Pedestrian Outdoor RADAR Odometry

Students

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Definition of Task: This thesis investigates whether pedestrian outdoor ego-motion can be reliably estimated using a millimeter-wave phased-array radar and an inertial measurement unit. A portable measurement platform is developed to record synchronized radar, IMU, and GNSS/RTK data in outdoor environments. A compact mobile system design is chosen that is suited for field operation. An important objective is to identify under what environmental conditions radar-based trajectory estimation is supported and when limitations become apparent. Therefore, measurements are conducted in different outdoor scenarios. The recorded data is used to estimate the platform trajectory and to compare it against a centimeter-accurate GNSS/RTK reference.

Approach / Technology: The work combines embedded system development with offline trajectory estimation. The portable sensor platform was implemented using a mmWave FMCW radar, an IMU, an RTK-capable GNSS receiver, and a Raspberry Pi 5 as the central computing and logging unit. A local user interface with a small display and hardware buttons was added for field operation. A ROS 2 based acquisition framework records synchronized sensor data directly on the system. Based on these recordings, a radar-inertial processing pipeline was developed to transform the measurements into an estimated trajectory. Radar data is processed frame by frame, stationary targets are selected using a RANSAC algorithm, and motion direction is estimated by solving a linear system of equations derived from Doppler measurements. The resulting velocity vectors are transformed into world coordinates according to orientation information form the IMU. Integrated of the velocity over time reconstructs the trajectory. Additional calibration and alignment steps improve robustness. The estimated x-axis direction is averaged over the whole time span to determine the fixed relative orientation between both sensors. The gravity vector is averaged over the recording to estimate the device orientation with respect to the world frame. Finally, yaw alignment is performed by matching the first part of the estimated trajectory to the GNSS/RTK reference, with the associated parameters determined through analytical parameter sweeps. GNSS/RTK data is prepared separately and used as ground truth for the final comparison. This combination of synchronized sensing, local user interaction, ROS 2 logging, and offline radar-inertial trajectory estimation forms the technological basis of the presented work.

Result: The results show that the system can estimate the platform trajectory with surprisingly high accuracy in the horizontal plane. Motion in x- and y-direction, including forward, lateral, and diagonal movement, could be reconstructed reliably from radar and IMU data. In contrast, the radar could not provide accurate vertical z-motion information in the considered setup because of physical limitations of the mmWave sensor. Trajectory estimation also remained robust during running sequences, where the device was exposed to stronger vibrations and more irregular motion. At the same time, outdoor recording quality depended strongly on the surrounding environment. Environments with rigid, geometrically well-defined objects represented stronger and more reliable reflectors, improving estimation stability. Therefore, indoor recordings provided the best overall conditions, since flat walls, straight surfaces, and corners yielded a denser and more consistent set of reflections than typical outdoor scenes.

urban and open field scenario
Own presentment

recording device
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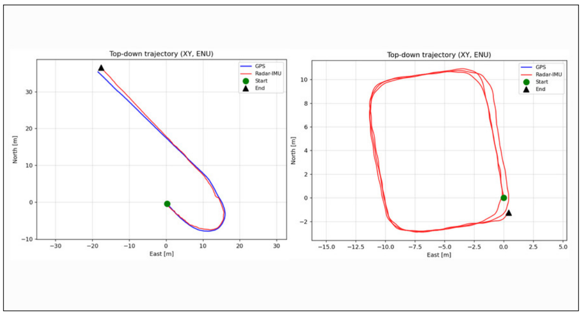
left: outdoor scenario - GPS-path in blue, estimate in red
right: indoor scenario - no GPS-path, estimate in red
Own presentment



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Subject Area
Image Processing and Computer Vision