Application Note

Developing Multiple-Camera Applications on AM6x

Jianzhong Xu, Qutaiba Saleh

ABSTRACT

This report describes application development using multiple CSI-2 cameras on the AM6x family of devices. A reference design of object detection with deep learning on 4 cameras on the AM62A SoC is presented with performance analysis. General principles of the design apply to other SoCs with CSI-2 interface, such as AM62x and AM62P.

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Trademarks

1 Introduction

Embedded cameras play an important role in modern vision systems. Using multiple cameras in a system expands the capabilities of these systems and enables capabilities that are not possible with a single camera. Below are some examples of the applications using multiple embedded cameras:

Security Surveillance: Multiple cameras placed strategically provide comprehensive surveillance coverage. They enable panoramic views, reduce blind spots, and enhance the accuracy of object tracking and recognition, improving overall security measures.

Surround View: Multiple cameras are used to create a stereo vision setup, enabling three-dimensional information and the estimation of depth. This is crucial for tasks such as obstacle detection in autonomous vehicles, precise object manipulation in robotics, and enhanced realism of augmented reality experiences.

Cabin Recorder and Camera Mirror System: A car cabin recorder with multiple cameras can provide more coverage using a single processor. Similarly, a camera mirror system with two or more cameras can expand the driver's field of view and eliminate blind spots from all sides of a car.

Medical Imaging: Multiple cameras can be used in medical imaging for tasks like surgical navigation, providing surgeons with multiple perspectives for enhanced precision. In endoscopy, multiple cameras enable a thorough examination of internal organs.

Drones and Aerial Imaging: Drones often come equipped with multiple cameras to capture high-resolution images or videos from different angles. This is useful in applications like aerial photography, agriculture monitoring, and land surveying.

With the advancement of microprocessors, multiple cameras can be integrated into a single System-on-Chip (SoC) to provide compact and efficient solutions. The AM62Ax SoC, with high-performance video/vision processing and deep learning acceleration, is an ideal device for the above-mentioned use cases. Another AM6x device, the AM62P, is built for high-performance embedded 3D display applications. Equipped with 3D graphics acceleration, the AM62P can easily stitch together the images from multiple cameras and produce a high-resolution panoramic view. The innovative features of the AM62A/AM62P SoC have been presented in various publications, such as [4], [5], [6], etc. This application note will not repeat those feature descriptions but instead focuses on integrating multiple CSI-2 cameras into embedded vision applications on AM62A/AM62P.

Table 1-1 shows the main differences between AM62A and AM62P as far as image processing is concerned.

Table 1-1. Differences Between AM62A and AM62P in Image Processing

SoC	AM62A	AM62P
Supported Camera Type	With or without built-in ISP	With Built-in ISP
Camera Output Data	Raw/YUV/RGB	YUV/RGB
ISP HWA	Yes	No
Deep Learning HWA	Yes	No
3-D Graphics HWA	No	Yes

2 Connecting Multiple CSI-2 Cameras to the SoC

The Camera Subsystem on the AM6x SoC contains the following components, as shown in Figure 2-1:

- MIPI D-PHY Receiver: receives video streams from external cameras, supporting up to 1.5 Gbps per data lane for 4 lanes.
- CSI-2 Receiver (RX): receives video streams from the D-PHY receiver and either directly sends the streams to the ISP or dumps the data to DDR memory. This module supports up to 16 virtual channels.
- SHIM: a DMA wrapper that enables sending the captured streams to memory over DMA. Multiple DMA contexts can be created by this wrapper, with each context corresponding to a virtual channel of the CSI-2 Receiver.

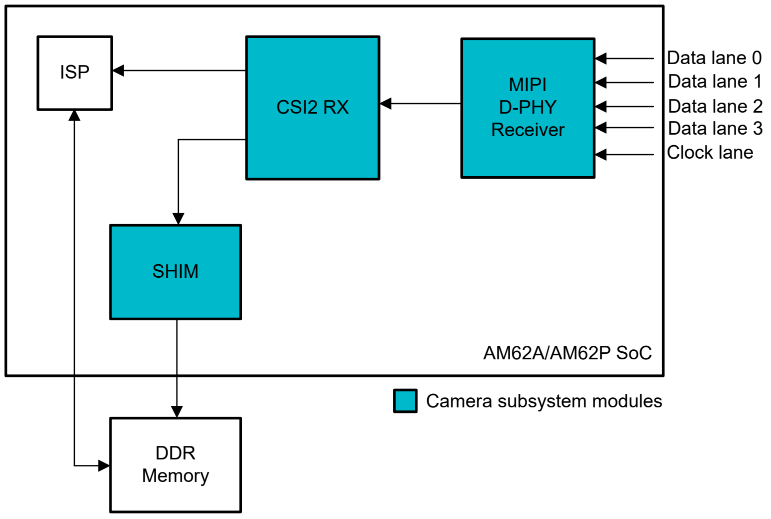


Figure 2-1. High-Level Block Diagram of the Camera Subsystem on AM62A/AM62P SoC

Multiple cameras can be supported on the AM6x through the use of virtual channels of CSI-2 RX, even though there is only one CSI-2 RX interface on the SoC. An external CSI-2 aggregating component is needed to combine multiple camera streams and send to a single SoC. There are two types of CSI-2 aggregating solutions that can be used, described in the following sections.

2.1 CSI-2 Aggregator Using SerDes

One way of combining multiple camera streams is to use a serializing and deserializing (SerDes) solution. The CSI-2 data from each camera is converted by a serializer and transferred through a cable. The deserializer receives all serialized data transferred from the cables (one cable per camera), converts the streams back to CSI-2 data, and then sends out an interleaved CSI-2 stream to the single CSI-2 RX interface on the SoC. Each camera stream is identified by a unique virtual channel. This aggregating solution offers the additional benefit of allowing long-distance connection of up to 15m from the cameras to the SoC.

The FPD-Link or V3-Link serializers and deserializers (SerDes), supported in the AM6x Linux SDK, are the most popular technologies for this type of CSI-2 aggregating solution. Both the FPD-Link and V3-Link deserializers have back channels that can be used to send frame sync signals to synchronize all the cameras, as explained in [7].

Figure 2-2 shows an example of using the SerDes to connect multiple cameras to a single AM6x SoC.

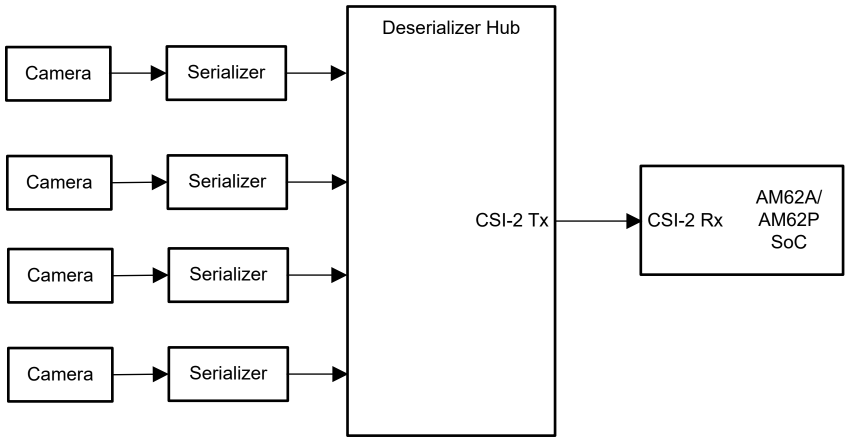


Figure 2-2. Connecting Multiple Cameras Using SerDes

An example of this aggregating solution can be found in the Arducam V3Link Camera Solution Kit. This kit has a deserilizer hub which aggregates 4 CSI-2 camera streams, as well as 4 pairs of V3link serializers and IMX219 cameras, including FAKRA coaxial cables and 22-pin FPC cables. The reference design discussed later is built on this kit.

2.2 CSI-2 Aggregator without Using SerDes

This type of aggregator can directly interface with multiple MIPI CSI-2 cameras and aggregate the data from all cameras to a single CSI-2 output stream.

Figure 2-3 shows an example of such a system. This type of aggregating solution does not use any serializer/deserializer but is limited by the maximum distance of CSI-2 data transfer, which is up to 30cm. The AM6x Linux SDK does not support this type of CSI-2 aggregator.

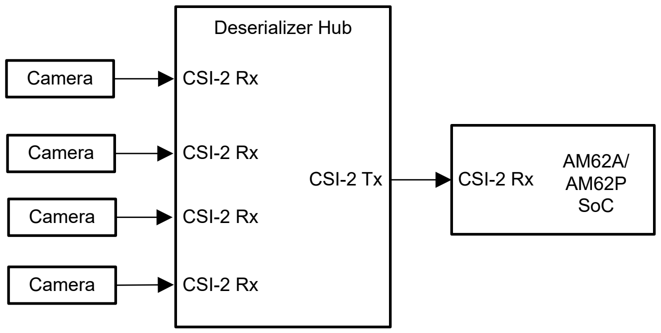


Figure 2-3. Connecting Multiple Cameras Using CSI-2 Aggregator

3 Enabling Multiple Cameras in Software

3.1 Camera Subsystem Software Architecture

Figure 3-1 shows a high-level block diagram of the camera capture system software in AM62A/AM62P Linux SDK, corresponding to the HW system in Figure 2-2.

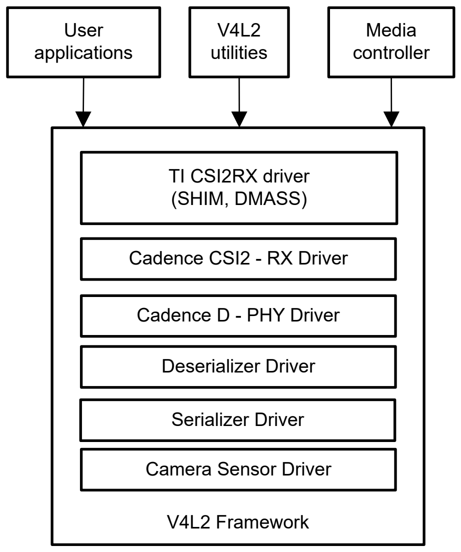


Figure 3-1. High-Level Block Diagram of Camera Capture System Using SerDes

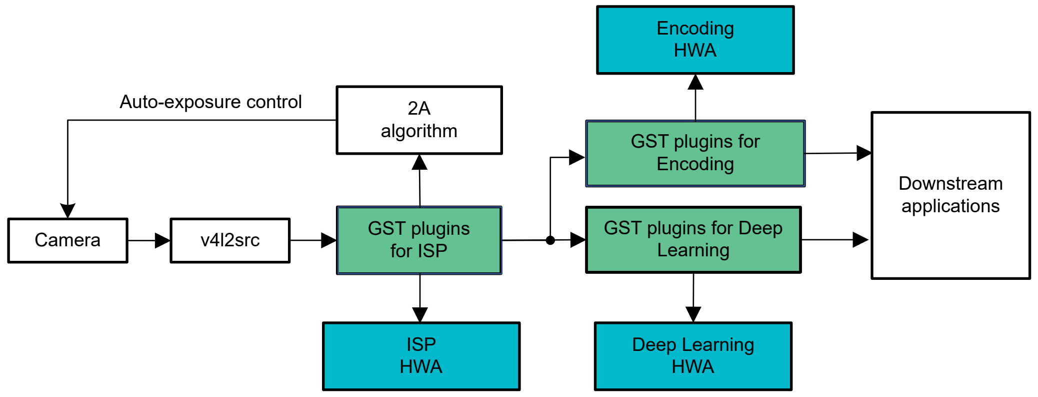
This software architecture enables the SoC to receive multiple camera streams with the use of SerDes, as shown in Figure 2-2. The FPD-Link/V3-Link SerDes assigns a unique I2C address and virtual channel to each camera. A unique device tree overlay should be created with the unique I2C address for every camera. The CSI-2 RX driver recognizes each camera using the unique virtual channel number and creates a DMA context per camera stream. A video node is created for every DMA context. Data from each camera is then received and stored using DMA to the memory accordingly. User space applications use the video nodes corresponding to each camera to access the camera data. Examples of using this software architecture are given in chapter 4 - reference design.

Any specific sensor driver that is compliant with the V4L2 framework can plug and play in this architecture. Refer to [8] regarding how to integrate a new sensor driver into the Linux SDK.

3.2 Image Pipeline Software Architecture

The AM6x Linux SDK provides GStreamer (GST) framework which can be used in user space to integrate the image processing components for various applications. The Hardware Accelerators (HWA) on the SoC, such as the Vision Pre-processing Accelerator (VPAC) or ISP, video encoder/decoder, and deep learning compute engine, are accessed through GST plugins. The VPAC (ISP) itself has multiple blocks, including Vision Imaging Sub-System (VISS), Lens Distortion Correction (LDC), and Multiscalar (MSC), each corresponding to a GST plugin.

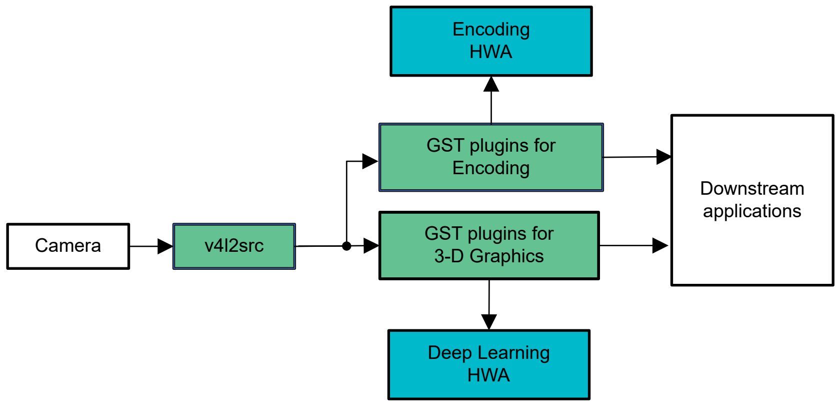
Figure 3-2 shows the block diagram of a typical image pipeline from the camera to encoding or deep learning applications on AM62A. For more details about the end-to-end data flow, refer to the EdgeAI SDK documentation.



🟩 Gstreamer (GST) plugin
🟦 AM62A Hardware Accelerator (HWA)

Figure 3-2. A Typical AM62A Image Pipeline Using GStreamer

For AM62P, the image pipeline is simpler because there is no ISP on AM62P.



🟩 Gstreamer (GST) plugin
🟦 AM62P Hardware Accelerator (HWA)

Figure 3-3. A Typical AM62P Image Pipeline Using GStreamer

With a video node created for each of the cameras, the GStreamer-based image pipeline allows the processing of multiple camera inputs (connected through the same CSI-2 RX interface) simultaneously. A reference design using GStreamer for multi-camera applications is given in the next chapter.

4 Reference Design

This chapter presents a reference design of running multiple-camera applications on AM62A EVM, using the Arducam V3Link Camera Solution Kit to connect 4 CSI-2 cameras to AM62A and running object detection for all 4 cameras.

4.1 Supported Cameras

The Arducam V3Link kit works with both FPD-Link/V3-Link based cameras and Raspberry Pi compatible CSI-2 cameras. The following cameras have been tested:

- D3 Engineering D3RCM-IMX390-953
- Leopard Imaging LI-OV2312-FPDLINKIII-110H
- IMX219 cameras in the Arducam V3Link Camera Solution Kit

4.2 Setting up Four IMX219 Cameras

Follow the instructions provided in the AM62A Starter Kit EVM Quick Start Guild to setup the SK-AM62A-LP EVM (AM62A SK) and ArduCam V3Link Camera Solution Quick Start Guide to connect the cameras to AM62A SK through the V3Link kit. Make sure the pins on the flex cables, cameras, V3Link board, and AM62A SK are all aligned properly.

Figure 4-1 shows the setup used for the reference design in this report. The main components in the setup includes:

- 1X SK-AM62A-LP EVM board
- 1X Arducam V3Link d-ch adapter board
- FPC cable connecting Arducam V3Link to SK-AM62A
- 4X V3Link camera adapters (serializers)
- 4X RF coaxial cables to connect V3Link serializers to V3Link d-ch kit
- 4X IMX219 Cameras
- 4X CSI-2 22 pin cables to connect cameras to serializers
- Cables: HDMI cable, USB-C to power SK-AM62A-LP and 12V power sourced for V3Link d-ch kit)
- Other components not shown in Figure 4-1: micro-SD card, micro-USB cable to access SK-AM62A-LP, and ethernet for streaming

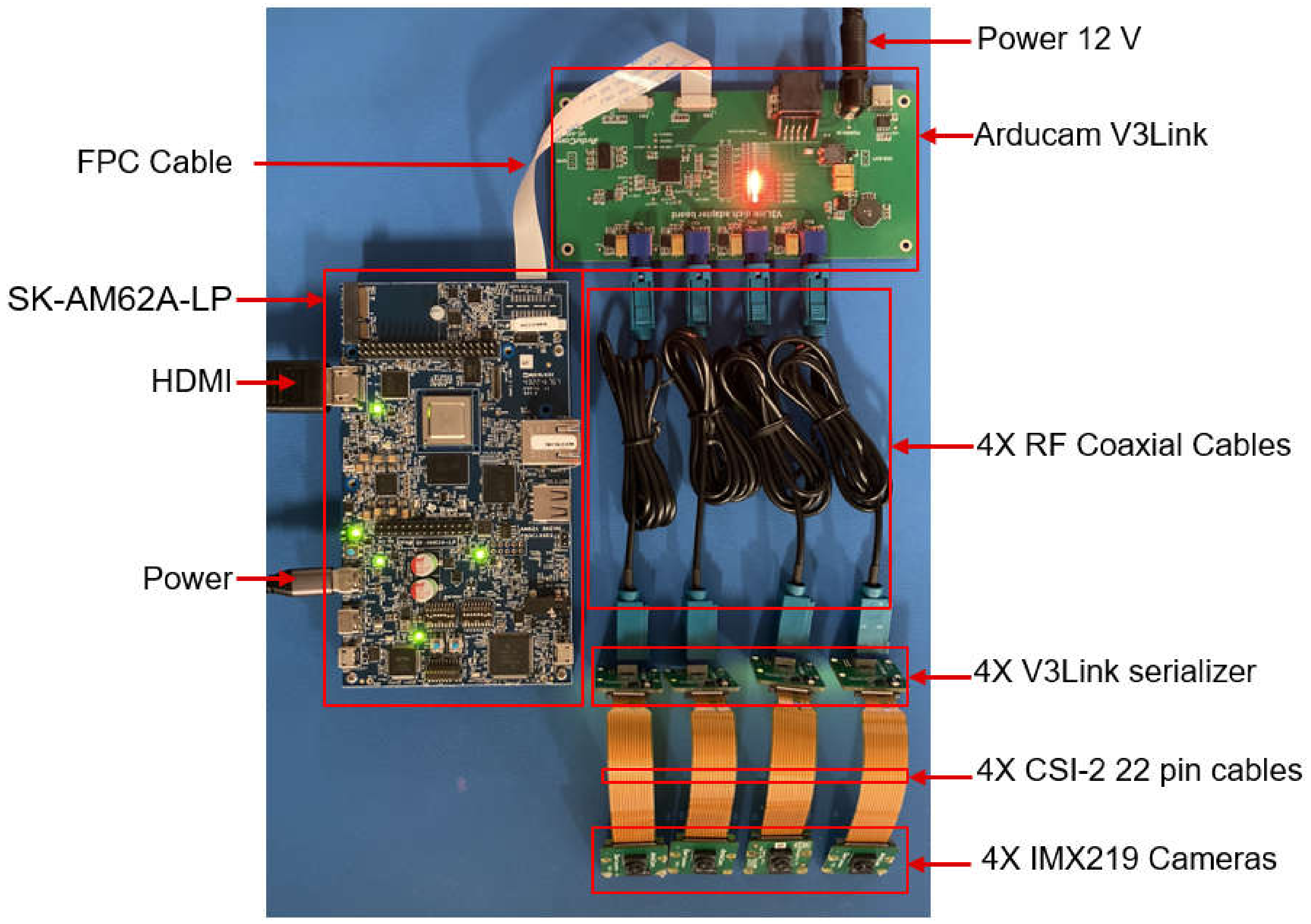


Figure 4-1. V3link Board and 4 Cameras Setup Used in the Reference Design

4.3 Configuring Cameras and CSI-2 RX Interface

Set up the software according to the instructions provided in the Arducam V3Link Quick Start Guide. After running the camera setup script, setup-imx219.sh, the cameras format, the CSI-2 RX interface format, and the routes from each camera to the corresponding video node will be configured properly. Four video nodes are created for the four IMX219 cameras. Command “v4l2-ctl --list-devices” displays all the V4L2 video devices, as shown below:

```
root@am62axx-evm:~# v4l2-ctl --list-devices
j721e-csi2rx (platform:30102000.ticsi2rx):
        /dev/video2
        /dev/video3
        /dev/video4
        /dev/video5
        /dev/video6
        /dev/video7
        /dev/media0

wave5-dec (platform:wave5-dec):
        /dev/video0

wave5-enc (platform:wave5-enc):
        /dev/video1
```

There are 6 video nodes and 1 media node under tiscsi2rx. Each video node corresponds to a DMA context allocated by the CSI2 RX driver. Out of the 6 video nodes, 4 are used for the 4 IMX219 cameras, as shown in the media pipe topology below:

```
root@am62axx-evm:~# media-ctl -p

Device topology
- entity 1: 30102000.ticsi2rx (7 pads, 7 links, 4 routes)
            type V4L2 subdev subtype Unknown flags 0
            device node name /dev/v4l-subdev0
        routes:
                0/0 -> 1/0 [ACTIVE]
                0/1 -> 2/0 [ACTIVE]
                0/2 -> 3/0 [ACTIVE]
                0/3 -> 4/0 [ACTIVE]
        pad0: Sink
                [stream:0 fmt:UYVY8_1X16/640x480 field:none colorspace:srgb xfer:srgb ycbcr:601
quantization:lim-range]
                [stream:1 fmt:UYVY8_1X16/640x480 field:none colorspace:srgb xfer:srgb ycbcr:601
quantization:lim-range]
                [stream:2 fmt:UYVY8_1X16/640x480 field:none colorspace:srgb xfer:srgb ycbcr:601
quantization:lim-range]
                [stream:3 fmt:UYVY8_1X16/640x480 field:none colorspace:srgb xfer:srgb ycbcr:601
quantization:lim-range]
                <- "cdns_csi2rx.30101000.csi-bridge":1 [ENABLED,IMMUTABLE]
        pad1: Source
                [stream:0 fmt:UYVY8_1X16/640x480 field:none colorspace:srgb xfer:srgb ycbcr:601
quantization:lim-range]
                -> "30102000.ticsi2rx context 0":0 [ENABLED,IMMUTABLE]
        pad2: Source
                [stream:0 fmt:UYVY8_1X16/640x480 field:none colorspace:srgb xfer:srgb ycbcr:601
quantization:lim-range]
                -> "30102000.ticsi2rx context 1":0 [ENABLED,IMMUTABLE]
        pad3: Source
                [stream:0 fmt:UYVY8_1X16/640x480 field:none colorspace:srgb xfer:srgb ycbcr:601
quantization:lim-range]
                -> "30102000.ticsi2rx context 2":0 [ENABLED,IMMUTABLE]
        pad4: Source
                [stream:0 fmt:UYVY8_1X16/640x480 field:none colorspace:srgb xfer:srgb ycbcr:601
quantization:lim-range]
                -> "30102000.ticsi2rx context 3":0 [ENABLED,IMMUTABLE]
        pad5: Source
                -> "30102000.ticsi2rx context 4":0 [ENABLED,IMMUTABLE]
        pad6: Source
                -> "30102000.ticsi2rx context 5":0 [ENABLED,IMMUTABLE]
```

As shown above, media entity 30102000.ticsi2rx has 6 source pads, but only the first 4 are used, each for one IMX219. The media pipe topology can also be illustrated graphically. Run the following command to generate a dot file:

```
root@am62axx-evm:~# media-ctl --print-dot > media.dot
```

Then run the command below on a Linux host PC to generate a png file:

```
$ dot -Tpng media-top.dot -o media-top.png
```

Figure 4-2 is a picture generated using the commands given above. The components in the software architecture of Figure 3-1 can be found in this graph.

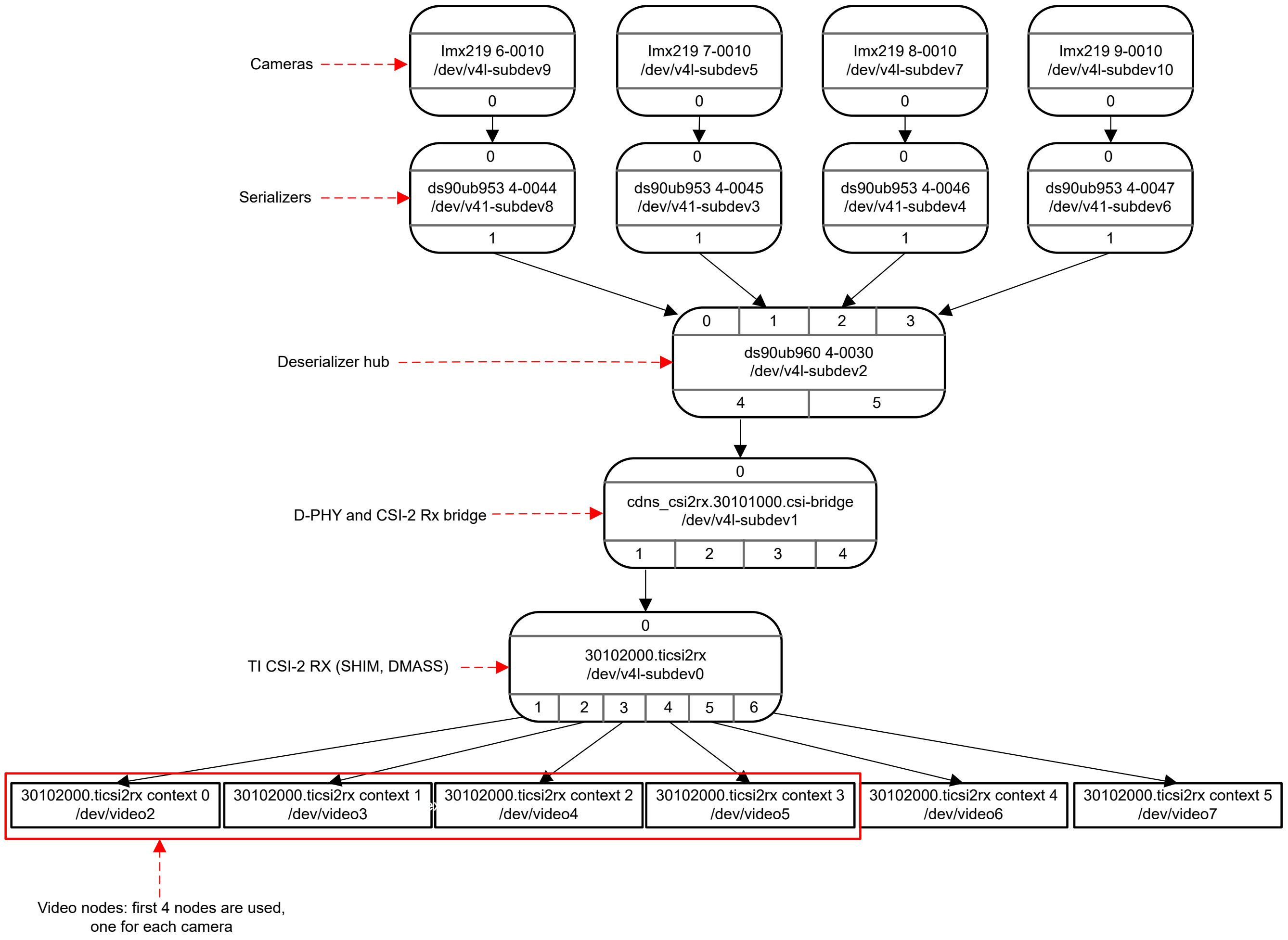

Cameras
Imx219 6-0010 /dev/v4l-subdev9
Imx219 7-0010 /dev/v4l-subdev5
Imx219 8-0010 /dev/v4l-subdev7
Imx219 9-0010 /dev/v4l-subdev10
Serializers
ds90ub953 4-0044 /dev/v41-subdev8
ds90ub953 4-0045 /dev/v41-subdev3
ds90ub953 4-0046 /dev/v41-subdev4
ds90ub953 4-0047 /dev/v41-subdev6
Deserializer hub
ds90ub960 4-0030 /dev/v4l-subdev2
D-PHY and CSI-2 Rx bridge
cdns_csi2rx.30101000.csi-bridge /dev/v4l-subdev1
TI CSI-2 RX (SHIM, DMASS)
30102000.ticsi2rx /dev/v4l-subdev0
30102000.ticsi2rx context 0 /dev/video2
30102000.ticsi2rx context 1 /dev/video3
30102000.ticsi2rx context 2 /dev/video4
30102000.ticsi2rx context 3 /dev/video5
30102000.ticsi2rx context 4 /dev/video6
30102000.ticsi2rx context 5 /dev/video7
Video nodes: first 4 nodes are used, one for each camera

Figure 4-2. Media Topology of a Multi-Camera System

4.4 Streaming from Four Cameras

With both hardware and software being set up properly, multiple-camera applications can run from the user space. For AM62A, the ISP must be tuned to produce good image quality. Refer to the AM6xA ISP Tuning Guide for how to perform ISP tuning. The following sections present examples of streaming camera data to a display, streaming camera data to a network, and storing the camera data to files.

4.4.1 Streaming Camera Data to Display

A basic application of this multi-camera system is to stream the videos from all cameras to a display connected to the same SoC. The following is a GStreamer pipeline example of streaming four IMX219 to a display (the video node numbers and v4l-subdev numbers in the pipeline will likely change from reboot to reboot).

```
gst-launch-1.0 \
v4l2src device=/dev/video2 io-mode=5 ! video/x-
bayer,width=1920,height=1080,framerate=30/1,format=bggr ! queue leaky=2 ! \
tiovxisp sink_0::device=/dev/v4l-subdev9 sensor-name=SENSOR_SONY_IMX219_RPI dcc-isp-file=/opt/
imaging/imx219/dcc_viss_1920x1080.bin \
sink_0::dcc-2a-file=/opt/imaging/imx219/dcc_2a_1920x1080.bin format-msb=7 sink_0::pool-size=8
src::pool-size=8 ! \
video/x-raw,format=NV12, width=1920,height=1080 ! queue ! mosaic.sink_0 \
v4l2src device=/dev/video3 io-mode=5 ! video/x-
bayer,width=1920,height=1080,framerate=30/1,format=bggr ! queue leaky=2 ! \
tiovxisp sink_0::device=/dev/v4l-subdev5 sensor-name=SENSOR_SONY_IMX219_RPI dcc-isp-file=/opt/
imaging/imx219/dcc_viss_1920x1080.bin \
sink_0::dcc-2a-file=/opt/imaging/imx219/dcc_2a_1920x1080.bin format-msb=7 sink_0::pool-size=8
src::pool-size=8 ! \
video/x-raw,format=NV12, width=1920,height=1080 ! queue ! mosaic.sink_1 \
v4l2src device=/dev/video4 io-mode=5 ! video/x-
```

```
bayer,width=1920,height=1080,framerate=30/1,format=bggr ! queue leaky=2 ! \
tiovxisp sink_0::device=/dev/v4l-subdev7 sensor-name=SENSOR_SONY_IMX219_RPI dcc-isp-file=/opt/
imaging/imx219/dcc_viss_1920x1080.bin \
sink_0::dcc-2a-file=/opt/imaging/imx219/dcc_2a_1920x1080.bin format-msb=7 sink_0::pool-size=8
src::pool-size=8 ! \
video/x-raw,format=NV12, width=1920,height=1080 ! queue ! mosaic.sink_2 \
v4l2src device=/dev/video5 io-mode=5 ! video/x-
bayer,width=1920,height=1080,framerate=30/1,format=bggr ! queue leaky=2 ! \
tiovxisp sink_0::device=/dev/v4l-subdev10 sensor-name=SENSOR_SONY_IMX219_RPI dcc-isp-file=/opt/
imaging/imx219/dcc_viss_1920x1080.bin \
sink_0::dcc-2a-file=/opt/imaging/imx219/dcc_2a_1920x1080.bin format-msb=7 sink_0::pool-size=8
src::pool-size=8 ! \
video/x-raw,format=NV12, width=1920,height=1080 ! queue ! mosaic.sink_3 \
tiovxmosaic name=mosaic \
sink_0::startx="<0>" sink_0::starty="<0>" sink_0::widths="<640>" sink_0::heights="<480>" \
sink_1::startx="<0>" sink_1::starty="<480>" sink_1::widths="<640>" sink_1::heights="<480>" \
sink_2::startx="<640>" sink_2::starty="<0>" sink_2::widths="<640>" sink_2::heights="<480>" \
sink_3::startx="<640>" sink_3::starty="<480>" sink_3::widths="<640>" sink_3::heights="<480>" ! \
queue ! video/x-raw, width=1920, height=1080 ! kmssink driver-name=tidss sync=false force-
modesetting=true
```

4.4.2 Streaming Camera Data through Ethernet

Instead of streaming to a display connected to the same SoC, the camera data can also be streamed through the Ethernet. The receiving side can be either another AM62A/AM62P processor or a host PC. The following is an example of streaming the camera data through the Ethernet (using two cameras for simplicity) (note the encoder plugin used in the pipeline):

```
gst-launch-1.0 \
v4l2src device=/dev/video2 io-mode=5 ! video/x-
bayer,width=1920,height=1080,framerate=30/1,format=bggr ! queue leaky=2 ! \
tiovxisp sensor-name=SENSOR_SONY_IMX219_RPI dcc-isp-file=/opt/imaging/imx219/dcc_viss_1920x1080.bin
\
sink_0::dcc-2a-file=/opt/imaging/imx219/dcc_2a_1920x1080.bin sink_0::device=/dev/v4l-subdev9 !
queue ! \
video/x-raw,format=NV12,width=1920,height=1080,framerate=30/1 ! v4l2h264enc ! rtph264pay ! udpsink
port=5000 host=<receiving IP address> \
v4l2src device=/dev/video3 io-mode=5 ! video/x-
bayer,width=1920,height=1080,framerate=30/1,format=bggr ! queue leaky=2 ! \
tiovxisp sensor-name=SENSOR_SONY_IMX219_RPI dcc-isp-file=/opt/imaging/imx219/dcc_viss_1920x1080.bin
\
sink_0::dcc-2a-file=/opt/imaging/imx219/dcc_2a_1920x1080.bin sink_0::device=/dev/v4l-subdev5 !
queue ! \
video/x-raw,format=NV12,width=1920,height=1080,framerate=30/1 ! v4l2h264enc ! rtph264pay ! udpsink
port=5001 host=<receiving IP address>
```

The following is an example of receiving the camera data and streaming to a display on another AM62A/AM62P processor:

```
gst-launch-1.0 -v \
udpsrc port=5000 ! 'application/x-rtp, encoding-name=H264, payload=96' ! rtph264depay !
avdec_h264 ! queue ! videoconvert ! queue ! \
video/x-raw,format=NV12,width=1920,height=1080 ! queue ! mosaic.sink_0 \
udpsrc port=5001 ! 'application/x-rtp, encoding-name=H264, payload=96' ! rtph264depay !
avdec_h264 ! queue ! videoconvert ! queue ! \
video/x-raw,format=NV12,width=1920,height=1080 ! queue ! mosaic.sink_1 \
tiovxmosaic name=mosaic \
sink_0::startx="<0>" sink_0::starty="<0>" sink_0::widths="<960>" sink_0::heights="<540>" \
sink_1::startx="<960>" sink_1::starty="<540>" sink_1::widths="<960>" sink_1::heights="<540>" ! \
queue ! kmssink driver-name=tidss sync=false
```

4.4.3 Storing Camera Data to Files

Instead of streaming to a display or through a network, the camera data can be stored to local files. The pipeline below stores each camera's data to a file (using two cameras as an example for simplicity).

```
gst-launch-1.0 \
v4l2src device=/dev/video2 io-mode=5 ! video/x-
bayer,width=1920,height=1080,framerate=30/1,format=bggr ! queue leaky=2 ! \
tiovxisp sensor-name=SENSOR_SONY_IMX219_RPI dcc-isp-file=/opt/imaging/imx219/dcc_viss_1920x1080.bin
\
sink_0::dcc-2a-file=/opt/imaging/imx219/dcc_2a_1920x1080.bin sink_0::device=/dev/v4l-subdev9 !
```

```
queue ! \
video/x-raw,format=NV12,width=1920,height=1080,framerate=30/1 ! v4l2h264enc ! filesink location=cam-
cap-1.mp4 \
v4l2src device=/dev/video3 io-mode=5 ! video/x-
bayer,width=1920,height=1080,framerate=30/1,format=bggr ! queue leaky=2 ! \
tiovxisp sensor-name=SENSOR_SONY_IMX219_RPI dcc-isp-file=/opt/imaging/imx219/dcc_viss_1920x1080.bin
\
sink_0::dcc-2a-file=/opt/imaging/imx219/dcc_2a_1920x1080.bin sink_0::device=/dev/v4l-subdev5 !
queue ! \
video/x-raw,format=NV12,width=1920,height=1080,framerate=30/1 ! v4l2h264enc !  filesink
location=cam-cap-2.mp4
```

4.5 Multicamera Deep Learning Inference

AM62A is equipped with a deep learning accelerator (C7x-MMA) with up to two TOPS, which are capable of running various types of deep learning models for classification, object detection, semantic segmentation, and more. This section shows how AM62A can simultaneously run four deep learning models on four different camera feeds.

4.5.1 Model Selection

The TI's EdgeAI-ModelZoo provides hundreds of state-of-the-art models which are converted/exported from their original training frameworks to an embedded friendly format so that they can be offloaded to the C7x-MMA deep learning accelerator. The cloud-based Edge AI Studio Model Analyzer provides an easy-to-use "Model Selection" tool. It is dynamically updated to include all models supported in TI EdgeAI-ModelZoo. The tool requires no previous experience and provides an easy-to-use interface to enter the features required in the desired model.

The TFL-OD-2000-ssd-mobV1-coco-mlperf was selected for this multi-camera deep learning experiment. This multi-object detection model is developed in the Tensor Flow framework with 300x300 input resolution. Table 4-1 shows the important features of this model when trained on the coco dataset with about 80 different classes.

Table 4-1. Highlight Features of the Model TFL-OD-2000-ssd-mobV1-coco-mlperf.

Model	Task	Resolution	FPS	mAP 50% Accuracy On COCO	Latency/Frame (ms)	DDR BW Utilization (MB/ Frame)
TFL-OD-2000-ssd-mobV1-coco-mlperf	Multi Object Detection	300x300	~152	15.9	6.5	18.839

4.5.2 Pipeline Setup

Figure 4-3 shows the 4-camera deep learning GStreamer pipeline. TI provides a suit of GStreamer plugins that allow offloading some of the media processing and the deep learning inference to the hardware accelerators. Some examples of these plugins include tiovxisp, tiovxmultiscaler, tiovxmosaic, and tidlinferer. The pipeline in Figure 4-3 includes all required plugins for a multipath GStreamer pipeline for 4-camera inputs each with media preprocess, deep learning inference, and postprocess. The duplicated plugins for each of the camera paths are stacked in the graph for easier demonstration.

The available hardware resources are evenly distributed among the four camera paths. For instance, AM62A contains two image multiscalers: MSC0 and MSC1. The pipeline explicitly dedicated MSC0 to process camera 1 and camera 2 paths while MSC1 is dedicated to camera 3 and camera 4.

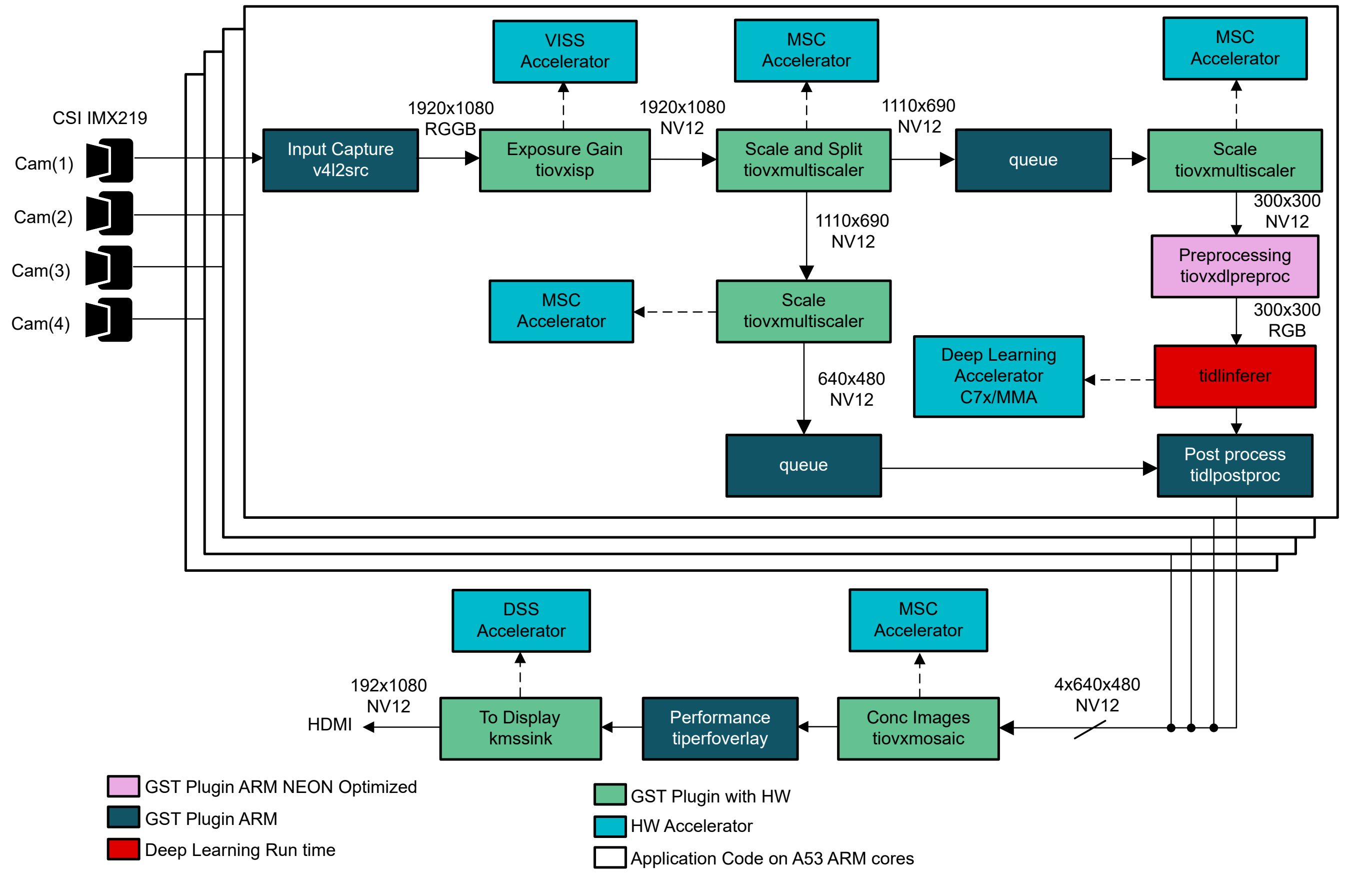


Figure 4-3. GStreamer Pipeline for Quad CSI IMX219 Camera Deep Learning Inference on AM62A

The output of the four camera pipelines are scaled down and concatenated together using tiovxmosaic plugin. The output is displayed on a single screen. Figure 4-4 shows the output of the four cameras with deep learning model running object detection. Each pipeline (camera) is running at 30 FPS and total 120 FPS.

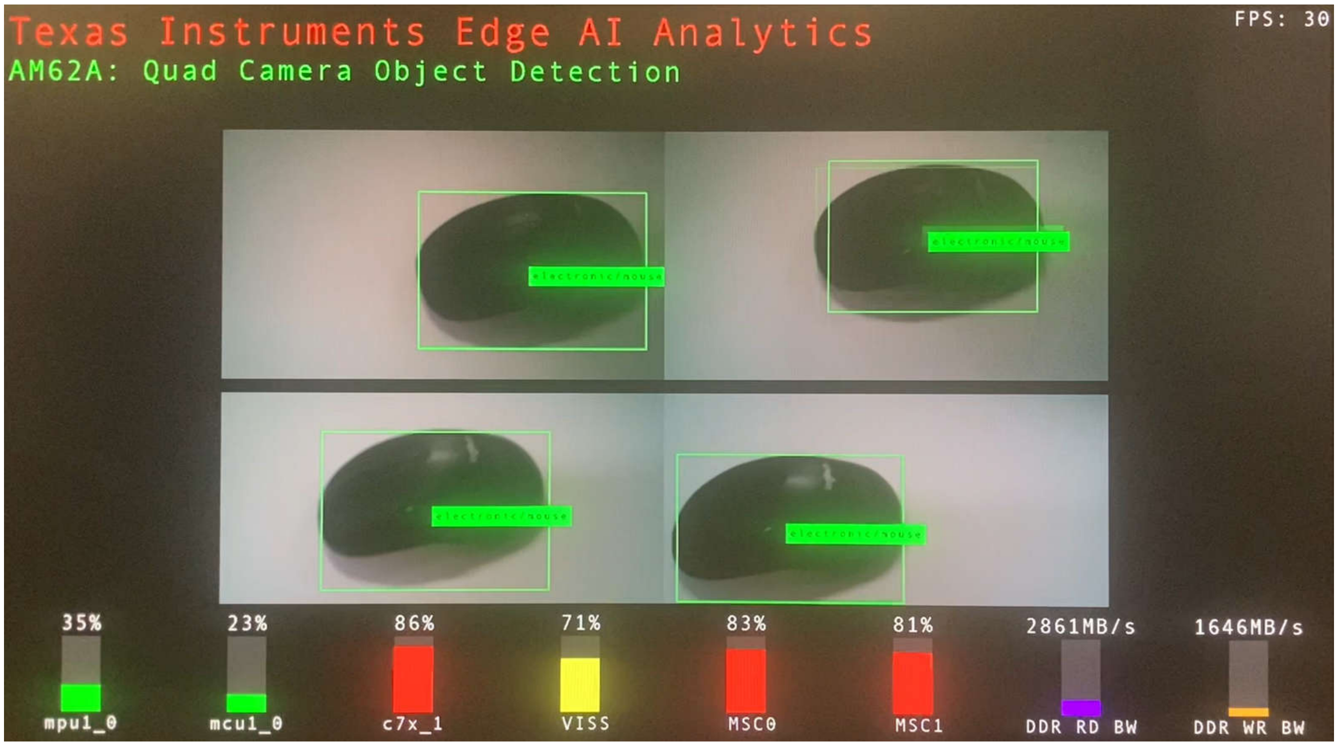


Figure 4-4. Screenshot of Quad Camera Object Detection Deep Learning Inference using AM62A with Graphical Performance Overlay

Next is the full pipeline script for the multicamera deep learning use case shown in Figure 4-3.

```
gst-launch-1.0 -v \
v4l2src device=/dev/video2 io-mode=5 ! queue leaky=2 ! video/x-bayer, width=1920, height=1080,
format=rggb ! tiovxisp sensor-name=SENSOR_SONY_IMX219_RPI dcc-isp-file=/opt/imaging/imx219/
dcc_viss.bin format-msb=7 sink_0::dcc-2a-file=/opt/imaging/imx219/dcc_2a.bin sink_0::device=/dev/
v4l-subdev2 ! video/x-raw, format=NV12 ! \
tiovxmultiscaler target=0 name=split_01 \
split_01. ! queue ! video/x-raw, width=1110, height=690 ! tiovxmultiscaler target=0 ! video/x-
raw, width=300, height=300 ! tiovxdlpreproc data-type=3 channel-order=1 tensor-format=rgb out-
pool-size=4 ! application/x-tensor-tiovx ! tidlinferer target=1 model=/opt/model_zoo/TFL-OD-2000-
ssd-mobv1-coco-mlperf-300x300 ! post_0.tensor \
split_01. ! queue ! video/x-raw, width=640, height=360 ! post_0.sink \
tidlpostproc name=post_0 model=/opt/model_zoo/TFL-OD-2000-ssd-mobv1-coco-mlperf-300x300
alpha=0.400000 viz-threshold=0.600000 top-N=5 ! queue ! mosaic_0. \
\
v4l2src device=/dev/video3 io-mode=5 ! queue leaky=2 ! video/x-bayer, width=1920, height=1080,
format=rggb ! tiovxisp sensor-name=SENSOR_SONY_IMX219_RPI dcc-isp-file=/opt/imaging/imx219/
dcc_viss.bin format-msb=7 sink_0::dcc-2a-file=/opt/imaging/imx219/dcc_2a.bin sink_0::device=/dev/
v4l-subdev2 ! video/x-raw, format=NV12 ! \
tiovxmultiscaler target=0 name=split_11 \
split_11. ! queue ! video/x-raw, width=1110, height=690 ! tiovxmultiscaler target=0 ! video/x-
raw, width=300, height=300 ! tiovxdlpreproc data-type=3 channel-order=1 tensor-format=rgb out-
pool-size=4 ! application/x-tensor-tiovx ! tidlinferer target=1 model=/opt/model_zoo/TFL-OD-2000-
ssd-mobv1-coco-mlperf-300x300 ! post_1.tensor \
split_11. ! queue ! video/x-raw, width=640, height=360 ! post_1.sink \
tidlpostproc name=post_1 model=/opt/model_zoo/TFL-OD-2000-ssd-mobv1-coco-mlperf-300x300
alpha=0.400000 viz-threshold=0.600000 top-N=5 ! queue ! mosaic_0. \
\
v4l2src device=/dev/video4 io-mode=5 ! queue leaky=2 ! video/x-bayer, width=1920, height=1080,
format=rggb ! tiovxisp sensor-name=SENSOR_SONY_IMX219_RPI dcc-isp-file=/opt/imaging/imx219/
dcc_viss.bin format-msb=7 sink_0::dcc-2a-file=/opt/imaging/imx219/dcc_2a.bin sink_0::device=/dev/
v4l-subdev2 ! video/x-raw, format=NV12 ! \
tiovxmultiscaler target=1 name=split_21 \
split_21. ! queue ! video/x-raw, width=1110, height=690 ! tiovxmultiscaler target=1 ! video/x-
raw, width=300, height=300 ! tiovxdlpreproc data-type=3 channel-order=1 tensor-format=rgb out-
pool-size=4 ! application/x-tensor-tiovx ! tidlinferer target=1 model=/opt/model_zoo/TFL-OD-2000-
ssd-mobv1-coco-mlperf-300x300 ! post_2.tensor \
split_21. ! queue ! video/x-raw, width=640, height=360 ! post_2.sink \
tidlpostproc name=post_2 model=/opt/model_zoo/TFL-OD-2000-ssd-mobv1-coco-mlperf-300x300
alpha=0.400000 viz-threshold=0.600000 top-N=5 ! queue ! mosaic_0. \
\
v4l2src device=/dev/video5 io-mode=5 ! queue leaky=2 ! video/x-bayer, width=1920, height=1080,
format=rggb ! tiovxisp sensor-name=SENSOR_SONY_IMX219_RPI dcc-isp-file=/opt/imaging/imx219/
dcc_viss.bin format-msb=7 sink_0::dcc-2a-file=/opt/imaging/imx219/dcc_2a.bin sink_0::device=/dev/
v4l-subdev2 ! video/x-raw, format=NV12 ! \
tiovxmultiscaler target=1 name=split_31 \
split_31. ! queue ! video/x-raw, width=1110, height=690 ! tiovxmultiscaler target=1 ! video/x-
raw, width=300, height=300 ! tiovxdlpreproc data-type=3 channel-order=1 tensor-format=rgb out-
pool-size=4 ! application/x-tensor-tiovx ! tidlinferer target=1 model=/opt/model_zoo/TFL-OD-2000-
ssd-mobV1-coco-mlperf-300x300 ! post_3.tensor \
split_31. ! queue ! video/x-raw, width=640, height=360 ! post_3.sink \
tidlpostproc name=post_3 model=/opt/model_zoo/TFL-OD-2000-ssd-mobV1-coco-mlperf-300x300
alpha=0.400000 viz-threshold=0.600000 top-N=5 ! queue ! mosaic_0. \
\
tiovxmosaic src::pool-size=3 name=mosaic_0 \
sink_0::startx="<320>"  sink_0::starty="<180>"  sink_0::widths="<640>"   sink_0::heights="<360>"  \
sink_1::startx="<960>"  sink_1::starty="<180>"  sink_1::widths="<640>"   sink_1::heights="<360>"  \
sink_2::startx="<320>"  sink_2::starty="<560>"  sink_2::widths="<640>"   sink_2::heights="<360>"  \
sink_3::startx="<960>"  sink_3::starty="<560>"  sink_3::widths="<640>"   sink_3::heights="<360>"  \
! video/x-raw,format=NV12, width=1920, height=1080 ! queue ! tiperfoverlay title="AM62A: Quad
Camera Object Detection" ! kmssink sync=false driver-name=tidss force-modesetting=true
```

5 Performance Analysis

The setup with four cameras using the V3Link board and the AM62A SK was tested in various application scenerios, including directly displaying on a screen, streaming over Ethernet (four UDP channels), recording to 4 separate files, and with deep learning inference. In each experiment, we monitored the frame rate and the utilization of CPU cores to explore the whole system capabilities.

As previously shown in Figure 4-4, the deep learning pipeline uses the tiperfoverlay GStreamer plugin to show CPU core loads as a bar graph at the bottom of the screen. By default, the graph is updated every two seconds to show the loads as a utilization percentage. In addition to the tiperfoverlay GStreamer plugin, the perf_stats tool is a second option to show cores performance directly on the terminal with an option for saving to a file. This tool is more accurate compared to the tiperfoverlay as the later adds extra load on the Arm cores and the DDR to draw the graph and overlay it on the screen. The perf_stats tool is mainly used to collect hardware utilization results in all of the test cases shown in this document. Some of the important processing cores and accelerators studied in these tests include the main processors (four A53 Arm cores @ 1.25GHz), the deep learning accelerator (C7x-MMA @ 850MHz), the VPAC (ISP) with VISS and multiscalers (MSC0 and MSC1), and DDR operations.

Table 5-1 shows the performance and resource utilization when using AM62A with four cameras for three use cases, including streaming four cameras to a display, streaming over ethernet, and recording to four separate files. Two tests are implemented in each use case: with camera only and with deep learning inference. In addition, the first row in Table 5-1 shows hardware utilizations when only the operating system was running on AM62A without any user applications. This is used as a baseline to compare against when evaluating hardware utilizations of the other test cases. As shown in the table, the four cameras with deep learning and screen disiplay operated at 30 FPS each with total 120 FPS for the four cameras. This high frame rate is achieved with only 86% of the deep learning accelerator (C7x-MMA) full capacity. In addition, it is important to note that the deep learning accelerator was clocked at 850MHz instead of 1000MHz in these experiments, which is about only 85% of its maximum performance.

Table 5-1. Performance (FPS) and Resource Utilization of AM62A when used with 4 IMX219 Cameras for Screen Display, Ethernet Stream, Record to Files, and Performing Deep Learning Inferencing

Application	Pipeline (operation)	Output	FPS avg pipelines	FPS total	MPUs A53s @ 1.25 GHz [%]	MCU R5 [%]	DLA (C7x-MMA) @ 850 MHz [%]	VISS [%]	MSC0 [%]	MSC1 [%]	DDR Rd [MB/s]	DDR Wr [MB/s]	DDR Total [MB/s]
No App	**Baseline No operation**	NA	NA	NA	1.87	1	0	0	0	0	560	19	579
Camera only	**Stream to Screen**	Screen	30	120	12	12	0	70	61	60	1015	757	1782
	Stream over ethernet	UDP: 4 ports 1920x1080	30	120	23	6	0	70	0	0	2071	1390	3461
	Record to files	4 files 1920x1080	30	120	25	3	0	70	0	0	2100	1403	3503
Cam with Deep learning	**Deep learning: Object detection MobV1-coco**	Screen	30	120	38	25	86	71	85	82	2926	1676	4602
	Deep learning: Object detection MobV1-coco and Stream over ethernet	UDP: 4 ports 1920x1080	28	112	84	20	99	66	65	72	4157	2563	6720
	Deep learning: Object detection MobV1-coco and record to files	4 files 1920x1080	28	112	87	22	98	75	82	61	2024	2458	6482

6 Summary

This application report describes how to implement multi-camera applications on the AM6x family of devices. A reference design based on Arducam's V3Link Camera Solution Kit and AM62A SK EVM is provided in the report, with several camera applications using four IMX219 cameras such as streaming and object detection. Users are encouraged to acquire the V3Link Camera Solution Kit from Arducam and replicate these examples. The report also provides detailed analysis of the performance of AM62A while using four cameras under various configuration including displaying to a screen, streaming over Ethernet, and recording to files. It also shows AM62A capability of performing deep learning inference on four separate camera streams in parallel. If there are any questions about running these examples, submit an inquiry at the TI E2E forum.

7 References

1. AM62A Starter Kit EVM Quick Start Guide
2. ArduCam V3Link Camera Solution Quick Start Guide
3. Edge AI SDK documentation for AM62A
4. Edge AI Smart Cameras Using Energy-Efficient AM62A Processor
5. Camera Mirror Systems on AM62A
6. Driver and Occupancy Monitoring Systems on AM62A
7. Quad Channel Camera Application for Surround View and CMS Camera Systems
8. AM62Ax Linux Academy on Enabling CIS-2 Sensor
9. Edge AI ModelZoo
10. Edge AI Studio
11. Perf_stats tool

TI Parts Referred in This Application Note:

- https://www.ti.com/product/AM62A7
- https://www.ti.com/product/AM62A7-Q1
- https://www.ti.com/product/AM62A3
- https://www.ti.com/product/AM62A3-Q1
- https://www.ti.com/product/AM62P
- https://www.ti.com/product/AM62P-Q1
- https://www.ti.com/product/DS90UB960-Q1
- https://www.ti.com/product/DS90UB953-Q1
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