Multi-Core SoCs for ADAS and Image Recognition Applications

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Background

Image recognition technology ➔ A variety of products

Face Detection

Face Recognition for Door Security

Hand Gesture

Forward Collision Warning

Pedestrian Detection

Traffic Sign Recognition

Lane Change Assistance

Backover Prevention

Driver Monitoring

Image recognition technology

A variety of products
## The Top 10 Causes of Death

<table>
<thead>
<tr>
<th>Rank</th>
<th>2015 Cause</th>
<th>2030 Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ischaemic heart disease</td>
<td>Ischaemic heart disease</td>
</tr>
<tr>
<td>2</td>
<td>Stroke</td>
<td>Stroke</td>
</tr>
<tr>
<td>3</td>
<td>Lower respiratory infections</td>
<td>Chronic obstructive pulmonary disease</td>
</tr>
<tr>
<td>4</td>
<td>Chronic obstructive pulmonary disease</td>
<td>Lower respiratory infections</td>
</tr>
<tr>
<td>5</td>
<td>Diarrhoeal diseases</td>
<td>Diarrhoeal diseases</td>
</tr>
<tr>
<td>6</td>
<td>HIV/AIDS</td>
<td>Trachea, bronchus, lung cancers</td>
</tr>
<tr>
<td>7</td>
<td>Trachea, bronchus, lung cancers</td>
<td>Road injury</td>
</tr>
<tr>
<td>8</td>
<td>Diabetes mellitus</td>
<td>HIV/AIDS</td>
</tr>
<tr>
<td>9</td>
<td><strong>Road injury</strong></td>
<td><strong>Road injury</strong></td>
</tr>
<tr>
<td>10</td>
<td>Hypertensive heart disease</td>
<td>Hypertensive heart disease</td>
</tr>
</tbody>
</table>

Source: World Health Organization (WHO) Projections of mortality and causes of death, 2015 and 2030

- More than **1 million** people die in traffic accidents every year
- **50 million** people are injured in non-fatal accidents

How can we decrease Road Injuries?
**ADAS (Advanced Driving Assistant System) Market Growth**

ADAS CAGR 18%

cf. Overall Automotive Electronic System 6%
Powertrain System 8%
Steering/Brake System 3%

Source: Strategy Analytics Advanced Driver Assistance Systems Demand Forecast

**Euro NCAP Requirements**

2004: Lane Departure Warning
2013: Forward Collision Warning
2014: Pedestrian Detection (Daytime)
2016: Pedestrian Detection (Daytime & Night)
2017: Pedestrian Detection (Daytime & Night)
2018: Cyclists Detection (Daytime & Night)

NCAP: New Car Assessment Programme
Roadmap of Image Recognition SoCs

TMPV750 Series
3rd Generation
- TMPV7528XBG
- TMPV7506XBG
- TMPV7504XBG
- TMPV7502XBG

TMPV750 Series
2nd Generation
- T5BG3XBG

TMPV760 Series
4th Generation
- TMPV7608XBG

Next Generation

Euro NCAP Requirements
- 2004: Lane Departure Warning
- 2013: Forward Collision Warning
- 2014: Pedestrian Detection (Daytime)
- 2016: Pedestrian Detection (Daytime & Night)
- 2017: Pedestrian Detection (Daytime & Night)
- 2018: Cyclists Detection (Daytime & Night)

NCAP: New Car Assessment Programme
Image Recognition SoCs

1st Gen. T5BG3XBG [CICC 2004]
- 0.13μm CMOS
- 1W@1.5V
- Core x3 + HWA x1

2nd Gen. TMPV7506XBG [ISSCC 2012]
- 40nm CMOS
- 1W@1.1V
- Core x4 + HWA x6
- 464GOPS
- 617GOPS/W

4th Gen. TMPV7608XBG [ISSCC 2015]
- 40nm CMOS
- 3W@1.1V
- Core x8 + HWA x14
- 1900GOPS
- 564GOPS/W

Single application (Lane Detection, Forward Collision Warning, or Night Vision)

4 apps. execution including Pedestrian Detection (PD)

8 apps. execution including PD at night-time
Demo Video of 2\textsuperscript{nd} Generation SoC

- Lane Detection
- Pedestrian Detection and Vehicle Detection (Daytime)
Multiple ADAS Applications

- Vehicle Detection (include Motorbike etc.)
- Pedestrian Detection (include Wheelchair)
- General Obstacle Detection
- Traffic Light Recognition
- Lane Detection
- Traffic Sign Recognition
- Automatic High Beam

New features of 4th Gen.
Design Concept of Image Recognition SoCs

Requirements:

• High performance with low power consumption
• High accuracy of object recognition

Heterogeneous Multi-core Architecture

• Energy efficient multi-core
• Hardware accelerators
  • Performance bottlenecks and frequently used tasks
  • High accurate image recognition features

Adopted “Highly parallelized” approach rather than “High clock frequency” approach
Image Recognition Processing

**Preprocessing**
- Distortion Correction
- Noise Reduction
- Pyramid image
- Integral image
- Gradient Image

**Feature Extraction**
- Haar-Like
- HOG, CoHOG
- etc.

**Classification/Tracking**
- SVM
- Random Forest
- etc.

**Clustering/Decision-Making**

**ROI**

**Full Size Image**

**Date Size**
- Large
- Small

**Algorithm**
- Simple
- Complex

**HW Accelerator**

**Multi-Core**

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Hardware Accelerators

1st Gen. T5BG3XBG

Affine Trans. Accelerator

Image recognition feature descriptors

Filter Accelerator

CoHOG Accelerator

Template

Matching Accelerator

Histogram Accelerator

5 types of 6 HWAs

2nd Gen. TMPV7506XBG

5 types of 6 HWAs

3rd Gen.

4th Gen. TMPV7608XBG

8 types of 14 HWAs

Pyramid Image Accelerator

SfM Accelerator
(SfM: Structure from Motion)

HOX Accelerator
(HOX: Histogram of X)
Block Diagram of TMPV7608XBG

Accelerators

Crossbar switch 128b x 133MHz

Pyramid Acc#1

HOX Acc. #1

Matching Acc.#1

Histogram Acc.

CoHOG Acc.

Crossbar switch 128b x 133MHz

32b RISC

LPDDR2 I/F

Video In (4ch)

Video out (2ch)

CAN I/F

Misc I/F

Memory Bandwidth: LPDDR2 64-bit x 2ch: 12.8GB/sec
4-Core Processor Clusters

- Each cluster has four 3-way VLIW processors
  - 3-way VLIW: 32b RISC core + 2-way coprocessor
  - Coprocessor supports
    - Integer 8/4/2-parallel 8/16/32-bit SIMD instructions
    - Double precision floating-point instructions
Improvement by Color-Based Feature

Euro NCAP will adopt Automatic Emergency Braking (AEB) test (with pedestrian and cyclist detection) in darkness in 2018.

- Improved recognition accuracy using a new image feature
  - Color-based image features to describe shape and texture
  - Extension to CoHOG feature

Background object is similar luminance

Color information can tell us boundary of pedestrians
Four Color-Based Feature Descriptors*

- Four feature descriptors work complementarily
  - Color Histogram, CoHD, Color-CoHOG, and CoHED
- They are designed to capture different types of information

**Legend**
- Direct Color
- Relative Color
- Monochrome

**Descriptor Definitions**
- CoHOG: Co-occurrence histograms of oriented gradients
- CoHED: Co-occurrence histograms of pairs of edge orientations and color differences
- CoHD: Co-occurrence histograms of color differences

Performance of HOX Accelerator

**Accuracy of Pedestrian Recognition**

- **[Daytime dataset]**
- **[Night-time dataset]**

- **Accuracy** at night using HOX accelerator is almost the same as at daytime using CoHOG accelerator.

* Original dataset

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**4th Gen.**

- **4 color feature:**
  - **CoHOG:** [Daytime]
  - **[Night]**

- **Better**

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**Highlights:**

- **Accuracies:**
  - 0.0001
  - 0.001
  - 0.01
  - 0.1
Demo Video of 4th Generation SoC

- Traffic Sign Recognition
- Pedestrian Detection
- Bicycle Detection
- Distance Estimation
- Lane Detection
- Vehicle Detection
- Moving Object Detection
- Head Light Detection
3D Reconstruction (SfM: Structure from Motion)

TMPV7608XBG (4th generation SoC) supports 3D reconstruction using a “single” camera for general obstacle detection.

Multiple images are taken from different viewing angles.

Single camera → 3D Reconstruction → 3D shape

Camera motion
Principle of SfM: Triangulation

Step 1) Find corresponding points

Step 2) Estimate movement of camera

Step 3) Depth is estimated by triangulation

Time: t

Time: t+1
## Performance and power consumption

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Total performance (GOPS)</td>
<td>464</td>
<td>1900</td>
</tr>
<tr>
<td>Power consumption (mW)</td>
<td>749</td>
<td>3368</td>
</tr>
<tr>
<td>Performance per Watt (GOPS/W)</td>
<td>617</td>
<td>564</td>
</tr>
</tbody>
</table>

- **Power consumption for real apps. on 4th gen.**

![Diagram of traffic scene with various detection systems]

8 applications

1.4W

(Typical condition)

Vdd=1.1V, Process=Center, Temp=25°C
# Chip Micrograph and Features

<table>
<thead>
<tr>
<th>Process</th>
<th>Chip Size</th>
<th>Peak Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>40nm CMOS LP</td>
<td>105.6mm² (9.60mm x 11.0mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Multi-core (x2): 266MHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Affine (x3): 266MHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pyramid (x2): 266MHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CoHOG: 266MHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HOX (x2): 266MHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Filter (x2): 180MHz</td>
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<tr>
<td></td>
<td></td>
<td>Histogram: 266MHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Matching (x2): 266MHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SfM: 266MHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Perf. /W: 564GOPS/W</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total: 1900GOPS</td>
</tr>
</tbody>
</table>

**Total Performance:** 1900GOPS

**Perf. /W:** 564GOPS/W
Conclusion

• Multi-core SoCs dedicated for ADAS and image recognition applications
  – High performance with low power consumption
    • Energy efficient multi-core
    • Highly parallelized hardware accelerators
  – High accurate recognition
    • CoHOG and four color-based features (Color Histogram, CoHD, Color-CoHOG, and CoHED)
    • Accurate detection for pedestrian even at night
  – Structure from Motion (SfM) for general obstacle detection
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