Surround View Camera Systems

AMF-AUT-T0499

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Agenda

• Motivation
• System architecture
• Application
• Summary
Motivation

• Natural surround view helps drivers to capture all hazards at a glance in slow driving situations like parking or turning

• Holistic 360° object detection for every driving situation like
  – obstacle detection during reversing
  – blind spot detection
  – intersection management

• Advanced 3D graphics with virtual camera views creates new and differentiating driver experience
Communication has significant cost impact

<table>
<thead>
<tr>
<th>Analog (PAL / NTSC)</th>
<th>LVDS</th>
<th>Ethernet (AVB)</th>
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</thead>
<tbody>
<tr>
<td>✓ Low cost and widely available</td>
<td>✓ Very high bandwidth</td>
<td>✓ Low cost unshielded twisted pair cable</td>
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<tr>
<td>✗ Shielded co-axial cable required</td>
<td>✓ No compression</td>
<td>✓ High bandwidth up to 250 Mbps full duplex</td>
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<tr>
<td>✗ Low resolution and color deviations</td>
<td>✓ Expensive shielding required</td>
<td>✓ Network capabilities</td>
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<td>✗ Only for low-end systems without object detection</td>
<td>✓ Costly manufacture of wiring harness</td>
<td>✓ Widely adopted, ease of use</td>
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<td></td>
<td>✓ Long-term EMC and quality issues</td>
<td>✓ EMC performance proven</td>
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**Ethernet is a proven and cost-effective alternative to conventional video communication**
Ethernet based camera module

- **Video compression reduces cost**
  - Low latency MJPEG compressed 1.2 Mpixel, 30 fps video stream fits 100 Mbps Ethernet link
  - Predictive compression control allows high quality factor
  - Negligible degradation of object detection rate at high quality factor
  - 12-bit per YUV color space component for high dynamic range

- **Ethernet simplifies architecture**
  - Camera synchronization via IEEE 1588v2 PTP real-time clock
  - IEEE 1722 Layer 2 AVB transport protocol
MPC5604E – Salsa

- 64MHz e200 Core
- M-JPEG Video Encoder
- Real-Time Ethernet
- 512K Flash
- 64K Data Flash
- 96K SRAM

... samples available
Freescale Salsa Camera Software

- Purple: AUTOSAR OS 3.0, licensable from Freescale
- Green: Camera Application Software, licensable from Freescale
- Blue: Ethernet Streaming Software, licensable from Freescale
- Orange: Off the shelf Software, licensable from 3rd party (Elektrobit, IXXAT)
- Red: Hardware

Diagram:
- Camera application
- Control Algo
- STREAM IF
- UDP Stream Builder
- 1722 Stream Builder
- AVA_LL_PTP_If (wrapper)
- AVA_LL_EB_If (wrapper+limiter)
- AVA_LL_FEC_DRIVER Ethernet Low level Driver Freescale
- Ethernet MAC
- PTP v2 Stack (IXXAT, optional)
- Normal IP-Stack (Elektrobit)
- Video encoder Data access
- Jpeg_encoder configuration
- I2C driver
- PORT HW
- Sensor interface Port PIN initialization, controlling static signals like imager reset
- ICTR (imager init)
- I2C HW
- Jpeg_encoder HW
Primary focus (phase 2):
- High level integration to save cost and footprint

Secondary focus (phase 3):
- Image signal processing integrated to save cost and power

Phase 1 – 2013 SOP
Ethernet Proof of Concept
- LVDS Elimination
- Ethernet proven in mass production

Phase 2 – 2015 SOP
Systems Cost Reduction Through Integration
- PHY integrated through SiP (stacked die wire bond)
- Small low cost package (8x8mm targeted)
- Cost, size, complexity reduction

Phase 3 – 2017 SOP
Value Added Features
- Image signal processing integrated (monolithic)
- PHY integrated through SiP (stacked die wire bond)
Highly integrated fusion unit

- HW accelerated video decode for low power
- GPU efficiently handles graphics processing using standardized programming models
- Scalable multi-core platform for object detection
i.MX 6 Family

i.MX 6Solo

• Single ARM Cortex A9 at up to 800MHz auto / 1.0GHz consumer
• 256KB L2 cache, Neon, VFPvd16, TrustZone
• 3D graphics with 1 shader up to 27MT/s, plus hardware X-acceleration engine
• External memory support up to 32bit DDR3 and LPDDR2

i.MX 6Dual

• Dual ARM Cortex A9 at 850MHz and 1GHz auto / 1.2GHz consumer
• 1 MB L2 cache, Neon, TrustZone
• 3D graphics with 4 shaders up to 176MT/s and OpenCL Embedded Profile support, plus hardware OpenVG and X-acceleration
• External memory support up to 64-bit DDR3 and 2-channel 32-bit LPDDR2
• Integrated SATA-II

i.MX 6Quad

• Quad ARM Cortex A9 up to 1GHz
• 1 MB L2 cache, Neon, TrustZone
• 3D graphics with 4 shaders up to 176MT/s and OpenCL Embedded Profile support
• OpenVG accelerator for overlays
• External memory support up to 64-bit DDR3 and 2-channel 32-bit LPDDR2
• ≥ 64 bit bus architecture
• Integrated SATA-II

Common Features of the i.MX 6 Series Platform

• Pin compatible ARM Cortex A9 based solutions up to 1GHz per core for automotive and 1.2GHz per core for consumer
• HD 1080p encode and decode
• 3D video playback in high definition
• Integrated IO’s that include HDMI v1.4, MIPI and LVDS display ports, MIPI camera, Gigabit Ethernet, multiple USB 2.0, PCI-Express, dual CAN controllers, MLB150/50/25 support
• Consumer, Industrial and Automotive temperature range qualifications
• SW support: Google Android™, Microsoft Windows® Embedded CE, Linux®,/Linaro™, QNX®, GENIVI™
Multicore data fusion on i.MX 6

- Neon-powered ARM® cores for advanced object detection
- Minimum 64-bit busses offer high system throughput
- ARM® A9
- Gigabit Ethernet + IEEE 1588
- Video Processing Unit
- 3D Graphics Processing Unit
- Image Processing Unit
- Vector Graphics Unit
- DDR3
- Display

MJPEG videodecode and 3D graphics pipeline support up to 5 cameras at 30 fps

OpenVG accelerator for overlay graphics
i.MX6 Performance for Multi-Camera Applications

• Memory sub-system and internal busses are minimum 64-bit wide ➔ very high data throughput with sufficient headroom

• MJPEG video decode and 3D graphics processing tested with 4 streams until 40 fps

• Less than one ARM core required for the video streaming and graphics processing ➔ up to 3 Neon-powered ARM cores available for advanced object detection

• 3D engine can additionally support object detection via OpenCL

• Separate OpenVG vector graphics accelerator available for overlay creation
Multi-camera 360° sensing application

- **Camera calibration** and control
- Data stream handling
- Lens distortion correction
- Image stitching
- 2D to 3D transformation and scene rendering
- Object detection
- Diagnosis and communication
- Operating system providing Quality-of-Service
- Functional safety (ISO 26262)
Camera calibration – intrinsic

• **Purpose**
  - Minimize differences between an ideal lens model and the used camera-lens combination
  - Compensate optical defects such as distortions, exposure differences between images, camera response and chromatic aberrations
  - Optical centre & radial distortion

• **Mapping function**
  - Calculated based on measured reference data and least squares fit of parameters
Camera calibration – extrinsic

Positions and angles of cameras relative vehicle and other cameras:

- **Offline calibration (in factory or service station)**
  - Similar measurements as in intrinsic case
  - Multi-dimensional minimization problem
- **Online calibration (while driving)**
  - Image filtering
  - Motion estimation
Image stitching

- **Static**
  - Interpolation of well-calibrated overlapping areas
  - Minimization of sum of absolute differences between overlapping pixels

- **Dynamic**
  - On-the-fly filtering for detection of matching features in adjacent images
  - Utilize environment model for feature matching stage
  - Dynamic geometric optimization of the images to minimize the sum of absolute difference between overlapping areas
  - Cost-effective implementation will be possible with future MPUs
2D to 3D transformation and scene rendering

• **Different projections**
  - Projection to ground
  - Projection to virtual wall

  ![Three views with different virtual camera positions](image)

• **Features**
  - Efficient image processing in OpenGL on (embedded) GPU
  - Cross platform portability for embedded i.MX systems and PC
  - Full 3D coordinate model
Object detection

- **State of the art object detection uses e.g.**
  - Haar wavelet features (e.g. Viola & Jones)
  - Histogram of oriented gradients (HOG) descriptors
  - Support Vector Machines or AdaBoost for classification

- **Requirements for video compression**
  - 12bit per YUV component for difficult light conditions
  - Algorithms react different on MJPEG and H.264 artifacts: no winner
  - Degradation negligible for high quality factors (e.g. 1:5 compression)

- **Algorithms can be optimized for SW implementation**
  Separate system for high-speed forward-looking as fish-eye lens is suboptimal for faraway objects
  → Objects have limited speed difference relative to car
  → Object detection range limited to short distance
Summary

• Camera based 360° sensing makes driving safer as the driver can capture hazards at a glance supported by holistic object detection

• Multi-camera systems are directly experienced by the driver and a differentiating element

• Ethernet over unshielded twisted pair cable is a cost-effective technology for a scalable real-time ADAS network in the car ready for production

• Embedded multi-core compute platforms enable highly integrated scalable fusion units for a multi-camera system

• FSL demonstrator and DSP Weuffen reference design including application software IP available