Where is your Guardian Angel?
Locating and Protecting Vulnerable Road Users

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ICL-GNSS 2018
Guimarães, 28.06.2018
VRU Accident Statistics

• On European roads:
  • Around 28,000 fatalities and 250,000 serious injuries every year
  • VRUs comprise 46% of all fatalities

Traffic accidents in Europe

Relevant Scenarios

Pedestrian

- 49.4 %
- 29.7 %
- 7.6 %

Cyclist

- 65.1 %
- 16.5 %
- 9.1 %

Source: GIDAS - German In-Depth Accident Study 2013

Schwäbisches Tagblatt - Franke
NWZ Online
Tim Henrichs
DLR.de • Chart 4
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Main Reasons for Accidents

- Distraction (smartphone, radio, etc.)
- Physiological (fatigue, effect of alcohol, etc.)
- Situational misinterpretation
- Circumstantial
  - Road conditions (wet, icy, etc.)
  - Meteorological conditions (rain, fog, low-sunlight, etc.)
VRU Protection - Passive

- Helmets for cyclists and motorbikers
- External pedestrian protection Airbags
- Lifting bonnet
- Infrastructure
VRU Protection - Active

- Driver Assistance Systems
  - Automatic Emergency Brake
  - Adaptive Headlights
  - Driver State monitoring
VRU Protection - Active

- Daimler Blind-Spot Assist for trucks: eligible equipment for 2.500 Euro!
- European Commission proposes the use of a right turning assist warning device (without AEB)
VRU Protection – Infrastructure deployment
Collision Detection/Avoidance Algorithms

- Warning
- Motion Control
- Collision Detection
- Trajectory prediction
- Map
- Perception
- Communication
- Localization
- Infrastructure

- Increase awareness:
  - Robustness
  - Reliability
  - Minimize false detections and mis-detections
  - Minimize the number of warnings
VRU in-vehicle Perception

- Mono/Stereo Camera and/or night-vision
- Process:
  - Detection via image processing: Segmentations
  - Classification via Machine Learning Techniques (Support Vector Machines and Neural Networks)
  - Tracking
- Detection rate of 90% on simple datasets
- Challenges remain:
  - Bad lighting and meteorological conditions
  - Partly or complete occlusion


VRU in-vehicle Perception

- Automotive Radar at 76 GHz
- Challenge:
  - lower reflectivity
  - smaller radar cross-section
  - Point targets
- Distinguish between pedestrians and small static objects
- Use of micro-Doppler for classification

VRU in-vehicle Perception

- Laser scanners and Lidar
- Advantage: range accuracy
- Disadvantage: climatologic conditions, resolution and price
VRU Detection via On-board sensors

- Limitations of on-board sensor detection:
  - Directive
  - Limited range
  - Blockage - line-of-sight – No obstructions
  - Limited availability: luminosity and climatological conditions
New Approaches for VRU Protection

Cooperative Awareness

Infrastructure-based Detection

VRU in-vehicle Perception
Smartphones

• Increased computational power

• Build-in sensors:
  • GNSS
  • Inertial and magnetic
  • Sound and light

• Built-in communication:
  • Cellular communication: LTE, 5G
  • Wireless communication: WiFi and V2X (ITS-G5 / DSRC)
  • Short-range: BLE

• Build-in HMI: visual, haptic and acoustic
V2X Communication

- Ad-hoc communication via ITS-G5 / DSRC
  - IEEE 802.11p PHY and MAC
  - Effective range of 300m
  - Omnidirectional awareness
- But….what about equipping VRUs?
  
  “Recently Qualcomm addressed this concern by announcing their capability to override and upgrade existing Wi-Fi firmware to operate in DSRC band without any additional hardware cost.”

V2X Communication

- Communication impairments:
  - Physical - Layer
    - Low signal level (attenuation, shadowing / LoS-blockage or Interference)
    - Non-ideal channel propagation (multipath, fading, Doppler, etc.)
  - Medium Access – Layer
    - Packet collisions (e.g. due to hidden terminal)
Vehicle-to-Pedestrian Communication

• Reliable vehicle-to-pedestrian communication (V2P):
  • Knowledge about propagation conditions
  • Accurate V2P channel model for critical situations
    • For communication system design
    • For evaluation in test environments
Vehicle-to-Pedestrian Communication

V2X Communication

• Dense traffic scenarios at urban intersections

Simulation Environment: Sumo and Omnet++

• Higher modulation rates → Shorter Packets → Less Congestion

• Current standardization activities in IEEE: Next Generation Vehicle Study Group

LTE-V2X (a.k.a cellular V2X)

- September 2016: Release 14 enables LTE-V2X over sidelink (PC5)
- Release 15 in Q3 2018 is already including the first 5G standards.
Vehicle Localization

- GNSS
  - DGPS, PPP, dual-frequency multi-constellation
- Sensor Fusion:
  - Inertial sensors
  - Perception sensors
  - Precise digital maps
- Trajectory prediction
- Accuracy vs. reliability and integrity

Urban Canyon

Tunnel + Bridges

High Definition Maps

[Images of high definition maps]
Vehicle Localization – Visual Odometry

Position estimate accurate to several cm relative to a pre-recorded feature map


Börner, Anko und Baumbach, Dirk und Buder, Maximilian und Choinowski, Andre und Ernst, Ines und Funk, Eugen und Grießbach, Denis und Schischmanow, Adrian und Wohlfel, Jürgen und Zuev, Sergey (2017) IPS – a vision aided navigation system. Advanced Optical Technologies, 6 (2), Seiten 121-130. de Gruyter
Vehicle Localization

- Vehicle heading estimation is crucial!
  - Gyroscope + Steering
  - Multiple-antenna setup
  - Magnetometer

Heading estimate with GNSS and IMU

Baseline
VRU Localization – GNSS in Smartphones

• Assisted GNSS
• Differential GNSS
• Broadcom BCM47755 dual-frequency GNSS receiver chip for smartphone
• Google announces supporting raw GNSS measurements from Android N on

• Challenges:
  • GNSS antenna (backplane, shielding, etc.)
  • TCXO
  • Location and orientation

VRU Localization – GNSS in Smartphones
VRU Localization – GNSS in Smartphones
Urban Pedestrian Localization with GNSS and IMU

- Pedestrian Localization in the city-center of Munich
- 40 minutes
- 2.2 km length
Urban Pedestrian Localization with GNSS and IMU
Urban Pedestrian Localization with GNSS and IMU

- Large position errors while in urban canyons
- Large position errors while standstill
- Error-prone heading while severe multipath propagation
- No reliable heading when at standstill
Urban Pedestrian Localization with GNSS and IMU

![GPS Odometry](#)  ![Pocket-based IMU Odometry with compensated Drift](#)
Urban Pedestrian Localization with GNSS and IMU

- Wearable device in the pedestrian’s pocket
  - Heading angle → Direction of movement
  - Pitch angle → Opening angel of the leg

Detected Steps

Pitch

Time (min)

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VRU Localization

• Context information
  • Navigation: Where is the road user heading?
  • Activity recognition:
    • Means of transport: cycling, kick-scooter, skates, etc.
    • Walking, standing, gazing, …
    • Texting, phoning,…
  • Age, physiological/psychological indicators
  • Turning lights in vehicle, wipers, …
  • Traffic light phase
Enhanced GNSS Localization in urban Environments

- Filtering GNSS observables: elevation mask, CN0, polarization, etc.
- Usage of 3D maps

Source: Li-Ta Hsu, Shunsuke Miura and Shunsuke Kamijo *Street Smart: 3D City Mapping and Modeling for Positioning with Multi-GNSS*, 2015 *Inside GNSS*
VRU Localization - Maps

- Reliable path prediction via static and dynamic maps.
- Path prediction

Challenges Road User Localization

Challenges:
- Non-LoS signal propagation
- Short acquisition time or convergence time
- Satellite occlusion
- Improved accuracy
- Measure of reliability and integrity
VRU Localization through Radio Ranging

• Opportunities with 5G
  • Larger bandwidth $\rightarrow$ Higher time resolution $\rightarrow$ Better ranging accuracy
  • mmWave: AoA, dense networks
  • Studies on network-based positioning foresee position accuracies at dm-level:

  "Assisted driving with accuracies below 30 cm is possible with high signal bandwidths, i.e., 50 and 100 MHz."


• IEEE 802.11 for Ranging for indoors and outdoors: Next Generation Positioning Working Group in IEEE
• Ultrawideband ranging
Inertial-aided Bicycle Localization

- IMU placed on:
  - Glasses
  - Wrist
  - Pocket
  - Foot

- RTK system:
  - Ground truth position
  - Ground truth speed

Inertial-aided Bicycle Localization

20 second GNSS Outage Trajectory

Distance while outage: 73 m
Error: 2.4 m

40 second GNSS Outage Trajectory

Distance while outage: 134 meters
→ Error: 9.4 m
New Approaches for VRU Protection

Cooperative Awareness

Infrastructure-based Detection

VRU in-vehicle Perception
Infrastructure-based Localization

- Electronic Fence: re-use existing V2I communication infrastructure (e.g. integrated in lamp poles) to:
  - Detect
  - Classify
  - Localize

All types of road users
Measurement Campaign – Overview
Delay-Doppler Profile

**Mercedes G 400**
- Transceiver pair $T_x-R_x^2$
- Movement in one direction
  - track distance $100m$
  - $T_x-R_x$ baseline crossed
- CIR samples over full movement period for calculation of delay-Doppler profile

Delay-Doppler Profile

Pedestrian

- Transceiver pair $Tx-Rx_2$
- Movement in one direction
  - track distance $100m$
  - $Tx-Rx$ baseline crossed
- CIR samples over full movement period for calculation of delay-Doppler profile

New Approaches for VRU Protection

Cooperative Awareness

Infrastructure-based Detection

VRU in-vehicle Perception
New Approaches for VRU Protection

Indoor Localization
- A segmentation-based matching algorithm for magnetic field indoor positioning
- High definition map-based vehicle localization for highly automated driving: Geometric analysis

Sensor Fusion
- Cows, buses, people: Context awareness sensing from positioning sensors for improved safety, efficiency and performance

Radio-based Ranging
- Cooperative localization and tracking using multipath channel information
- Movement Model Enhanced RSS Localization
- Data Fusion Approaches for WiFi Fingerprinting
- Feasibility study of 5G-based localization for assisted driving

New GNSS Receiver Techniques
- Robust Vector Tracking for GNSS carrier phase signals
- Analysis of the Measured RHCP and LHCP GNSS Signals in Multipath Environment

Pedestrian
- Carrier phase positioning experiences in consumer GNSS devices
- Compact 6+1 Antenna Array for Robust GNSS Applications
New Approaches for VRU Protection

Indoor Localization
- Received Signal Strength quantization for secure indoor positioning via fingerprinting
- Applicability of 3GPP Indoor Hotspot Models to the Industrial Environments

Radio-based Ranging
- Device Diversity Effects on RF Fingerprinting Based 3D Positioning System
- Mobile Station Localization Emitter in Urban NLoS using Multipath Ray Tracing Fingerprints and Machine Learning

Sensor Fusion
- Comparing 433 and 868 MHz Active RFID for Indoor Localization Using Multi-Wall Model
- Minimizing Indoor Localization Errors for Non-Line-of-Sight Propagation

New GNSS Receiver Techniques
- GNSS Measurement Exclusion and Weighting with Dual Polarized Antenna: The FANTASTIC project
- Joint Tracking of Multiple Frequency Signals from the same GNSS satellite

Pedestrian
- Improved NLOS Propagation Models for Wireless Communication in mmWave bands
- Localization and Tracking in mmWave Radio Networks using Beam-Based DoD Measurements

Vehicle
- AoA and ToA accuracy for antenna arrays in dense multipath channels
- Data-driven approach to satellite selection in multi-constellation GNSS receivers

Data-driven approach to satellite selection in multi-constellation GNSS receivers
So…Where is your Guardian Angel?

- In-vehicle VRU perception
- Reliable and accurate ego-localization and ego-kinematics
- Robust V2X communication
- Additional infrastructure-side localization

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