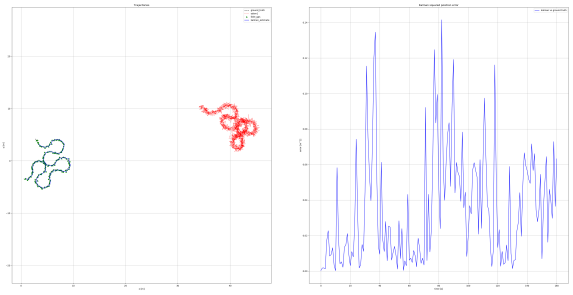
- vn4 had only code changes

Tuning Observations

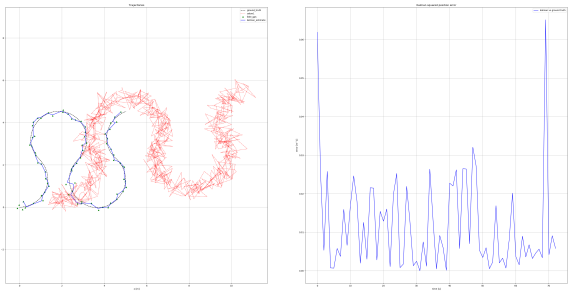
- **VN1**: Close to ground truth but jagged due to low R_GPS (trusting GPS too much)
- **VN2**: Smoother output but increased Q_DRIFT caused deviation from ground truth
- **VN3**: Reduced Q_DRIFT and increased R_GPS for better balance
- **VN4**: Final tuning with smooth output and good ground truth tracking

Graphs of New EKF

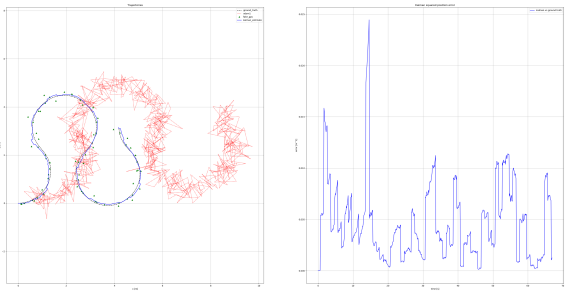
VN1



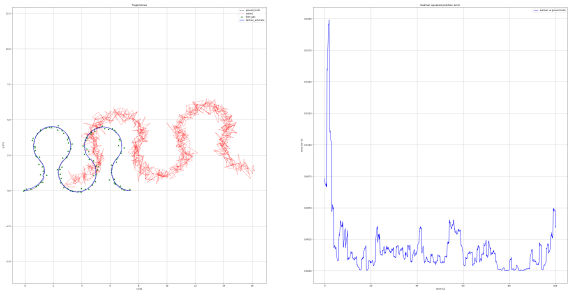
VN2



VN3



VN4



Final Configuration

"IC = 0.5, Q_DRIFT = 0.05 (m/s), Q_YAW = 2.0 (deg/s), R_GPS = 0.25 (m), ODOM_XY = 0.35, ODOM_YAW = 9.0"

Results

The redesigned EKF provides smooth trajectory estimation at 10Hz, gradual GPS corrections without abrupt jumps, proper sensor fusion of odometry velocities and IMU yaw rate, and accurate ground truth tracking with reduced overall error.