TIO - Thermal Inertial Odometry for Robots

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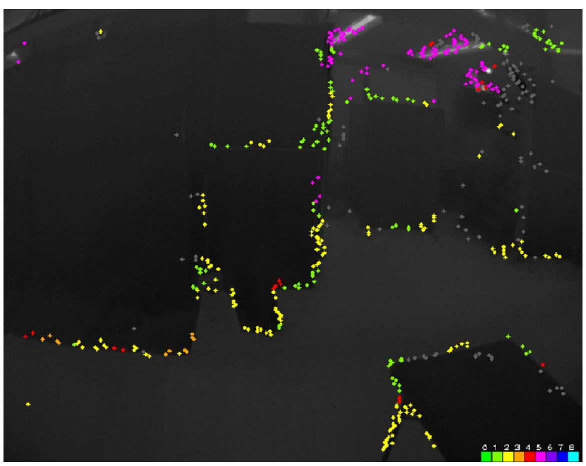
Visual-inertial odometry has been widely studied for embedded robotics, but classical RGB cameras degrade in darkness, smoke, dust, and low-texture environments. Thermal cameras are attractive in these cases because they observe infrared emission instead of reflected light. Therefore, thermal images have weak texture, low contrast, no color information. And due to the nature of the camera : radiometric drift, and sudden intensity jumps caused by online calibration. This project develops a direct semi-dense thermal-inertial odometry pipeline that operates on raw 14-bits thermal images instead of compressing them to 8-bit images such as classic VIO methods.

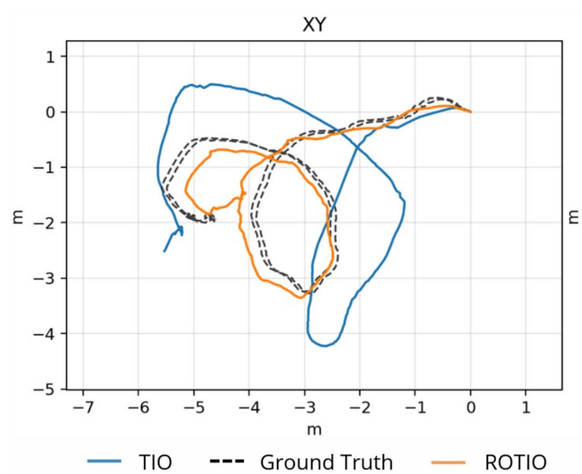


Thermal frame with selected features for different keyframes

It first runs a bootstrap phase to recover metric depth (solving the monocular inherent scale ambiguity). The first thermal image is kept as a keyframe (thermal image with selected features), while IMU integration provides a metric motion prior. This prior constrains the epipolar search used to update inverse-depth hypotheses for selected thermal pixels. Once enough depth hypotheses converge, the system switches to tracking.

During tracking, a bounded set of informative pixels is selected using image-gradient strength, grid sampling, and peripheral sampling, which improves parallax during forward motion. These pixels are reprojected into the current thermal image, and the front-end minimizes a direct photometric error using both intensity and gradient residuals. The gradient term improves robustness to thermal intensity drift and calibration jumps. This visual alignment is combined with IMU preintegration to estimate pose, velocity, and IMU biases.

To reduce drift, we add a keyframe backend optimisation. Keyframes are selected from sufficient translation or rotation. Converged depth hypotheses become landmarks observed across recent frames and keyframes. A bounded Ceres fixed-lag optimization refines keyframe poses, velocities, biases, and landmark positions using reprojection and IMU preintegration constraints.



XY Trajectory between the current and ROTIO odometry

I proposed algorithmic improvements toward a more accurate thermal-inertial odometry system, mainly through better scale recovery, calibration consistency, and front-end/backend state handoff.

The pipeline is modular, and its performance depends strongly on parameter tuning, including depth convergence thresholds, photometric and gradient weights, IMU noise, keyframe selection, and backend optimization limits. These parameters control the trade-off between accuracy, scale stability, and real-time performance, while leaving room for future improvements such as more robust depth initialization, better camera-IMU calibration, and stronger backend.