3D-Vision
Vom autonomen Fahrzeug zum Dentalscanner

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3D Vision @ AIT

**Forschung & Entwicklung**

- First 3D Vision concepts
- Prototype of a Stereo Vision sensor for autonomous systems
- Darpa Grande Challenge participation
- Stereo Vision for indoor robotic (EU project robots@home)
- Darpa Urban Challenge participation
- Demonstration system for indoor robots
- Demonstrator for dental scanner
- Obstacle detection for autonomous trucks and trains
- Dental scanner prototype
- Industrial 3D object reconstruction

**Verwertung**

- Cooperation with Auburn University
- Cooperation with Vienna University of Technology and ETH Zurich
- Cooperation with a.tron3D and companies for industrial automation
- Presentation of the dental scanner prototype at the International Dental Show in Cologne
Fundamentals of Area-based Stereo Vision
S³E – High Speed Stereo Software Engine

- Concept
  - Correlation-based, local-optimizing stereo matching
  - Algorithm uses the census transform with various additional features

- Strengths
  - Fast (up to 70 fps on PC)
  - Suitable for resource limited and cost efficient platforms
  - Flexible software solution (PC, DSP, GPU)
  - Excellent “depth-quality-vs.-computational-costs” ratio
  - Wide applicability of the technology
    - scalable 3D measurement (distances from sub-millimetres to >100 m)
    - usable with various kinds of image sensors / cameras
    - real-time 3D model creation by registration of point clouds
Census Transform based Correlation

- More robust compared to SAD, SSD,…
- Example for mask size 3x3 with bit vectors 8 bits long

\[
\begin{array}{ccc}
2 & 7 & 4 \\
3 & 5 & 6 \\
5 & 1 & 8 \\
\end{array}
\]

\[
\begin{array}{ccc}
1 & 1 & 0 \\
0 & 0 & 1 \\
1 & 0 & 1 \\
\end{array}
\]

\[
\begin{array}{ccc}
(5 > 2) & 1 & 1 \\
(5 > 7) & 0 & 0 \\
(5 > 4) & 1 & 0 \\
\end{array}
\]

Matching costs: 3

(= measure of dissimilarity)

- \(S^3E\) uses (much) larger masks – bit vectors are either 64 or 256 bits long
- Bit vectors must be compared for every pixel and every disparity in each frame, e.g. 640 pixels x 480 pixels x 80 disparities x 14 fps x 64 bits = 22 billion (!) bit comparisons per second
Target Platforms

- PC-based system
  - 70fps @450x375; 31fps @640x480
  - Bi- or trinokular USB camera head

- Embedded system – SmartCam with integrated DSP(s)
  - 15fps @450x375

- GPU-based system
  - > 100fps

- Embedded multi-core DSP system
  - > 100fps
### 3D Environment Sensors for Land Vehicles

<table>
<thead>
<tr>
<th>Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real-time stereo vision</td>
</tr>
<tr>
<td>Trinocular &amp; wide baseline stereo</td>
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<tr>
<td>Dynamic stereo calibration</td>
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<tr>
<td>Night vision stereo matching</td>
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<tr>
<td>Visual odometry</td>
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<tr>
<td>Sensor fusion (IMU, GPS, …)</td>
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</tbody>
</table>

#### Applications:
- 3D point cloud registration
- Surface modeling
- Object detection, tracking, classification
- Obstacle avoidance
- Autonomous path planning

**Images:**
- Vision based offroad terrain mapping
- High precision observation of hull volume in front of trains
- Autonomous path planning
Safecon
Proof-of-concept 2013

Autonomous Vehicle
= System of Systems
Technology Ecosystem

3D - Sensors
Daylight Stereo camera
Night vision Stereo camera
Laser scanner

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Daylight Stereo camera
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Actuators
Steering
Throttle
Braking
...

Processing Hardware

Autopilot & Cruise control

Path planning

Mapping

Odometry / Localisation
Visual Odometry
Wheel speed
GPS Receiver

Inertial sensor
Magnetometer

Tracking

Mission planning / Route definition

Autonomous Vehicle = System of Systems Technology Ecosystem

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Technology Ecosystem

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Visual Obstacle Detection for Autonomous Trains on open Tracks

- **AIT task**
  - Providing a dedicated stereo vision system
  - High performance image processing and analysis

- **Challenging requirements**
  - High depth resolution at long distances (>100m)
  - Small obstacles – no false detections
  - Short latency
Visual Obstacle Detection for Autonomous Trains on open Tracks – Results

- Railroad crossing in a curve – car is violating tracks area
- AIT 3D Vision sensor reports the obstacle earlier and more specific than the other sensor modalities under evaluation
trajectory of tracks augmented in camera view

3D data of obstacles within clearance (color-coded according to distance in meters)
trajectory of tracks augmented in camera view

3D data of obstacles within clearance (color-coded according to distance in meters)
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3D data of obstacles within clearance (color-coded according to distance in meters)
3D4Bombardier – Advanced Driving Assistance System for Trams

- AIT 3D Vision technology for advanced collision prevention for urban trains
- Trinocular wide baseline stereo vision
  - wide field-of-view
  - precise 3D data from close-range to more than 80 m
  - Object detection, localization, tracking
  - Speed and trajectory estimation of own vehicle and objects
- Received the Nomination for “Staatspreis Mobilität” 2013
- Field-prototypes in Frankfurt and Berlin
3D4Bombardier – Advanced Driving Assistance System for Trams

- Actual vehicle speed
- Required clearance indicated at 15 m distance
- Object with indications for:
  - bounding box
  - motion-vector (light blue)
  - object’s trajectory (dark blue)
- Vehicle acceleration / deceleration
- Required deceleration
- Distance to nearest object
- Tracks path
High Precision Intraoral 3D Scanning

Contactless optical dental impression – workflow of the future
Dental scanner device

- Miniaturized stereo camera
- Structured light projection unit
- Light source
- Electronics und software
- USB interface
Innovations

- **Mechanical robustness & ergonomy**
  - No moving parts
  - Smallest and und lightest 3D scanner for intra-oral application
  - Similar handling as with standard dental instruments

- **Open system**
  - Scanner device and software can be used with standard PC
  - Resulting 3D data in STL format – open for all CAD/CAM systems
Performance

- Online processing of 12 data sets per second
  - Image analysis
  - Stereo matching
  - 3D-registration
  - Surface reconstruction
  - Live visualization of reconstruction
  - Measurement of one jaw in 3 to 5 minutes
  - Accuracy up to 20 µm

[Images: camera image, stereo matching result (scanner raw data)]
Thank you for your attention!
AIT Austrian Institute of Technology

your ingenious partner

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