Multi-Sensor Fusion for Localization of a Mobile Robot in Outdoor Environments

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Introduction

AMROS

- Mobile platform equipped with multiple sensors for navigation and surveillance.
- R&D platform for prototypical implementation of new soft- and hardware concepts.

Design goals

- Interactive and intuitive GUI for mission planning and teleoperation.
- Autonomous patrolling indoors and outdoors.
Outline

- Mobile Platform
- Sensor Fusion
- Results
- Conclusion
Mobile Platform

Mobile Robot
- Onboard standard PC
- Differential drive

Sensor equipment
- Odometry
- IMU (Inertial Measurement Unit)
- Digital compass
- Low-cost DGPS (Differential GPS)
- PMD-Camera for collision avoidance
- LIDAR and stereo camera for SLAM and localization in map
Mobile Platform

Relative Sensors
- Localization by dead reckoning
- Advanced from known start position by relative movements
- Uncertainty grows unbounded over traveled distance
- Problem of loop closure
Mobile Platform

GPS
- LOS to at least 4 satellites
- Ionospheric and tropospheric delay, ephemeris and clock errors are mitigated by differential correction
- Local errors due to multipath propagation
- No reliable quality criterion available

Compass
- Local interferences of the terrestrial magnetic field for example by metal fences or ventilation fans from air condition systems
Sensor fusion

- No accurate localization is possible by any single sensor → sensor fusion

- Combination of relative and absolute measuring sensors
  - Local precision by relative sensors
  - Absolute sensors limit the growth of the global error

- Cascaded fusion for simplicity, reduction of computational cost and on-line capabilities
Sensor fusion

Challenges

- Sensors with different data rates
- Sensor data from different sensors not synchronized
- Sensor data acquired in different coordinate systems (frames)
- GPS data has to be projected (LLA -> UTM)
- On-line capability requires causal filters
- Requirement of robustness against outages of single sensors
- Reliability of some sensors changes over time
Sensor fusion

Synchronous processing

- Only small time offsets when fusing the sensors at the rate of slowest sensor
- Output rate limited by the slowest sensor
- Omitting a lot of information
- GPS outage may compromise whole system

Asynchronous processing

- Every measurement is fused at time of arrival
- Highest possible output data rate
Sensor fusion

Kalman filter

- Sensors are handled according to their uncertainties
- Asynchronous Processing: for every incoming measurement a suitable prediction and update step is performed

![Diagram of sensor fusion process]

- Preprocessing
- Prediction by the system model
- Correction with the sensor data
- Postprocessing

Meta-knowledge

Adaptive uncertainties

main Kalman filter

Rejection of implausible data

EKF

IMU

Odometry

Compass

DGPS

Z^-n
Sensor fusion

 Challenges
- Reliability of sensors (GPS) may vary over time
- Sensor fusion may lead to implausible results

 Utilization of meta knowledge
- Adaptive tuning of the uncertainties of the GPS
  - Very unreliable after outages
  - Unfortunately quality parameters of GPS (HDOP, SNR of satellite signals) are not usable as errors due to multipath propagation dominate
- Standing still is reliably detected by odometry
- Near zero updates of GPS are omitted while estimated velocity of the robot is above certain threshold
Results

Test site: Fraunhofer IOSB

- Large Building
- Heavy multipath propagation situations
Results

Odometry only
- Path through field
- About 10m error after loop closure
Results

Fusion
- Path through field
- Error reduced from 10m to 1m

UTM easting in m - 458056
UTM northing in m - 5429362

Filtered
Odometry
Results

GPS outages
- Temporal outages are compensated
Results

Qualitative examination

- Reduction of oscillations of GPS position fix
Results

“Sawtooth shape” of fusion result

- Caused by different data rates
- Relative sensors have higher data rates
- Cannot be overcome with a causal filter
Conclusion

Accurate localization for mobile robots requires sensor fusion

- Local precision by relative measuring sensors while global error is bounded by absolute measuring sensors

Asynchronous sensor data processing

- No complex synchronization of the sensors necessary
- Highest possible output data rate
- Temporal outages of single sensors can be compensated

Outlook

- Reduction of “sawtooth effect” with GPS receiver with higher data rate
- Integration in SLAM algorithm for robust loop closure
Thank you!