INTEL® REALSENSE™ DEPTH CAMERAS: MULTI-CAMERA OPERATION

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WHAT YOU WILL LEARN TODAY

1. The Intel® RealSense™ D415 and D435 depth cameras summary
2. How to use multiple Intel RealSense Cameras simultaneously
3. Demo of Interference (or lack there of)
4. Inward and Outward facing configurations
5. Many Factors limiting the total number of cameras
6. How to Hardware sync cameras

GET THE MOST OUT OF YOUR INTEL REALSENSE D415 AND D435 DEPTH CAMERA

CHOOSE BEST INTEL® REALSENSE™ DEPTH CAMERA FOR THE JOB

Intel RealSense D415

Intel RealSense D435

Image Sensor	OV2740	OV9282
Active Pixels	1920 × 1080 Color	1280 X 800 Monochrome
Sensor Aspect Ratio	16:9	8:5
Baseline	55mm	50mm
F Number	f/2.0	f/2.0
Focal Length	1.88mm	1.93mm
Filter Type	IR Cut – D400, None – D410	None
Focus	Fixed	Fixed
Shutter Type	Rolling Shutter	Global Shutter
Signal Interface	MIPI CSI-2, 2X Lanes	MIPI CSI-2, 2X Lanes
Horizontal Field of View	69.4	91.2
Vertical Field of View	42.5	65.5
Diagonal Field of View	77	100.6
Distortion	<=1.5%	<=1.5%

Intel RealSense D415

- Rolling shutter
- 2MP COLOR stereo.
- Narrower FOV (65HFOV)
- Offers higher depth resolution (~2.5x)

Intel RealSense D435

- Global image shutter
- 1MP MONOCHROME stereo
- Wider field of view (90HFOV)
- Great for high speed motion
- More photosensitive (~4x)

UPDATE TO LATEST FW AND SW

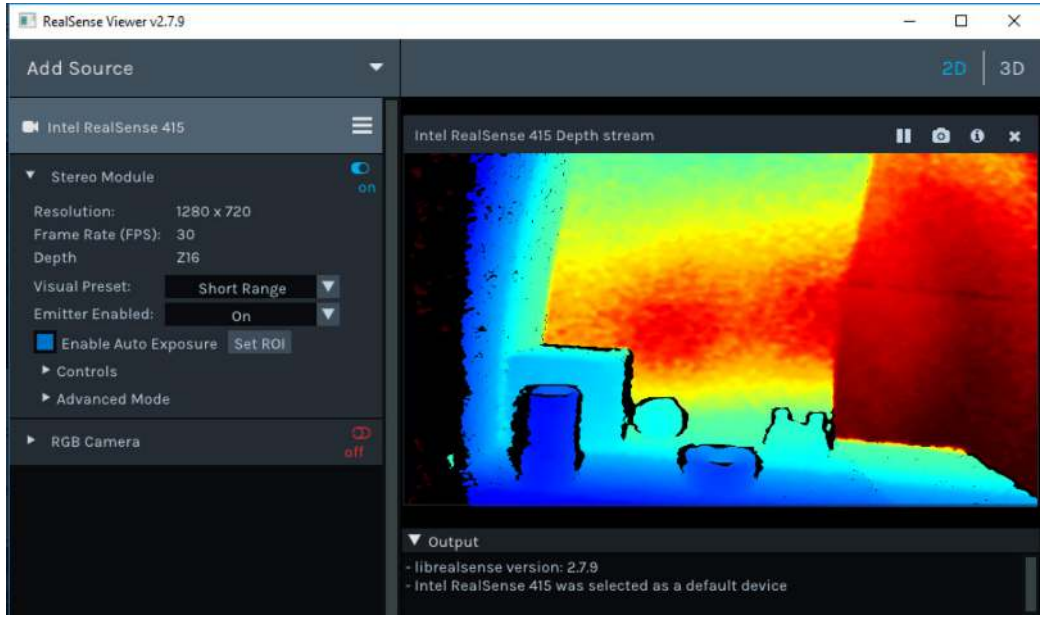
Intel RealSense D415

Intel RealSense D435

1. **Update FW:**
    1. https://realsense.intel.com/intel-realsense-downloads/

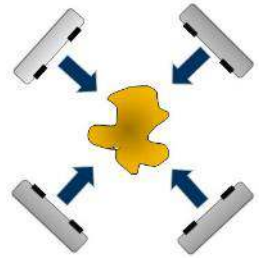
2. **Get latest version of Intel® RealSense™ SDK (aka "LibRS")**
    1. https://realsense.intel.com/sdk-2/
    2. Start with Intel RealSense Viewer
    3. Look at all sample code

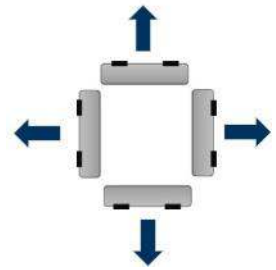
3. **Make sure you have a PC with USB3 port**
    1. The Intel RealSense cameras will support USB2 but with much diminished performance

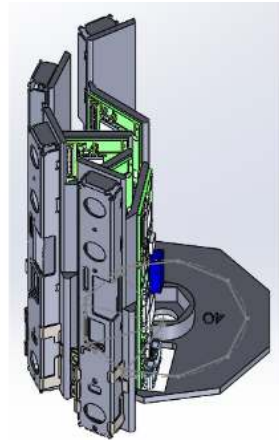


USE MULTIPLE DEPTH CAMERAS

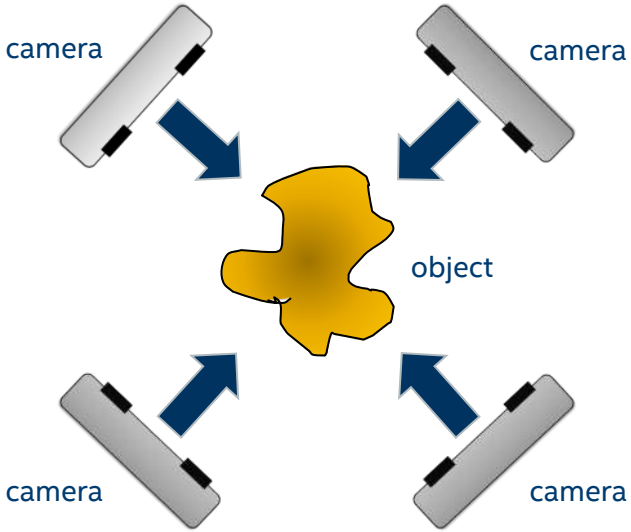
- **Outward facing:** Use this configuration to increase Field-of-view, FOV
- **Inward facing:** Use this configuration to capture full 3D volume, i.e. back and front of objects simultaneously.
- **No interference:** D4xx cameras do not interfere with each other.
- **Simultaneous capture:**
  - **Time stamps:** The API provides timestamps and frame counters that can be used to capture within 1 frame
  - **HW sync:** To get to few microseconds sync, it is possible to link the cameras together via an external sync cable and tell one to be master and the others to be slave.



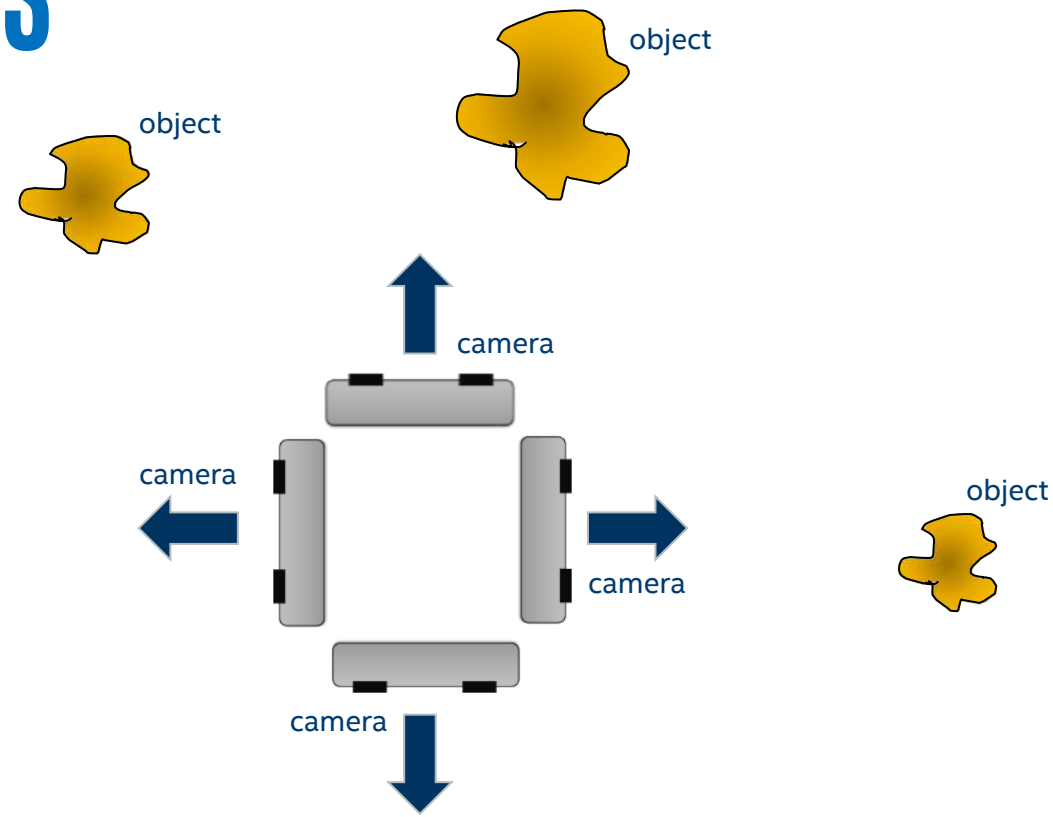




MULTI-CAMERA CONFIGURATIONS



Inward Facing

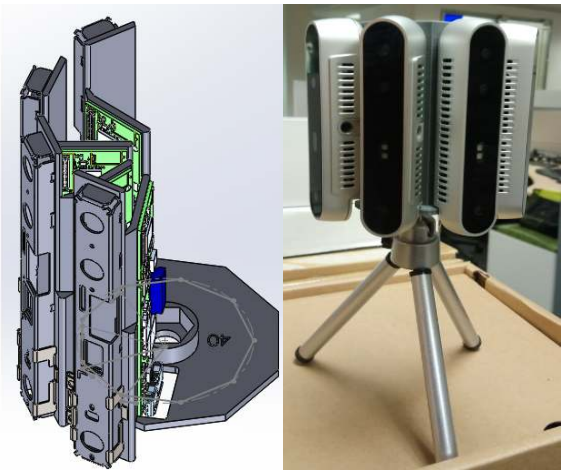


Outward Facing

EXAMPLE 3D CAMERA CONFIGURATIONS

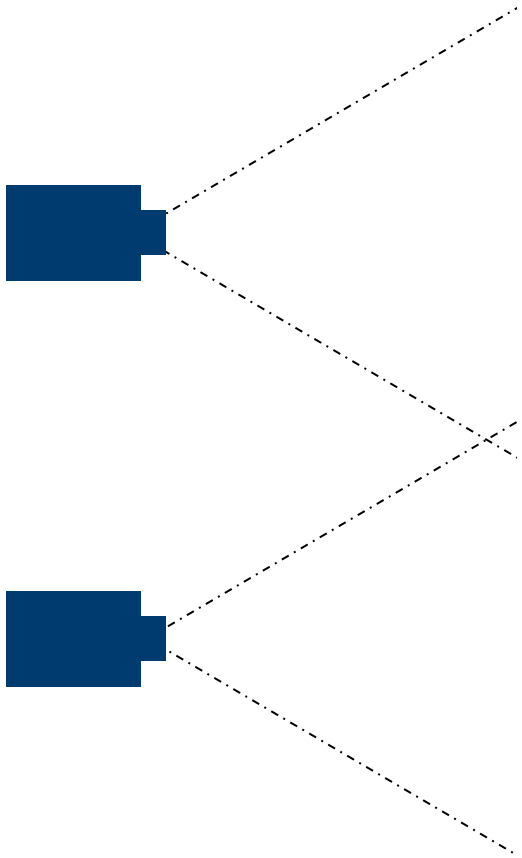
Back-to-Front

Co-Linear



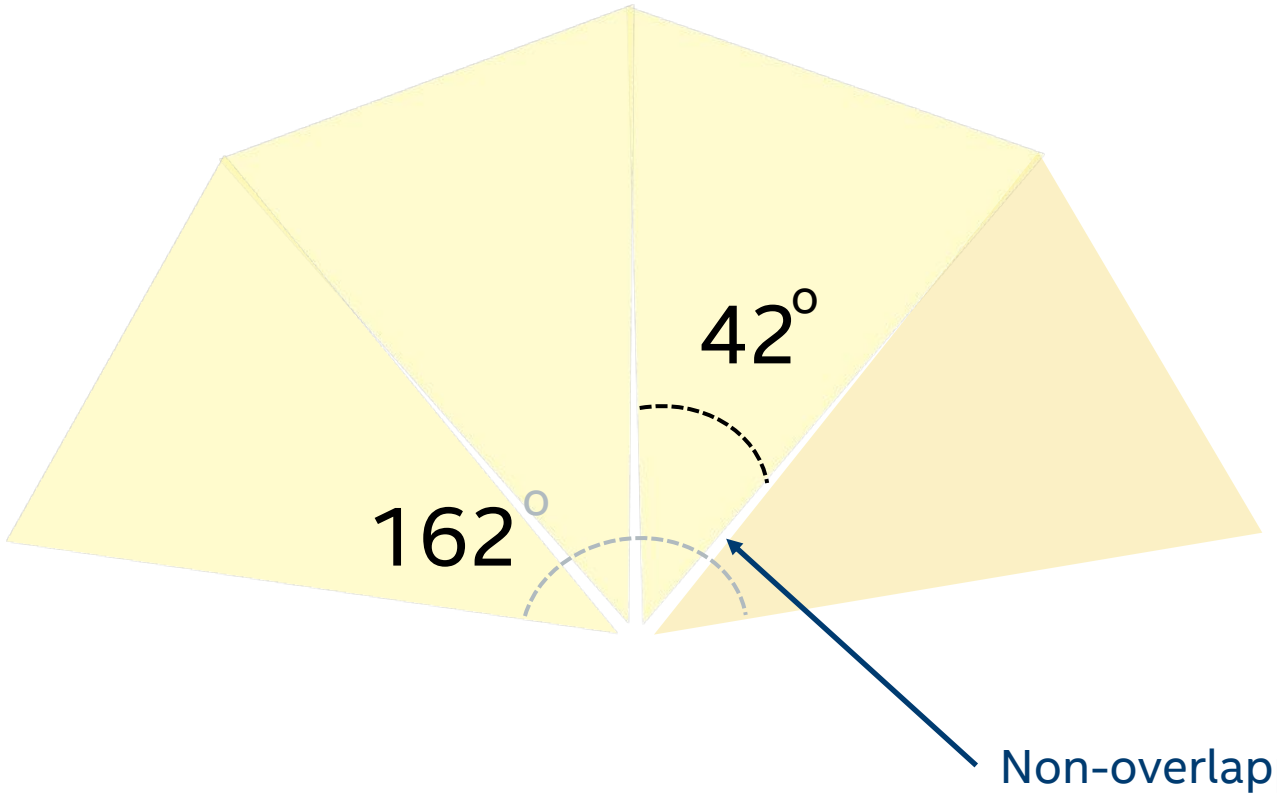
Outward facing

PARALLEL CONFIGURATION

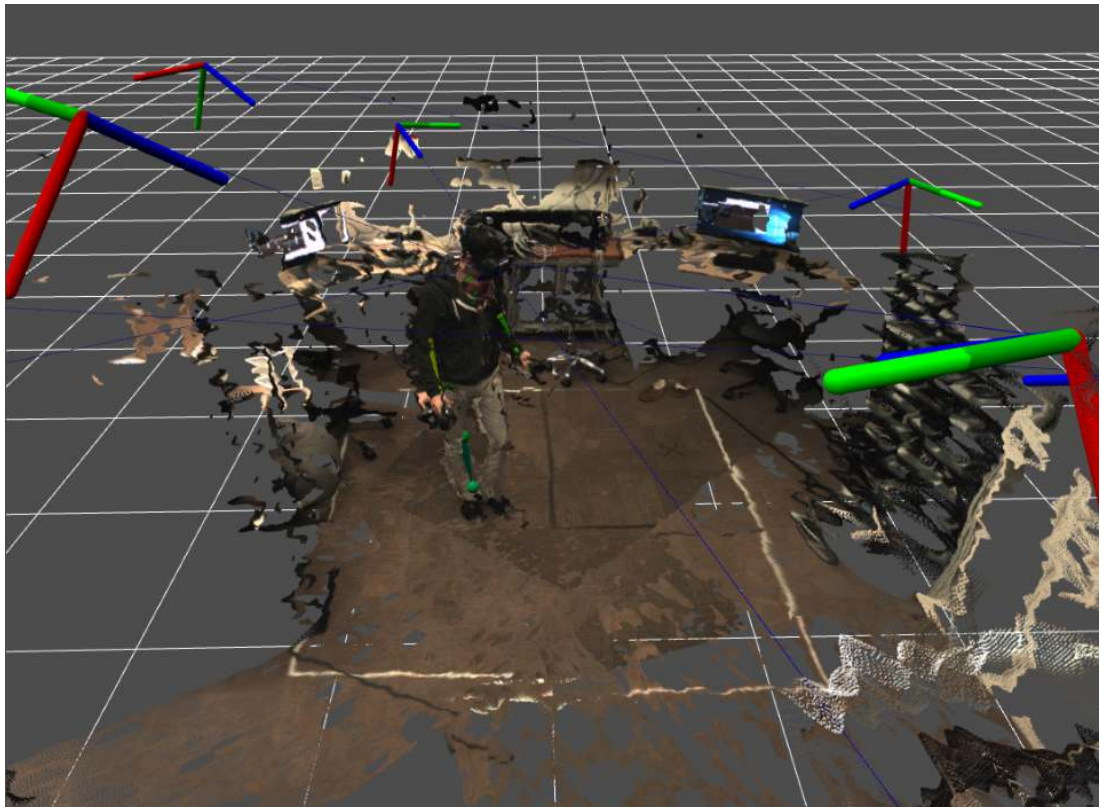


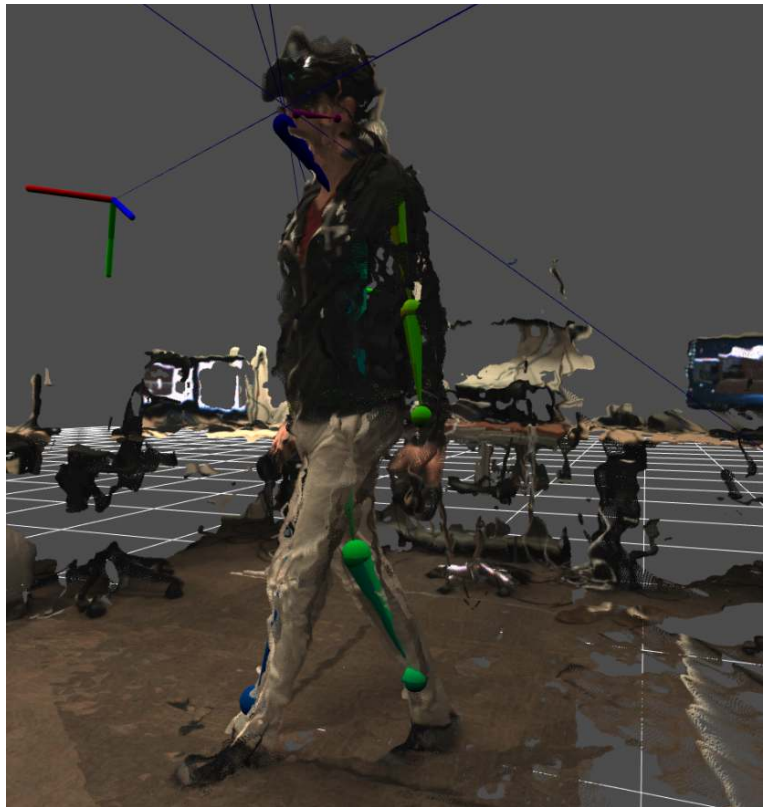
(0.5x distance means 4x better depth)

OUTWARD FACING COMBINED FOV FOR VERTICAL INTEL REALSENSE D415



MARKERLESS MOTION CAPTURE WITH INWARD CONFIGURATION





- Calibrated 6 inward facing cameras using open source lib Vicalib
- Body poses annotated using open source 3D body tracker, and triangulated to make 3D annotation

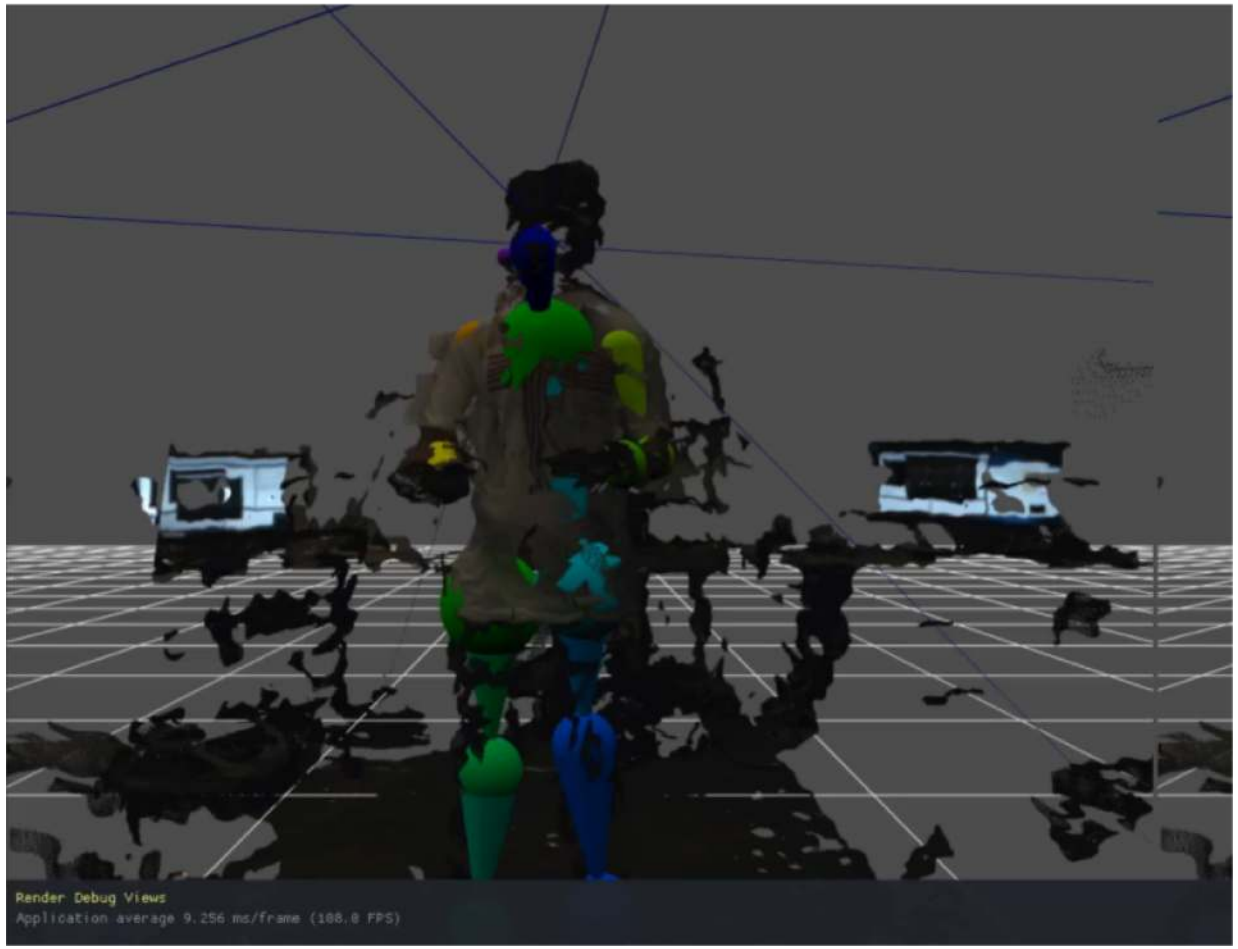
EXAMPLE RECODING AND PERFORMANCE CAPTURE

- Multi cameras allowed us to capture people like never before

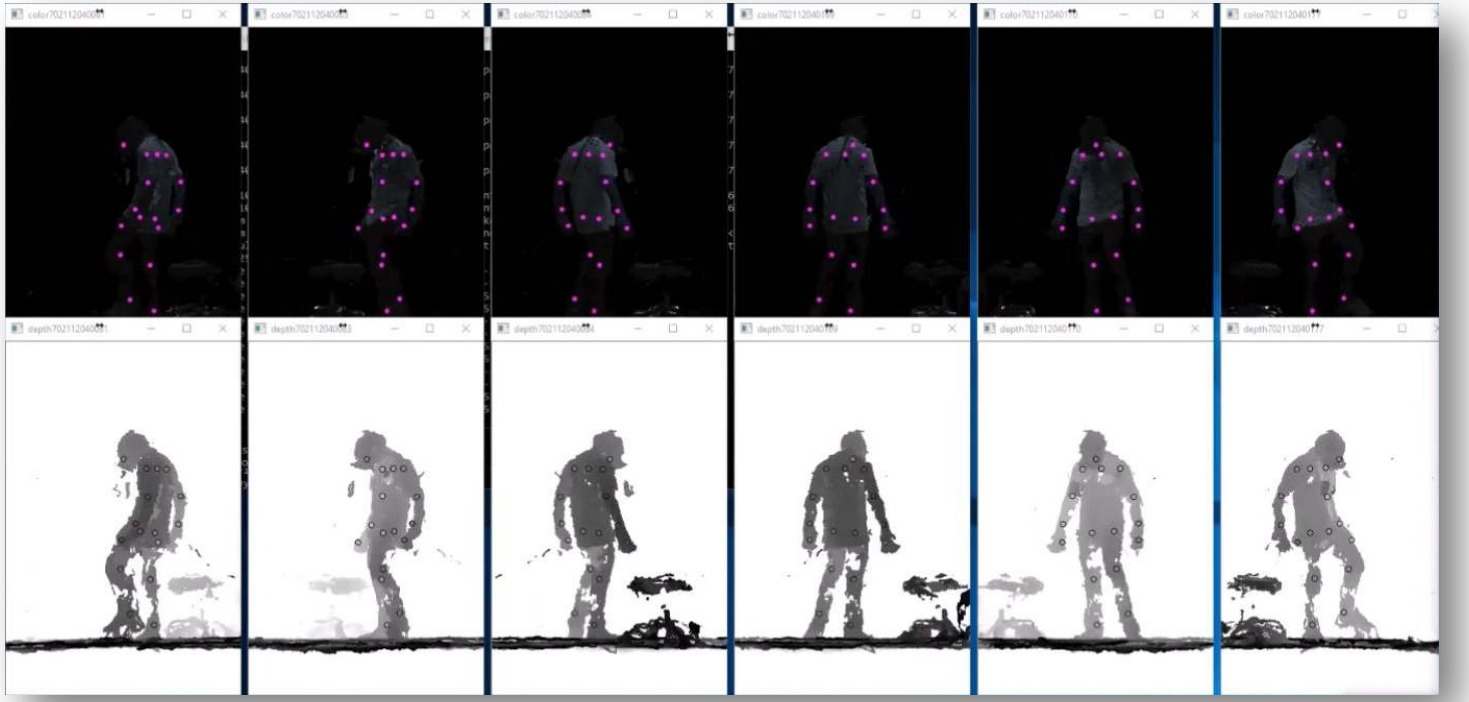
Collecting

- Depth and color of multiple people
- Track body parts
- Full frame rate capture of gestures

Note: no interference between cameras



DATA COLLECTION AND MACHINE LEARNING



- With all this data we could train machine learning to track humans in VR
- Using depth means its robust to cloths, users and lighting

RESULTS OF MACHINE LEARNING

- Trained to work with a single camera
- Inward facing Cameras captured, 1 million examples
- Used to train a simple Neural Network which works on CPU
- Great performance working at 300 fps on CPU and only one camera
- Robust to occlusion as it was trained using Multiple inward facing cameras

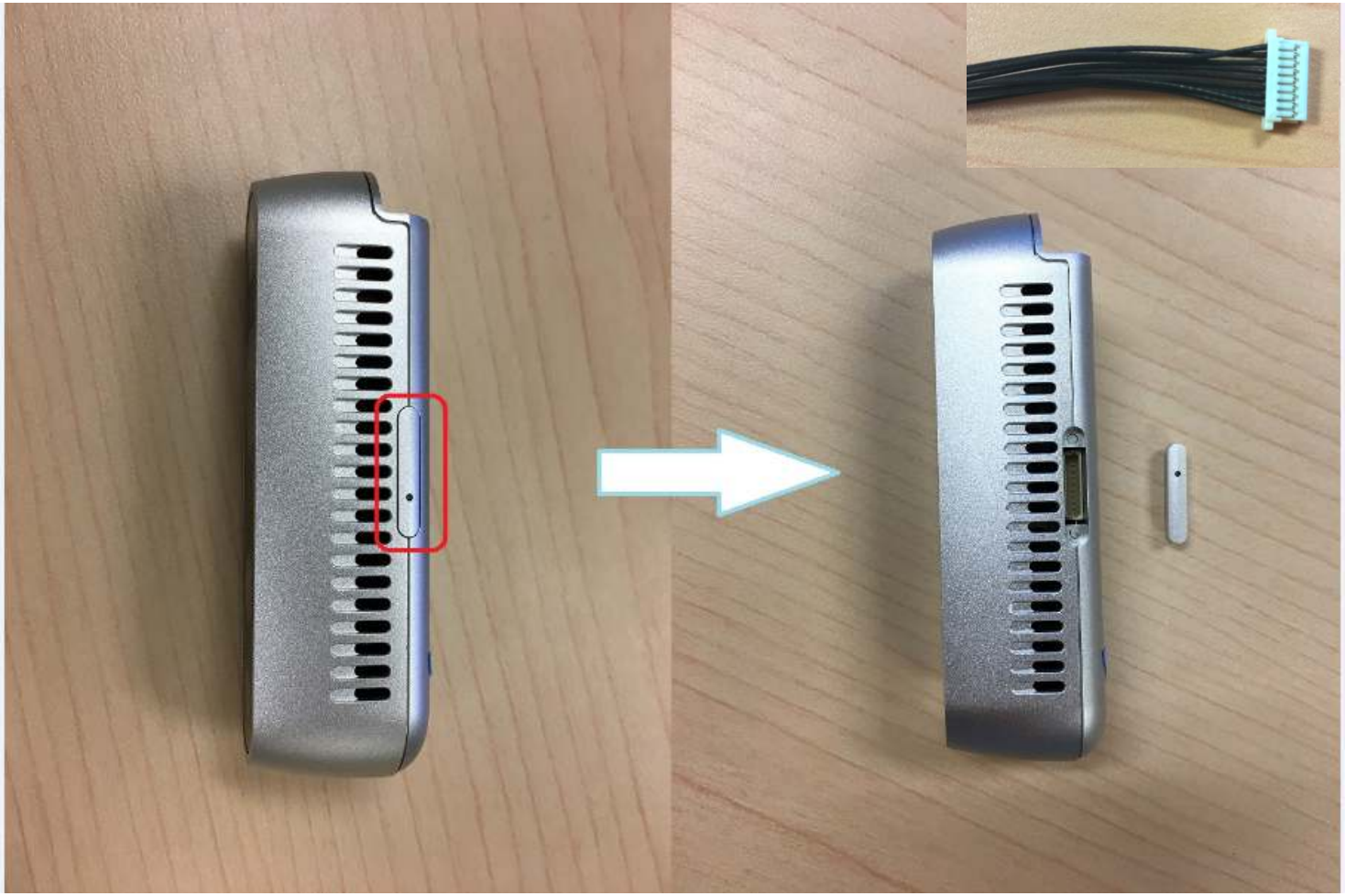
WHITE PAPER & MULTI-CAMERA LIMITATIONS

1. Issues to be aware of
    1. **Cabling and enumeration**
    2. **Bandwidth**
    3. Power
    4. CPU
    5. External Trigger
    6. Latency
    7. Compression
2. Programming LibRS
3. Aligning Point-Clouds

DOWNLOAD WHITE PAPERS ON OUR WEBSITE:

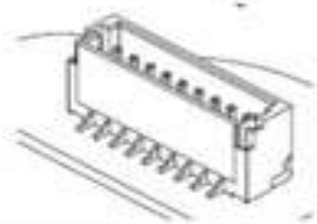
https://realsense.intel.com/intel-realsense-downloads/

THE CONNECTOR: 9 PIN CONNECTOR ON THE CAMERA

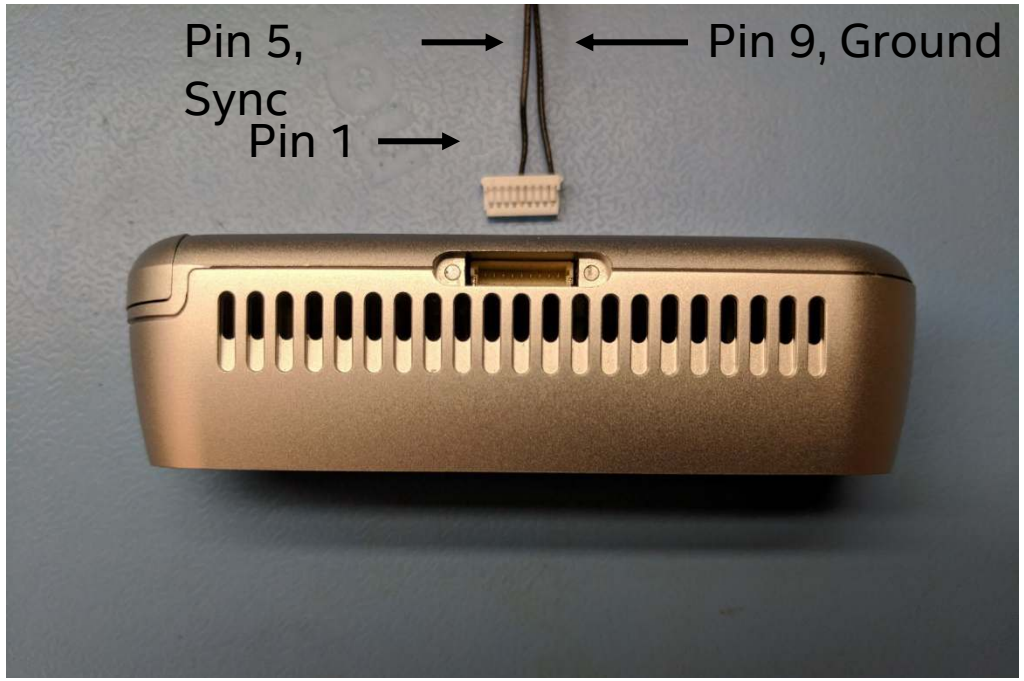


- To connect multiple cameras, you can daisy-chain or use a star-configuration.
- ESD protection, noise filtering, and shielded cables may be needed.

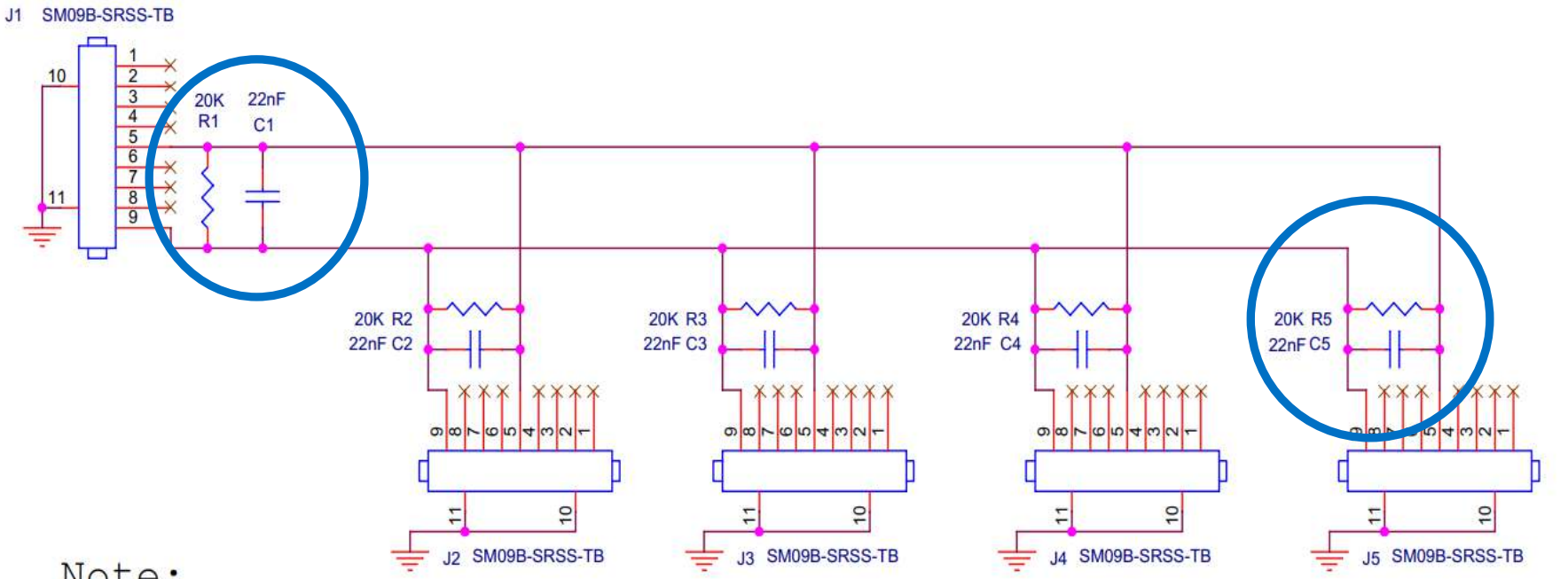
CABLING: D435 CAMERA SYNC CONNECTION

Parameter	Description	Diagram
Number of Contacts	9	
Product Name	9 Positions Header, Shrouded Connector	
Part Number	SM09B-SRSS-TB(LF)(SN)	
Manufacturer Website	www.jst-mfg.com	

Connector: [ASSHSSH28K152](), Housing: [SHR-09V-S-B]().

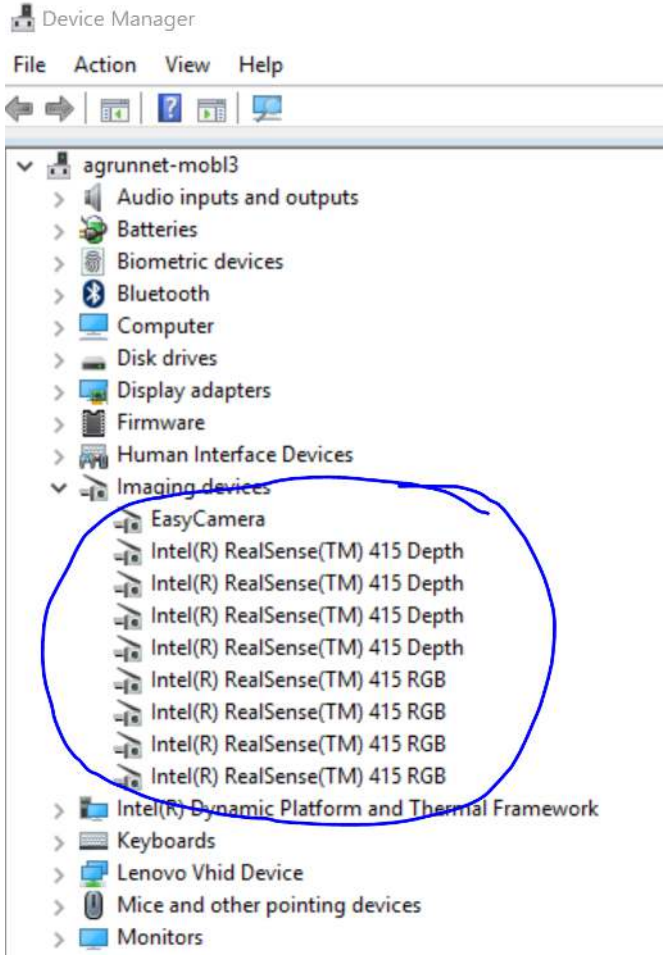


CABLING: REDUCING EMI/ESD EFFECTS



Note: For longer than 2m connections, an active circuit can ensure signal integrity and ESD protection. This is covered in a White Paper available for download on our website.

CONNECTING MULTIPLE CAMERAS



PROGRAMING REALSENSE SDK 2.0 (LIBREALSENSE)

There is a single command that will enable a device to be in either **Master, Slave, or Default mode**.

The HW command is **rs2_Set_Option**

with argument “rs2_option_inter_cam_sync_mode” for option ID,

and option value is 0=Default, 1=Master, and 2=Slave.

The pointer can be either the “Sensor” or the “Device”.

TIME STAMPS & COUNTERS

rs2_**get_frame_timestamp** (*frame, **error)

rs2_**get_frame_number**(*frame, **error)

HW CLOCK

Unit 1: Timestamp A + Counter A

Unit 2: Timestamp B + Counter B

Note: With HW sync ON, all cameras will capture at IDENTICAL time. They may arrive at different times over USB camera (i.e. different system time)

SYSTEM TIME

USB3 BANDWIDTH LIMITATION: SINGLE USB HUB

Single HUB							
Mode	**Bandwidth, Mbps**	**1 unit**	**2 units**	**3 units**	**4 units**	**5 units**	**6 units**
Depth: 848x480, 90fps + Left Color: 848x480, 90fps	**1172**	1172	2345	3517	4689	5861	7034
Depth: 1280x720, 30fps + Left Color: RGB 1280x720, 30fps	**885**	885	1769	2654	3539	4424	5308
Depth: 1280x720, 30fps + Left Mono: RGB 1280x720, 30fps	**664**	664	1327	1991	2654	3318	3981
Depth-only: 848x480, 90fps	**586**	586	1172	1758	2345	2931	3517
Depth-only: 1280x720, 30fps	**442**	442	885	1327	1769	2212	2654
Depth: 840x480, 30fps + Left Color: Mono 848x480, 30fps	**293**	293	586	879	1172	1465	1758
Depth: 640x360, 30fps + Left Color: RGB 640x360, 30fps	**221**	221	442	664	885	1106	1327
Depth-only: 640x360, 30fps	**111**	111	221	332	442	553	664

Streaming Results for *POWERED* 4-port USB3 HUB with HW sync enabled

USB3 BANDWIDTH LIMITATION: 4 PORT ON PC

Indivual USB connection (PC with multiple USB)							
Mode	**Bandwidth, Mbps**	**1 unit**	**2 units**	**3 units**	**4 units**	**5 units**	**6 units**
Depth: 848x480, 90fps + Left Color: 848x480, 90fps	**1172**	1172	2345	3517	4689	5861	7034
Depth: 1280x720, 30fps + Left Color: RGB 1280x720, 30fps	**885**	885	1769	2654	3539	4424	5308
Depth: 1280x720, 30fps + Left Mono: RGB 1280x720, 30fps	**664**	664	1327	1991	2654	3318	3981
Depth-only: 848x480, 90fps	**586**	586	1172	1758	2345	2931	3517
Depth-only: 1280x720, 30fps	**442**	442	885	1327	1769	2212	2654
Depth: 840x480, 30fps + Left Color: Mono 848x480, 30fps	**293**	293	586	879	1172	1465	1758
Depth: 640x360, 30fps + Left Color: RGB 640x360, 30fps	**221**	221	442	664	885	1106	1327
Depth-only: 640x360, 30fps	**111**	111	221	332	442	553	664

Streaming Results for connecting directly to 4 ports of a PC with HW sync enabled

DEPTH COMPRESSION (~3X)

Z16 STREAMING

Mode	Bandwidth, Mbps	1 unit	2 units	3 units	4 units	5 units	6 units
Depth: 848x480, 90fps + Left Color: 848x480, 90fps	1172	1172	2345	3517	4689	5861	7034
Depth: 1280x720, 30fps + Left Color: 1280x720, 30fps	885	885	1769	2654	3539	4424	5308
Depth: 1280x720, 30fps + Left Mono: 1280x720, 30fps	664	664	1327	1991	2654	3318	3981
Depth-only: 1280x720, 30fps	442	442	885	1327	1769	2212	2654

Z16H STREAMING

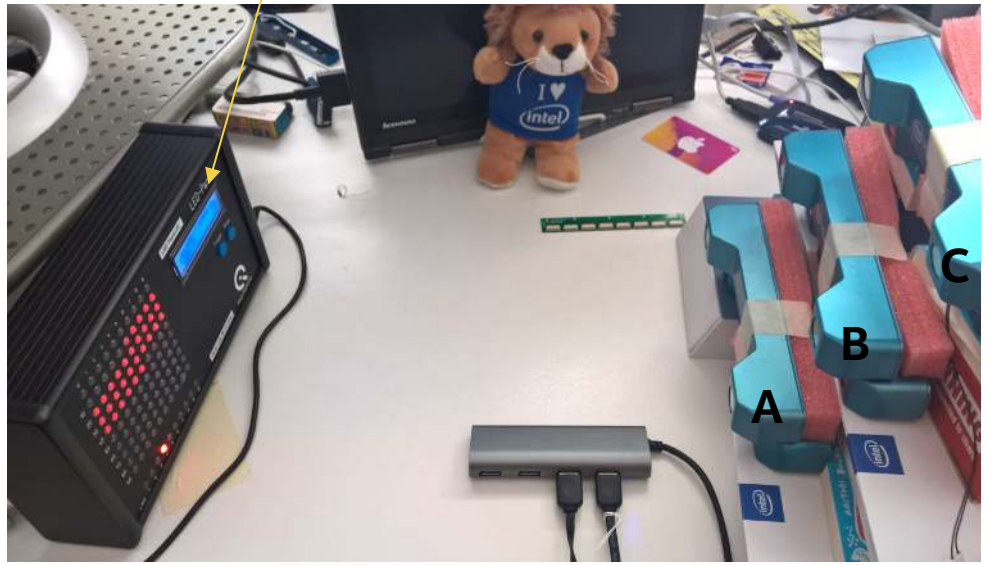
Mode	Compressed Bandwidth*, Mbps	1 unit	2 units	3 units	4 units	5 units	6 units
Depth: 848x480, 90fps + Left Color: 848x480, 90fps	782	782	1563	2345	3126	3908	4689
Depth: 1280x720, 30fps + Left Color: 1280x720, 30fps	590	590	1180	1769	2359	2949	3539
Depth: 1280x720, 30fps + Left Mono: 1280x720, 30fps	369	369	737	1106	1475	1843	2212
Depth-only: 1280x720, 30fps	147	147	295	442	590	737	885

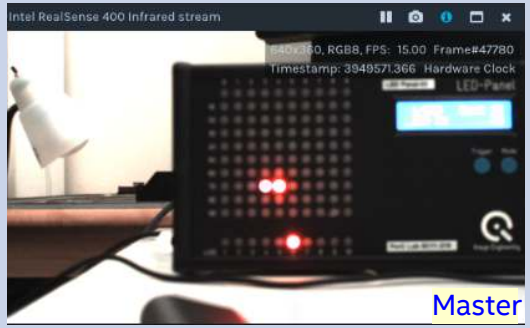
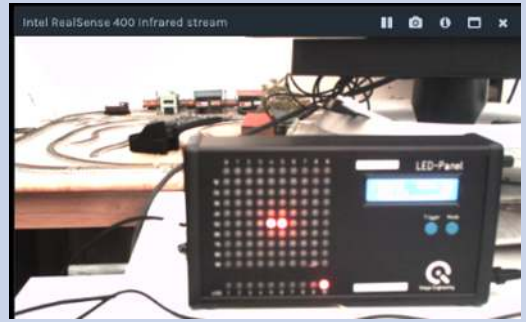
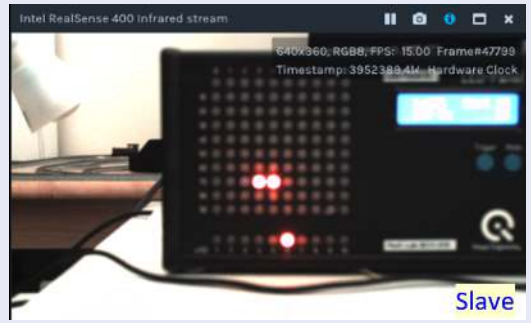
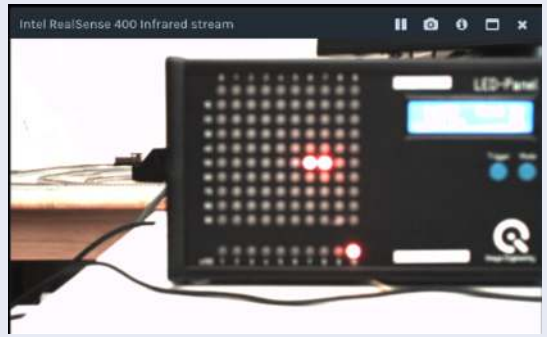
*Averaged bandwidth assuming 3x compression

ALIGNING POINT-CLOUDS

HW SYNC VALIDATION: THE HARD WAY

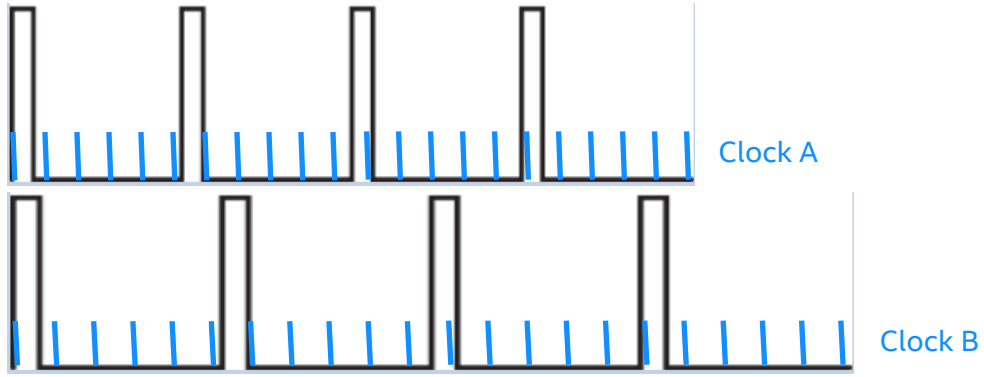
High-speed LED Panel



Camera	HW Sync	No Sync
A		
B		

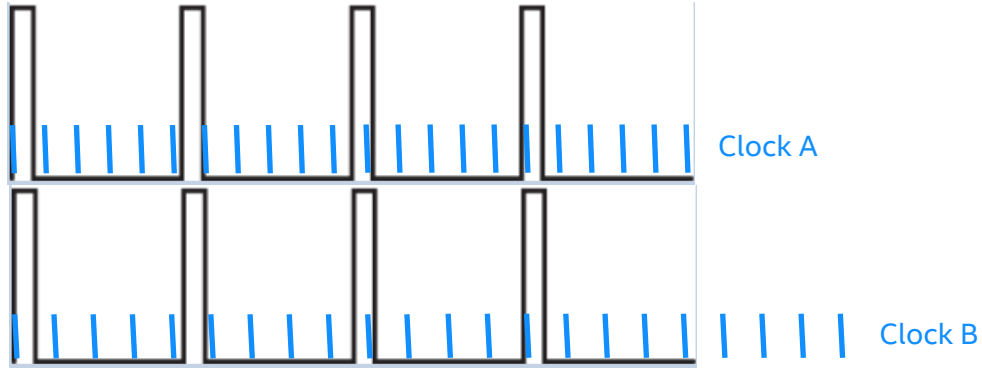
HW SYNC VALIDATION: THE EASY SW WAY

HW SYNC OFF ➔ Query HW Time stamp. Difference will NOT DRIFT.



The ASICs are telling each camera to sync based on OWN crystal clock.
They report time based on own clock.
So they all say the are running at exactly 30fps (for example).

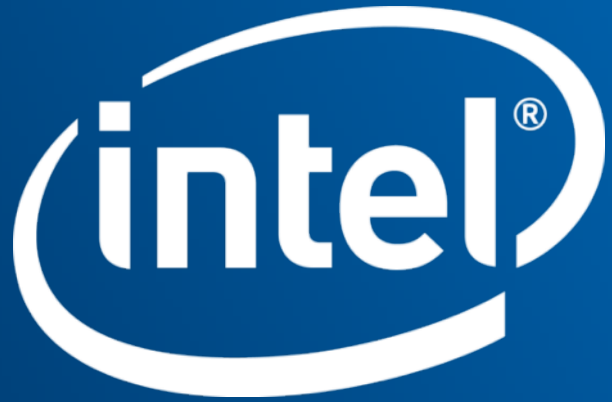
HW SYNC ON ➔ Query HW Time stamps. Difference WILL DRIFT over time. because each individual camera has different time scale.



Note: We are NOT sharing the CLOCK signals. We are sharing a SYNC line.
So now all SLAVE cameras are forced to fire when told to. But will still report frame time based on own clock.

IMPORTANT FINAL COMMENTS

1. FW needs to be updated to support HW Sync.
2. The configuration between master and slave are always same: resolution, frame rate.
3. Recommend to sync multiple RS415s or multiple RS435s. Do not mix cameras even with same frame rate.
4. EMI/ESD Bug: Sometimes the units reset and the counters are reset. WIP.
    1. Best practice: Use 2.2Kohm resistor/22nF capacitor near slave. Use twisted pair.
5. Using external sync source requires very fine frequency resolution
    1. Instead use one camera as master.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