Active Pedestrian Safety: from Research to Reality

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Environment Perception
Research and Development

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We originally thought Machine Intelligence would look like

1956 "Forbidden Planet"
Robby the Robot (Flickr)
Then more recently, some suggested it would be more like 2004 iRobot and 1983-2009 Terminator.
when in fact, Machine Intelligence is already with us, and has a familiar embodiment ...
Sensors and Coverage (Mercedes-Benz E- and S-Class)

- **MULTI MODE RADAR**
  - 80 m range / opening angle 16°
  - 30 m range / opening angle 80°

- **STEREO MULTI PURPOSE CAMERA**
  - 500 m range, with 3D capability over a range of 50 m / opening angle 45°

- **LONG RANGE RADAR WITH MID-RANGE SCAN**
  - 200 m range / opening angle 18°
  - 60 m range / opening angle 60°

- **360° CAMERAl**
  - 4 m range

- **ULTRASONIC SENSORS**
  - 1.2 m / 4.5 m range

- **SHORT RANGE RADAR**
  - 0.2 m - 30 m range / opening angle 80°

- **NEAR/FAR INFRARED CAMERA**
  - 160 m range / opening angle 20°
Driver Assistance at Mercedes Benz (E- and S-Class, 2013)

- Traffic Signs
- Adaptive High Beam
- Nightview
- Pre-Crash Braking (longitudinal & lateral traffic)
- ?
- Parking
- Adapt. Cruise Control w. Steering Assist
- (Active) Body Control S-Class only
- (Active) Lane Keeping

(E- and S-Class, 2013)
Worldwide Traffic Fatalities 2010: Share of Vulnerable Road Users

Illustration: Bosch

Sources:
1) Transport Canada, Canadian Motor Vehicle Traffic Collision Statistics 2010
2) Ministry of Road Transport and Highways, Government of India 2010
3) Ministério das Cidades, Departamento Nacional de Trânsito Brasília 2009
4) IRTAD 2010 (data available for AT, BE, CZ, DE, DK, ES, FI, FR, GR, HU, IE, IT, LU, NL, PL, PT, SE, SI, UK, USA, J, AUS, S-KOREA)
5) Traffic Accidents China, Annual yearbook 2010
6) Royal Thai Police, Traffic Accident National Highways 2005, extrapolated data (biased) based on 2005, known numbers from 2006: 12 691 fatalities
Why is it difficult?

Large variation in pedestrian appearance (viewpoint, pose, clothes).
Dynamic and cluttered backgrounds.
Pedestrians can exhibit highly irregular motion.
Real-time processing required.
Stringent performance requirements (especially for emergency manoeuvres).
Pedestrian Recognition Today

- Surroundview
- Pre-crash
- Nightview

Various requirements with respect to sensor coverage, vehicle speed range, recognition performance

Different HMI and vehicle control strategies
Pedestrian Recognition Performance Last Decade (Downtown)

Correctly recognized pedestrians

100%
90%
85%
65%
50%
40%

DE AKTIV-SFR (2010)
EU WATCH-OVER (2008)

50 km/h

100

Number of falsely recognized pedestrian trajectories per hour

EU PROTECTOR (2003)

30 km/h

600

1000

N.B. # False alarms per hour << # Falsely recognized trajectories per hour

1. Better Algorithms
Better Algorithms: System Architecture

- **Regions of Interest** (Stereo, Motion, Geometry)
- Pedestrian Classification
- Tracking / Fusion
- Path Prediction & Risk Assessment
- Driver Warning / Vehicle Control

D. M. Gavrila and S. Munder, „Multi-Cue Pedestrian Detection and Tracking from a Moving Vehicle“. *Int. J. Computer Vision*, vol. 73, 2007

Better Algorithms: Classifier Fusion


Performance boost over HOG/linSVM: Factor 42 less false positives
Pedestrian Recognition Performance Last Decade (Downtown)

N.B. # False alarms per hour << # Falsely recognized trajectories per hour
Better Processors and Sensors

Processing on embedded hardware (e.g. FPGA) for real-time performance

Shape-based Object Detection
Stefan Hezel, A Kugel, R Manner, DM Gavrila
FPGA-based template matching using distance transforms
Proc. IEEE Symp. on Field-Prog. Custom Comp. Machines, 2002

Dense Stereo Computation
S. Gehrig, F. Eberli and T. Mayer.

Pedestrian Classification
Pedestrian Recognition Performance Last Decade (Downtown)

N.B. # False alarms per hour << # Falsely recognized trajectories per hour
Training Data Size Matters (a Lot) ... 

ROC performance improves with enlarged training set

Labeling pedestrians in images is time-consuming and tedious.
Intelligent tools for the acquisition and enrichment of large databases.
Lots of Real Data ...

Ulm
Stuttgart
München
Aachen
Amsterdam
Parma
Brussels
Paris
Barcelona
San Francisco
Tokyo
...

$O(10^7)$ images
$O(10^6)$ labels
... and Some Artificial Data Too („Virtual“ Pedestrians)

Shape variation

Texture variation

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N.B. # False alarms per hour << # Falsely recognized trajectories per hour

4. Extensive Evaluation
# Daimler Pedestrian Benchmark Data Sets

1. **Mono Pedestrian Classification**  
   S. Munder and D. M. Gavrila. An Experimental Study on Pedestrian Classification.  

2. **Multi-Modal / Occluded Pedestrian Classification**  

3. **Mono/Stereo Pedestrian Detection**  
   *Proc. of the IEEE Intelligent Vehicles Symposium*, Baden-Baden, Germany, 2011.

Other benchmarks by CalTech (2009), KITTI (2012), TUD (2009) and UAB (2010)

<table>
<thead>
<tr>
<th>Data Set</th>
<th>Training</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mono Pedestrian Classification</td>
<td>14400 peds. / 15000 non-peds.</td>
<td>9600 peds. / 10000 non-peds. All 18x36 pixel.</td>
</tr>
<tr>
<td>2. Multi-Modal / Occluded Pedestrian Classification</td>
<td>&gt;130,000 samples (intensity, dense stereo, dense flow), 48x96 pixel</td>
<td></td>
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</tbody>
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*Available for download (Search web)*
How to perform realistic pre-crash tests?
Sensor View
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EU WATCH-OVER (2008)

50 km/h

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Where are we now?
Driver Assistance at Mercedes Benz (E- and S-Class, 2013)

- Traffic Signs
- Adaptive High Beam
- Nightview
- Attention
- Pre-Crash Braking (longitudinal & lateral traffic) with Pedestrian Recognition
- (Active) Body Control (S-Class only)
- Parking
- Adapt. Cruise Control w. Steering Assist
- (Active) Lane Keeping
Mercedes-Benz
PRE-SAFE® Brake with Pedestrian Recognition
Pedestrian Recognition Performance Last Decade (Downtown)

Correctly recognized pedestrians

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- EU PROTECTOR (2003)

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So What’s Next?
Quo Vadis, Pedestrian?

Pedestrian path prediction and action classification for short prediction horizons (< 1s)

Probabilistic matching of learned trajectories

Use of dense stereo / flow in addition to position

C. G. Keller, C. Hermes and D. M. Gavrila. „Will the pedestrian cross? Probabilistic Path Prediction based on Learned Motion Features“. German Pattern Recognition Conference (DAGM) 2011 Prize
Action Classification (Crossing or not)

Predicting the correct pedestrian’s action with accuracy 80% is reached
- 570 ms (human)
- 90 ms (Interacting Multiple Models KF)

before a possible standstill. Motion features help.

Initiating emergency braking 180 ms earlier reduces chances for hospital stay by 15% (TTC = 0.7s, vehicle speed = 50 km/h)

C. G. Keller and D. M. Gavrila. „Will the pedestrian cross? A Study on Pedestrian Path Prediction“.  
*IEEE Transactions on Intelligent Transportation Systems*, 2013, DOI 10.1109/TITS.2013.2280766
PedCut: An EM-like framework for pedestrian segmentation combining global shape models and multiple data cues


New public dataset with multi-cue (color, dense stereo) pedestrian cut-outs captured from a vehicle.
Automatic Braking vs. Automatic Evasion

300 ms from first sight of pedestrian to initiation of vehicle maneuver (braking or evasion)

Final Remarks

Dramatic progress on vision-based pedestrian sensing, mirroring the success of computer vision technology in driver assistance over the past decade.

Perseverance pays off.

Challenges still remain for pedestrian sensing. Additional focus: data fusion, situation understanding, new actuation concepts.

Accident analysis at Mercedes-Benz indicates that the currently deployed pedestrian recognition technology could avoid 6 percent of pedestrian accidents and reduce the severity of a further 41 percent.
Thank you

Credits

Markus Enzweiler, Christoph Keller, Stefan Munder, Jan Giebel, Fabian Flohr and others...