Techniques for Performing High-Bandwidth In-Vehicle Data Logging in Autonomous Vehicles

A Platform-Based Approach to ADAS Record & Playback
Application Overview: In-Vehicle ADAS Recording

V2X, WLAN, Bluetooth, GNSS

CAN, Ethernet
CAN, FlexRay, Ethernet

Audio, Camera (LVDS)
CAN, Lin, FlexRay, Ethernet

LiDAR

Radar

Camera

ECU

RAID

ADAS ECU

V2X Module
ADAS Record & Playback: 10 Challenges

1. Nonstandard, rapidly-evolving mixture of sensor types and data rates
2. Dedicated “black box” dataloggers with vendor-defined I/O capability
3. Vendor-defined GUI, file formats, OS support
4. Limited opportunity for in-line signal processing or fault injection
5. Hybrid systems lack defined power and environmental specifications
6. Record: timing, triggering, and synchronized recording of multi-rate, multi-sensor data
7. Playback: Synchronous output of multi-rate data from timestamped files
8. Performance limitations (aggregate data rates, storage, etc.)
9. Data management
10. Supplier risk (small, local, start-up, unavailable, etc.)
Typical Data Rates for ADAS Recording

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Expected Interface</th>
<th>Approximate Worst Case Bandwidth</th>
<th># of Sensors</th>
<th>Approximate Worst Case Total Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camera 2.5MP @ 60 FPS</td>
<td>GMSL/FPD Link III</td>
<td>5662 Mbit/s</td>
<td>6</td>
<td>33972 Mbit/s</td>
</tr>
<tr>
<td>Camera 1.3MP @ 30 FPS</td>
<td>GMSL/FPD Link III</td>
<td>1327 Mbit/s</td>
<td>2</td>
<td>2654 Mbit/s</td>
</tr>
<tr>
<td>Camera 1.3MP @ 69 FPS</td>
<td>GMSL/FPD Link III</td>
<td>3052 Mbit/s</td>
<td>2</td>
<td>6104 Mbit/s</td>
</tr>
<tr>
<td>LiDAR</td>
<td>1000 Base-T1</td>
<td>320 Mbit/s</td>
<td>1</td>
<td>320 Mbit/s</td>
</tr>
<tr>
<td>Radar</td>
<td>1000 Base-T1</td>
<td>12 Mbit/s</td>
<td>1</td>
<td>12 Mbit/s</td>
</tr>
<tr>
<td>Vehicle CAN Buses</td>
<td>CAN / CAN-FD</td>
<td>0.2 Mbit/s</td>
<td>20</td>
<td>4 Mbit/s</td>
</tr>
<tr>
<td>GNSS</td>
<td>Ethernet</td>
<td>0.1 Mbit/s</td>
<td>1</td>
<td>0.1 Mbit/s</td>
</tr>
<tr>
<td>Ultrasonic</td>
<td>CAN</td>
<td>0.01 Mbit/s</td>
<td>2</td>
<td>0.02 Mbit/s</td>
</tr>
</tbody>
</table>
Aggregate Data Rates for ADAS Recording

2.6 GB/s = 156 GB/min
9.36 TB/hour
Data Movement Challenges for ADAS Recording

- Data Storage/Data Movement Costs

~ 6 TB  \[\rightarrow\]  90+ minutes  \[\rightarrow\]  Network Server
PXie-1085 24GB/s Backplane Diagram
PXI Platform – Enabling ADAS Record & Playback

• PCI eXtensions for Instrumentation
• PC-based Platform for Measurement and Automation
• Governed by PXI Systems Alliance since 1997

• Features
  • PCIe bandwidths up to 24 GB/sec
  • Rugged CompactPCI Modular Packaging
  • Timing and Synchronization
Konrad / NI Record & Playback Architecture
LVDS Camera Interfaces
Key Terms

- LVDS = Low Voltage Differential Signaling
- MIPI = Mobile Industry Processor Interface
- CSI2 = Camera Serial Interface
- \( I^2C \) = Two Wire Serial Protocol
- MAX9296 = GMSL-1 or -2 Maxim Deserializer
- DS90UB953 = FPD-Link III TI Deserializer
- DS90UB954 = FPD-Link III TI Serializer
Camera Interfaces for ADAS Applications

ADAS Data Recording

Open Loop ADAS Data Playback

Camera Functional Test

Closed Loop HIL
Konrad Technologies KT-LVDS Terminal Daughter Board

- MIPI CSI-2 Interface to Camera Sensor
- Streaming of up to 3 LVDS I/O Channels
- Two Daughter Cards Available
  - TI FPD-Link III
    - 953, 954 Chipsets
  - Maxim GMSL
    - 9288 Chipset
  - New chipsets can be accommodated
- Data Rates up to 1.5 Gbits/sec/chan
  - 6 Gbits/sec aggregate
Konrad Technologies ABex TM-LVDS

<table>
<thead>
<tr>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABex TM-LVDS-6xRX-DS90UB954</td>
</tr>
<tr>
<td>ABex TM-LVDS-6xRX-MAX9296 GMSL1</td>
</tr>
<tr>
<td>ABex TM-LVDS-6xRX-MAX9296 GMSL2</td>
</tr>
<tr>
<td>ABex TM-LVDS 3xRX / 3xTX DS90UB954 / DS90UB953</td>
</tr>
</tbody>
</table>
ADAS Data Playback with PXIe

V2X, WLAN, Bluetooth, GNSS
Radar – CAN FD, Ethernet
LiDAR- CAN FD, Ethernet
CAN, LIN, FlexRay, Ethernet
Audio, Camera – LVDS, Ethernet
ADAS HIL Test with PXIe

- V2X, WLAN, Bluetooth, GNSS
- Radar – CAN FD, Ethernet
- LiDAR – CAN FD, Ethernet
- CAN, LIN, FlexRay, Ethernet
- Audio, Camera – LVDS, Ethernet
ADAS High-Fidelity Sensor Emulation with PXIe

- V2X, WLAN, Bluetooth, GNSS
- Radar – CAN FD, Ethernet
- LiDAR – CAN FD, Ethernet
- CAN, LIN, FlexRay, Ethernet
- Audio, Camera – LVDS, Ethernet

Ground Truth w/ Scene Labeling

monoDrive Simulation Engine

Perception
ADAS Record
Case Study:
KT ADE OEM ADAS Record Implementation

• 10 LVDS (FPD-Link-III) Cameras Logging to Binary File Format
  • Maximum combined transfer rate of 1.4 GB/sec
• 19 CAN Channels Logging to TDMS File Format
  • High Speed Vehicle Bus
  • Low Speed Vehicle Bus
  • IMU
  • Ultrasonic Sensors
• GPS Data Logging to TDMS Format
• Error Logging
• UDP Communication

• Long-Range Radar
• Short-Range Radar
• MobilEye Camera
Case Study: KT ADE OEM Implementation

INITIALIZE: Reads configuration; creates test artifacts

START LOGGING: CAN and GPS log to disk; circular buffer for video starts

TRIGGER: Video logs pre-trigger and post-trigger data to disk

STOP: Logger stops and enters idle state
Case Study: KT ADE OEM Implementation: Performance
ADAS Playback
Typical I/O List: ADAS Data Playback System

- 4 Short-Range Radar Sensors (CAN)
- 2 Long-Range Radar Sensors (CAN)
- Vehicle Bus (CAN)
- Wheel Speed (CAN)
- IMU (Ethernet – UDP)
- GPS (Ethernet – UDP)
- LiDAR (Ethernet – UDP)
- 7 GMSL 2.0 Cameras

- 8x CAN HS/FD
- 3x HW Timed Ethernet (UDP)
- 7x GMSL 2.0
Simplified Block Diagram: Data Playback System

RAID Timestamped data

KT ADE

GPS
IMU
LiDAR

100Base-T1

gPTP Enabled Switch

1000Base-T1

Radar and Camera ECUs (one of which is gPTP Grand Master)

7 CH GMSL2
7 CH CAN HS/FD
Differentiated Features of NI / Konrad Architecture

• Modular, PXIe architecture provides access to all current / future sensors and communication busses in scalable channel counts

• PXIe platform is COTS standard across multiple industries
  • Available since 1997 with increasing adoption annually
  • Defined lifecycle management on all NI PXIe products

• PXIe platform has defined power and environmental requirements

• PXIe platform has built in timing, triggering, and synchronization
Differentiated Features of NI / Konrad Architecture

• NI LabVIEW is world’s leading graphical system design environment for test and measurement applications providing software-defined instrumentation at all levels
  • Windows -> GUI, file format and I/O, enterprise connectivity, signal processing
  • Drivers -> hardware I/O and synchronization
  • FPGA -> custom protocols, in-line signal/image processing, fault insertion, custom timing
• Software can be certified to industry standards (*e.g.* ISO 26262 Functional Safety)
• Scalable storage based on removable RAID subsystems
  • Compatible with 3\textsuperscript{rd}-party COTS storage media
  • Data management solutions based on metadata possible using NI Data Management Suite
Implications of NI / Konrad Differentiated Features

• Evolving technical requirements can be accommodated in LabVIEW:
  • New sensor types and bus interfaces and changes in channel counts of existing I/O
  • Configurable user interfaces
  • New file formats and data management schemes

• Novel I/O (e.g., V2X interfaces) can be integrated with ADAS sensors

• Can be integrated directly with NI and 3rd-party hardware and software
  • NI HIL (VeriStand and SLSC)
  • Vehicle Dynamics Packages such as dSPACE MotionDesk, IPG CarMaker, VTD VIRES
  • Sensor Emulation Perception Modeling Tools such as monoDrive and ANSYS

• Multi-rate acquisition and playback rates supported
National Instruments / Konrad Business Differentiators

• No software deployment licenses required
• Dedicated NI and Konrad account managers and NI system engineering
• Global availability of low-cost, high-volume NI components with typically short lead times
• Stable supplier with ~ $1.5B in annual revenue (NI)
• Global support available on all three major continents from NI and Konrad
• Konrad’s stake in adas-iiT provides access to subject matter experts in HIL, data management, and V2X communications and technical path to integration
• ADAS Record & Playback platform has been deployed at a Detroit “Big 3” OEM and has been selected by multiple Tier 1 automotive suppliers
## Typical Project Schedule: ADAS Playback System

<table>
<thead>
<tr>
<th>Milestone Description</th>
<th>Milestone Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Kick-off Meeting</td>
<td>1 weeks After Receipt of Order (ARO) - Approximate</td>
</tr>
<tr>
<td>System Requirements and Preliminary Design Review</td>
<td>2 weeks from Kick-off</td>
</tr>
<tr>
<td>Critical Design Review</td>
<td>4 weeks from Kick-off</td>
</tr>
<tr>
<td>Build complete</td>
<td>8 weeks from Kick-off</td>
</tr>
<tr>
<td>Factory Acceptance Testing</td>
<td>14 weeks from Kick-off</td>
</tr>
<tr>
<td>Shipment</td>
<td>15 weeks from Kick-off</td>
</tr>
<tr>
<td>Site Acceptance Testing</td>
<td>16 weeks from Kick-off</td>
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</tbody>
</table>
Konrad Technologies Overview
WE KNOW HOW TO TEST!
Company Profile

Established: 1993 (Michael Konrad)
2018 Revenue: $60M
Installed Base: > 3500 systems
Headcount: 300 (> 50% engineers)
Certifications: ISO 9001, ISO 13485, CSIA

NI TestStand: 3 CTA, 5 CTD
NI LabVIEW: 11 CLA, 16 CLD, 9 CLAD, 3 Champion

Recognized Specialities: Vehicle Radar Test System (VRTS) Specialty, RF & Wireless Specialty
Global Footprint

**Konrad GmbH - Headquarters**
Fritz-Reichle-Ring 12
Radolfzell Lake of Constance
78315, Germany

**Konrad US - Headquarters**
27300 Haggerty Road Suite F-10
Farmington Hills, MI
48331, USA
Representative ADAS Test Capabilities

- Sensor Validation Test – Performance
  - Radar
    - RF
    - Electrical Test
  - Camera
    - Optical Test
    - Electrical Test
  - LiDAR
    - Optical Test
    - Electrical Test

- Sensor Validation Test – Environmental
  - Temperature
  - Humidity

- Sensor Production Test
  - Alignment
  - Calibration
  - Build Quality Verification

- Object Simulation
  - Radar
    - Behind ECU
    - In Front of Radar
  - Camera
    - Behind ECU
    - Between Camera and ECU
    - In Front of Camera
  - LiDAR
    - Behind ECU
    - In Front of LiDAR
  - V2X
  - ADAS HIL
  - ADAS Record & Playback
    - Program sensors
    - Environmental / ground truth sensors
    - Simulated sensors
ADAS iiT: Collaboration between 4 National Instruments Alliance Partners to address the needs for the next generation ADAS Test platform.
Contact Information

- Jeff Buterbaugh, Ph.D.
- Account Executive
- 27300 Haggerty Rd, Farmington Hills, MI 48331
- +1 (614) 975-8438
- jeff.buterbaugh@konrad-technologies.com
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Technical Appendix
KT-MIPI Hardware Block Diagram
I2C Backchannel; RX module is I2C master
I2C Simplified Backchannel; TX module is I2C slave and only acknowledges read data