8K Camera System with Multi-plane Phase-detection Autofocus

Kodai Kikuchi, Ryohei Funatsu, Tomohiro Nakamura,
Tosho Yasue, Kohei Tomioka, and Takayuki Yamashita

Japan Broadcasting Corporation (NHK)

Outline

- Introduction
  - 8K Ultra-high-definition TV (UHDTV2)
  - Sensor-based phase detection autofocus (PDAF)
- Multi-plane PDAF
  - Key idea
  - System design with three-chip 8K camera
- Experimental results
  - Disparity calculation experiment
  - AF demonstration movie
- Conclusion

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UHDTV2 service in Japan

- Regular UHDTV2 service via satellite (BS8K) launched on Dec. 1, 2018.
- A wide variety of 8K productions are appearing worldwide.

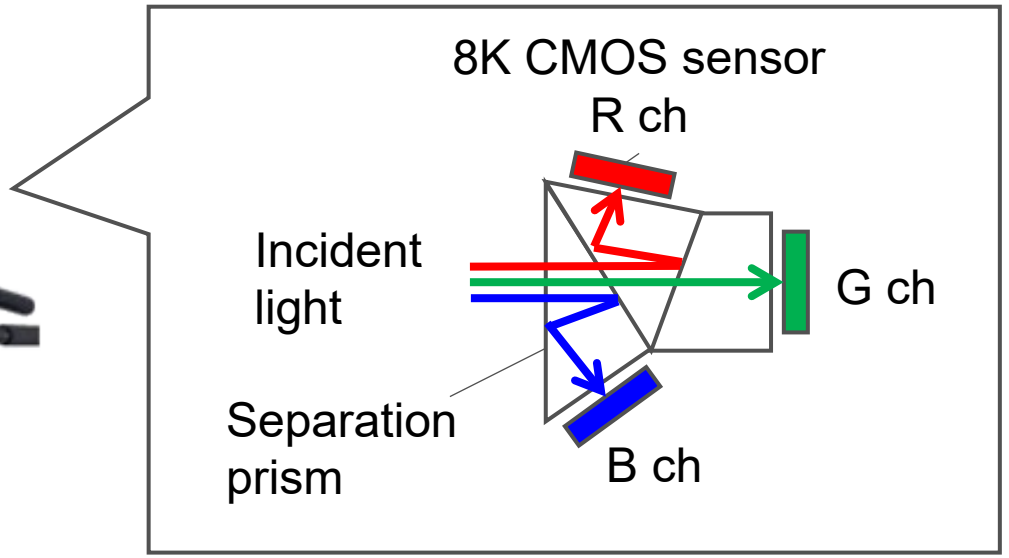
BS8K specifications		
Video	Pixels	7680 (H) × 4320 (V)
	Frame rate	60/1.001 fps
	Others	WCG (Rec.2020) HDR (HLG)
Audio	22.2 ch, 7.1 ch, 5.1 ch, and 2 ch	
Codec	Video	HEVC / H.265
	Audio	MPEG-4 AAC
	Total bitrate	85 Mbps

Previous work (8K high-speed camera)

- Shooting 8K at 240 fps for clear 60-fps (4x) slow-motion replay
- High color reproducibility with a three-chip imaging system

8K high-speed camera [1]

1.25-inch three-chip imaging system [2]



[1] R. Funatsu et al., SMPTE Motion Imaging J. April pp. 44–49 (2019).
[2] ARIB, TR-B37:1.1 (in Japanese).

Example of use in 8K programs (live sports)

Focusing difficulty in 8K shooting

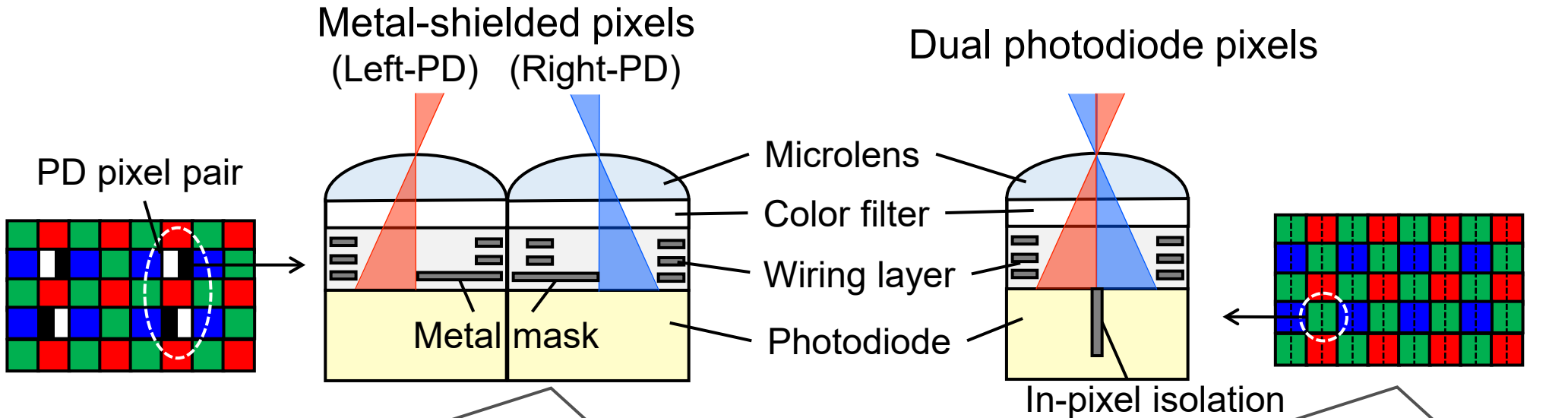
- Low-resolution viewfinder and shallower depth of field make manual focus extremely difficult.
- Out-of-focus blur on a large screen significantly degrades the user experience.

There is now a strong demand for a fast and accurate autofocus (AF).

AF method	Speed	Accuracy
Contrast AF	Needs two or more frames.	**Excellent**
Phase-detection AF (inner lens)	**Enables AF with a single frame.**	Good, but lens calibration is needed.
Sensor-based phase-detection AF	**Enables AF with a single frame.**	**Good**

Sensor-based phase-detection (PD) AF

- Lens focus is controlled using disparity from PD sensor.
- Two types of PD sensor have been studied.



Simple and inexpensive to manufacture

Disparity error may occur due to sampling differences between PD pixels pairs

Robust disparity calculation capability

Requires extra production costs and reduces effective aperture of sensor

Sensor-based phase-detection (PD) AF

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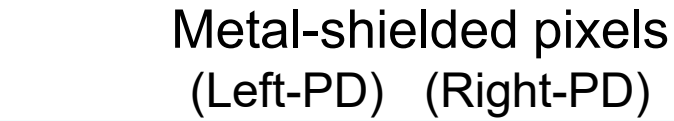
Metal-shielded pixels
(Left-PD) (Right-PD)



Dual photodiode pixels

However, most PDAF systems have been designed and optimized for **single-chip cameras**.

We are developing a **PDAF system** for **three-chip cameras**.

- Simple and inexpensive to manufacture
- Disparity error may occur due to sampling differences between PD pixels pairs

- Robust disparity calculation capability
- Requires extra production costs and reduces effective aperture of sensor

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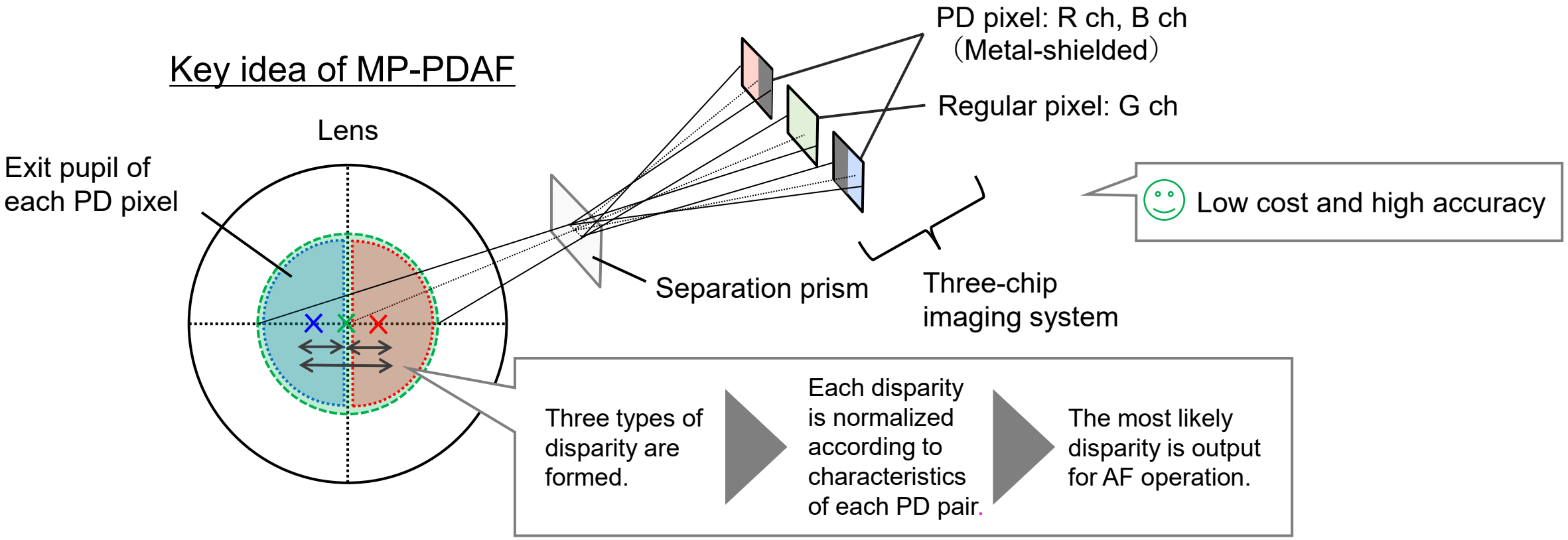
Multi-plane PDAF (MP-PDAF)

- Disparity is obtained by creating different apertures across multiple sensors.
- Incorporating PD pixels into R and B ch to avoid missing pixels on G ch

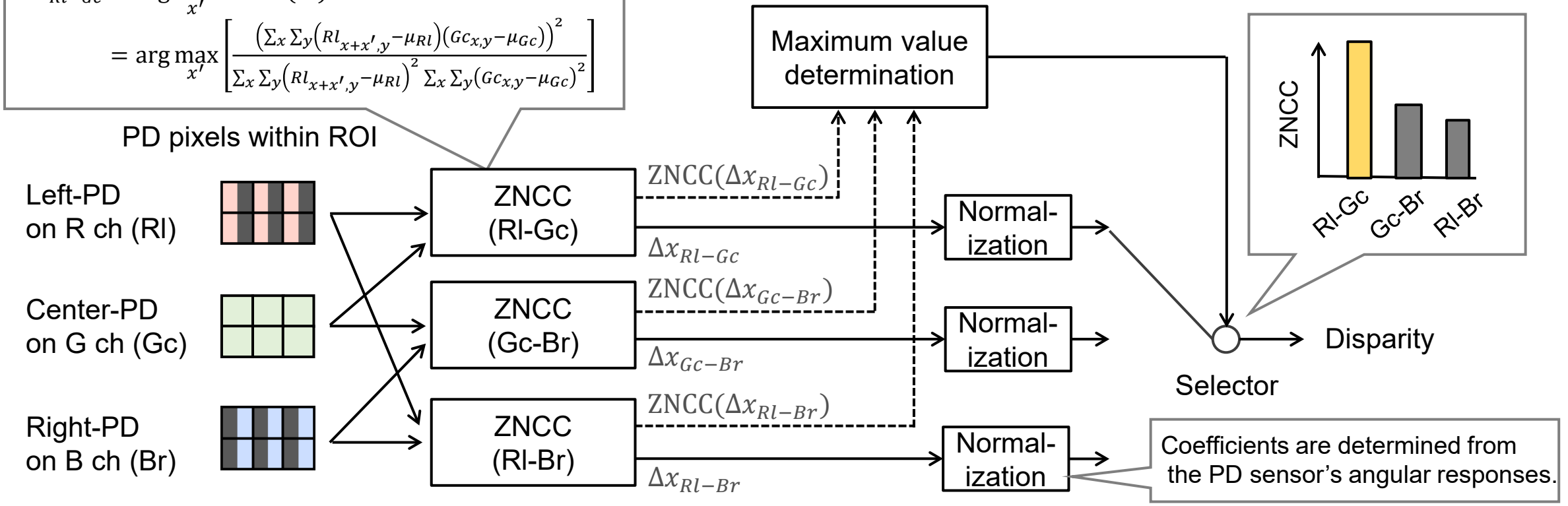


Disparity calculation flow

- ZNCC robust to level differences between RGB channels is used.
- Disparity with the maximum ZNCC is selected as output value.

$$\Delta x_{Rl-Gc} = \arg\max_{x'} ZNCC(x')$$
$$= \arg\max_{x'} \left[\frac{\left(\sum_x \sum_y \left(Rl_{x+x',y} - \mu_{Rl}\right)\left(Gc_{x,y} - \mu_{Gc}\right)\right)^2}{\sum_x \sum_y \left(Rl_{x+x',y} - \mu_{Rl}\right)^2 \sum_x \sum_y \left(Gc_{x,y} - \mu_{Gc}\right)^2} \right]$$

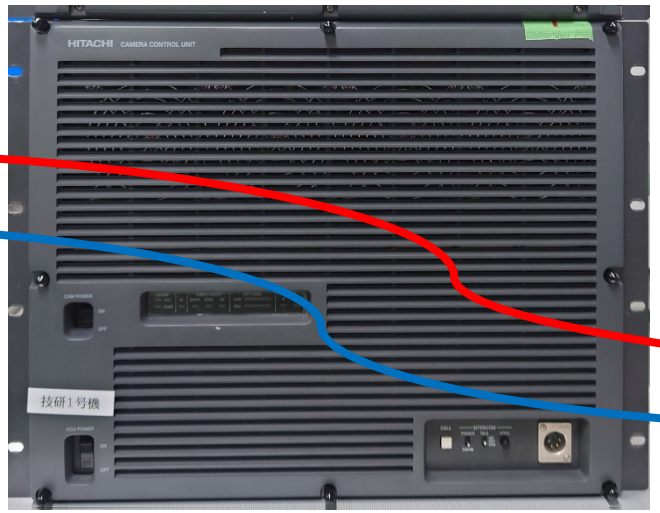
PD pixels within ROI



Overview of developed 8K camera with AF

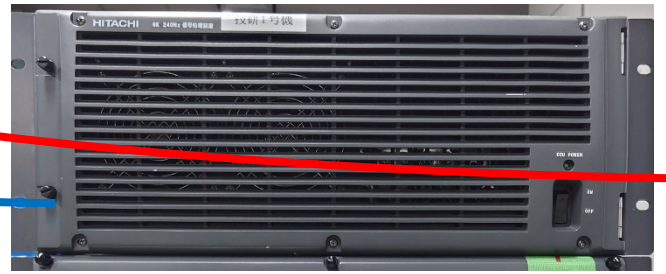
Camera head

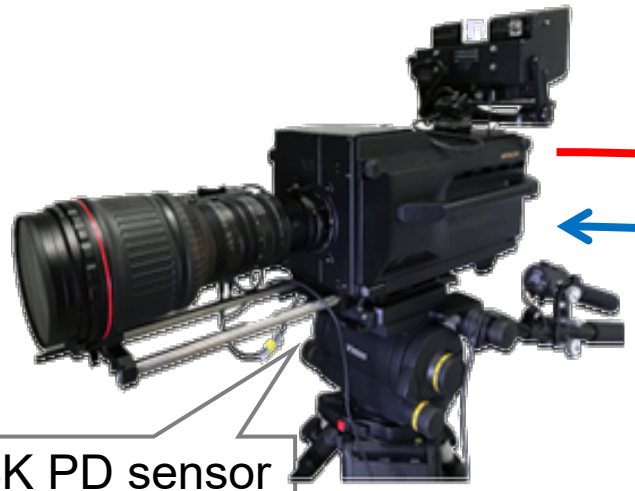
Camera control unit (CCU)



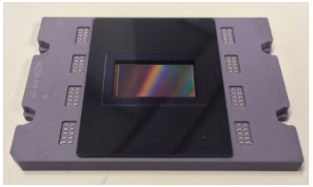
Video output
(8K 240 fps)

AF unit





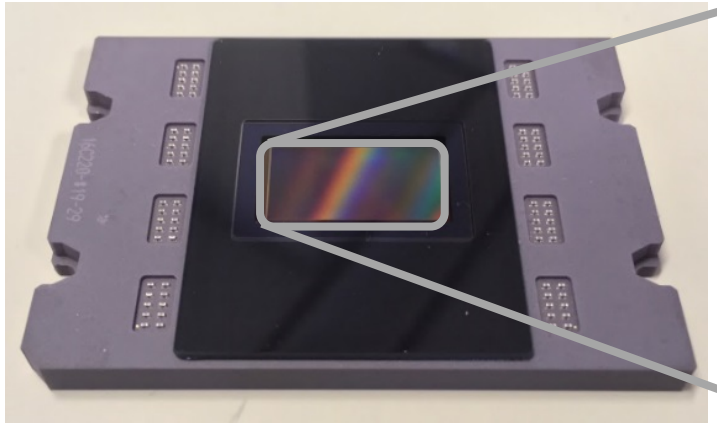
8K PD sensor



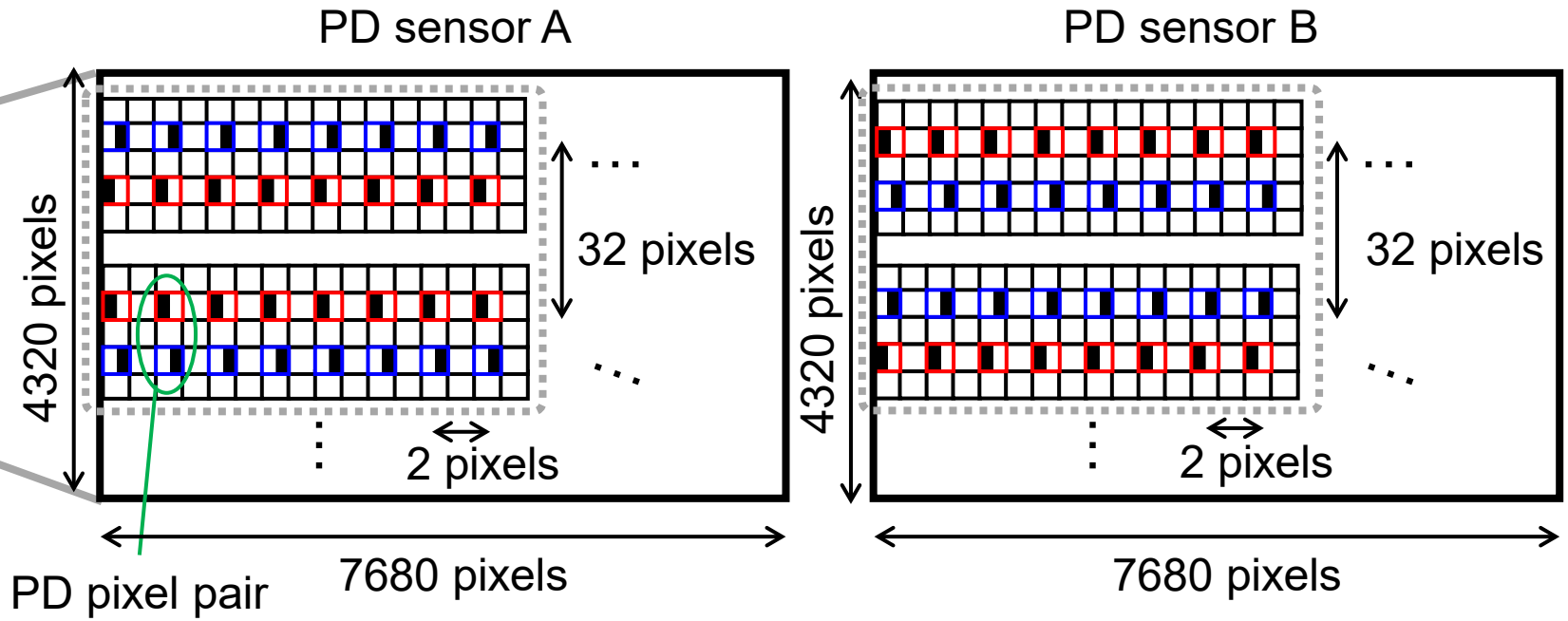
AF control signal

8K PD sensor

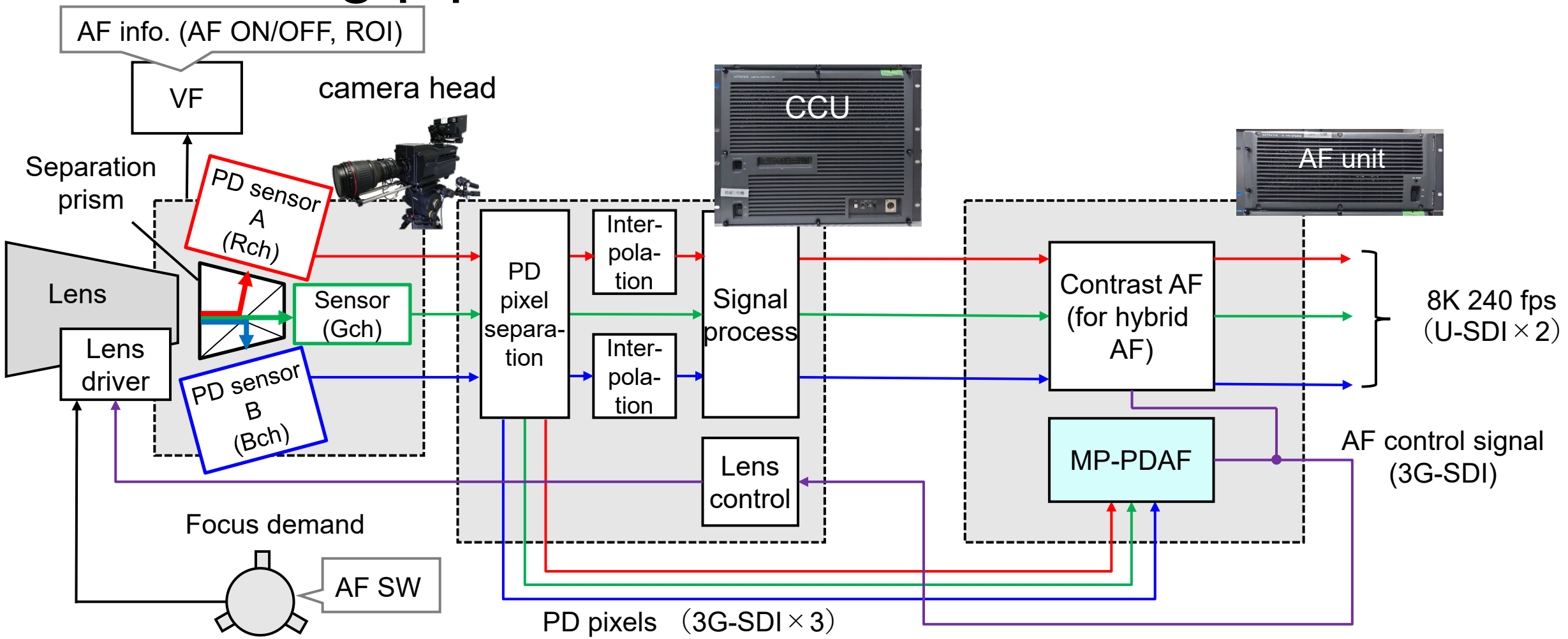
- Incorporates metal masks into our current 8K CMOS sensors.
- Capable of capturing 8K images and phase information at 240 fps.



Optical size: 1.25 inches
Pixel size: 2.1 × 2.1 μm



Processing pipeline



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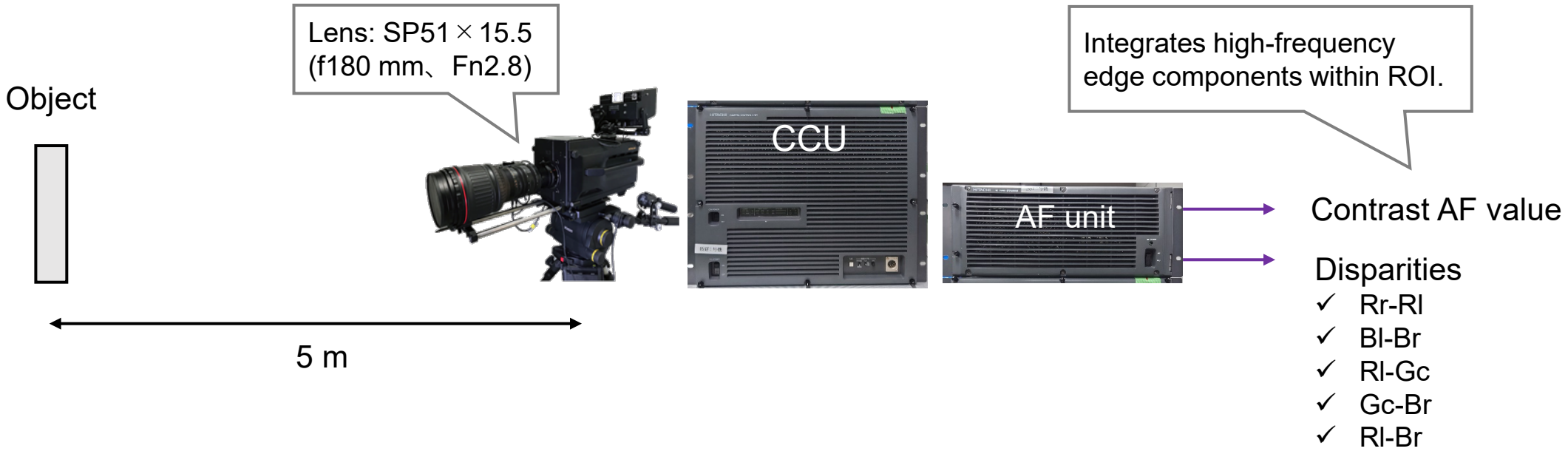
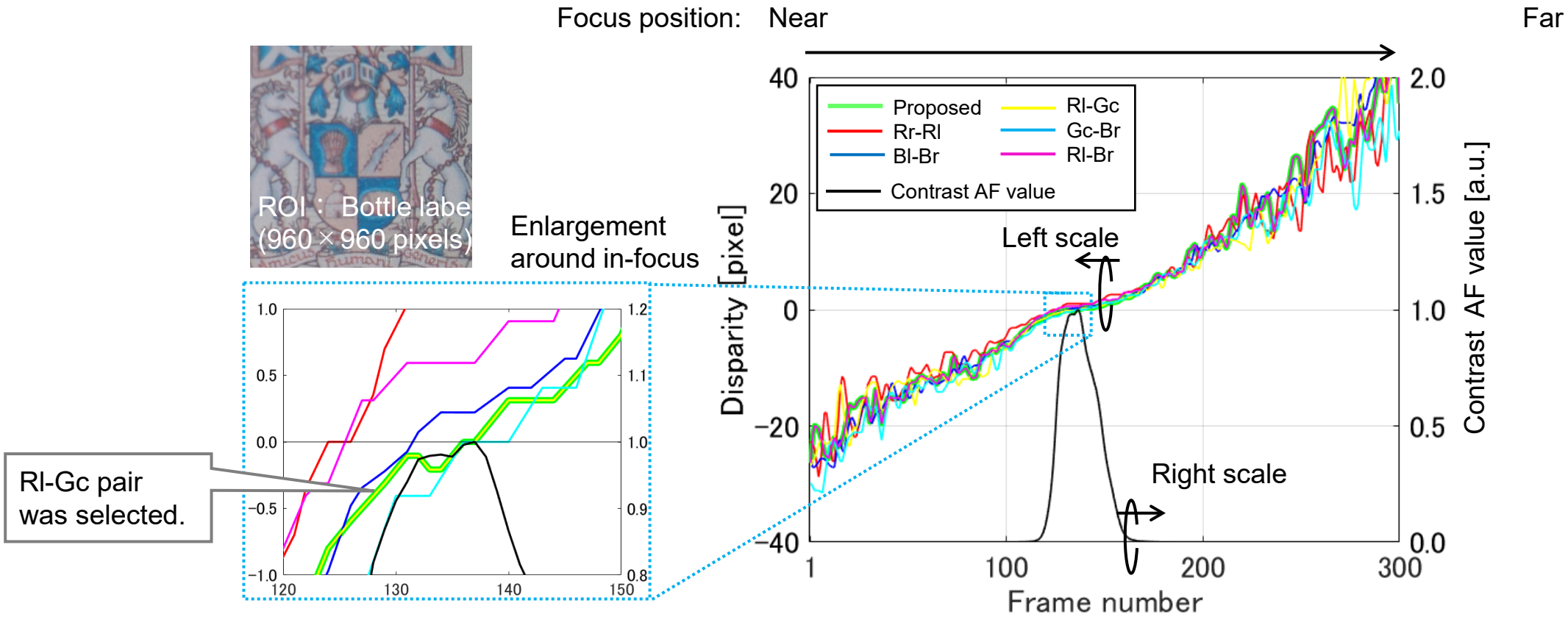
Experimental setup

- Disparities and contrast AF value whose peak indicates in-focus are measured while continuously changing focus position.
- Two methods are compared:
  - ✓Proposed method (Rl-Gc, Gc-Br, and Rl-Br)
  - ✓Conventional single-chip PD (Rr-Rl and Bl-Br)

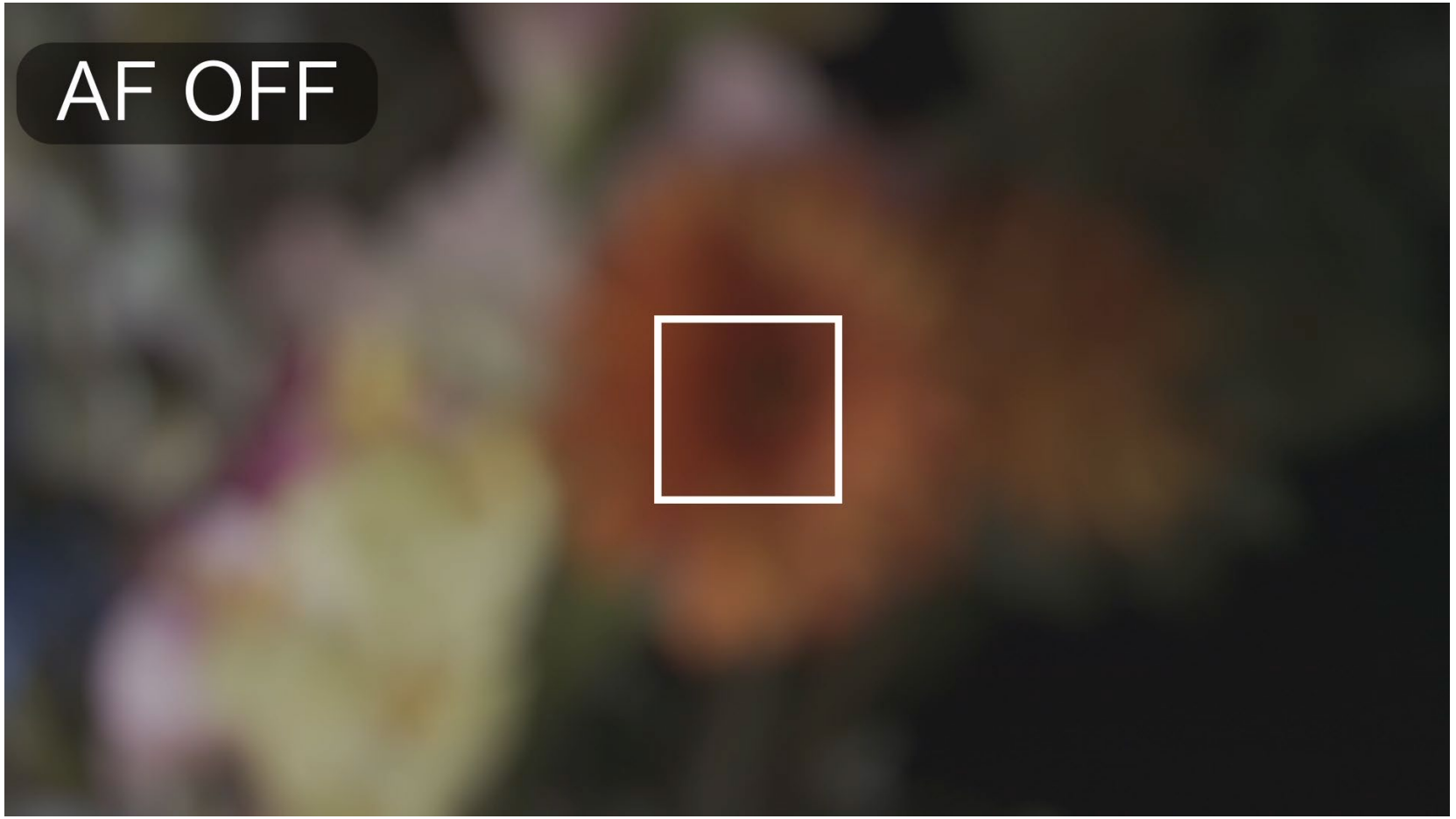


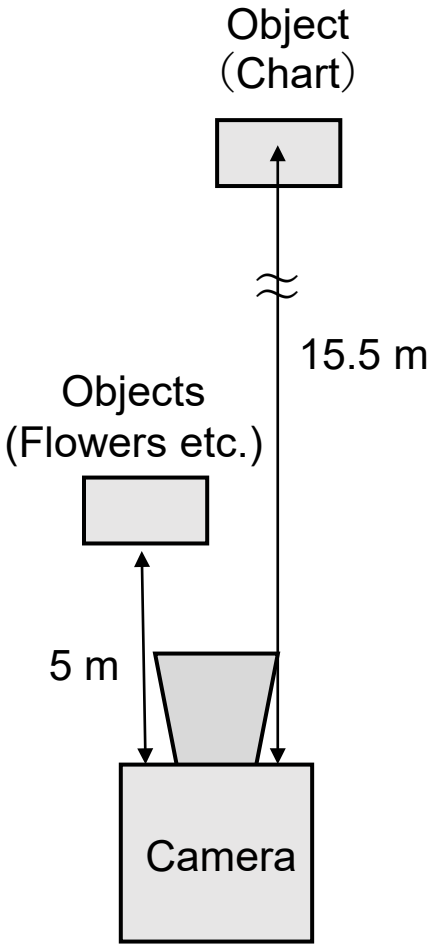
Disparity calculation results

- Proposed method output disparities closer to zero at in-focus position compared to conventional method.



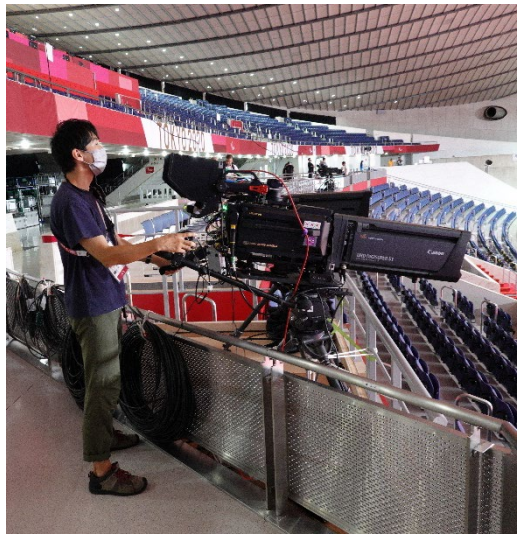
MP-PDAF demonstration movie

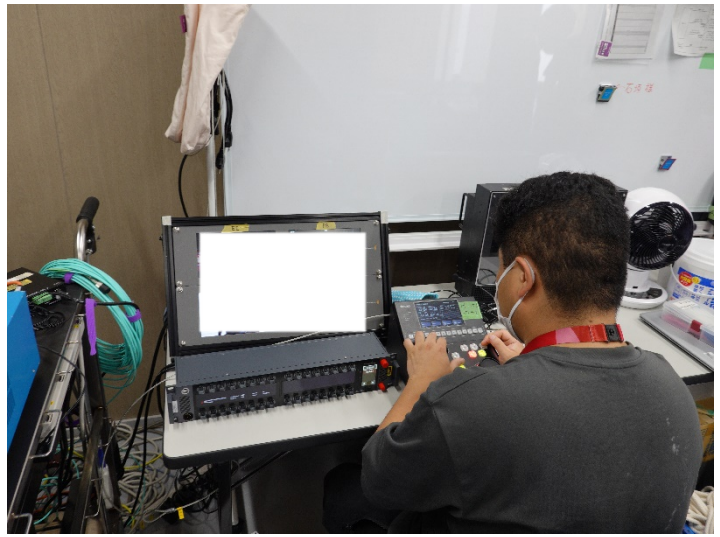




On-site operation of developed camera

- 8K production experiment at a big sports event (wheelchair rugby)
  - A 4x-speed slow-motion replay system was implemented in combination with an 8K slow-motion recorder.
  - An entire game was shot with AF always enabled (a camera operator did not control focus).
  - Over 30 slow-motion scenes with accurate focus were produced.





Conclusion

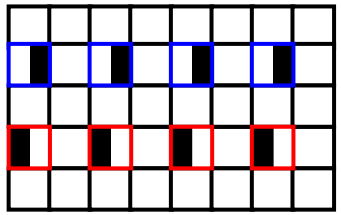
- A PDAF method suitable for three-chip cameras using disparities across multiple planes was proposed.
- The proposed method was implemented in an 8K 240-fps camera.
  - R ch and B ch: 8K PD sensor, G ch: regular 8K sensor
  - More likely disparity was determined from the ZNCC results.
  - Our method achieved better disparity calculation capability than the conventional single-chip based method.

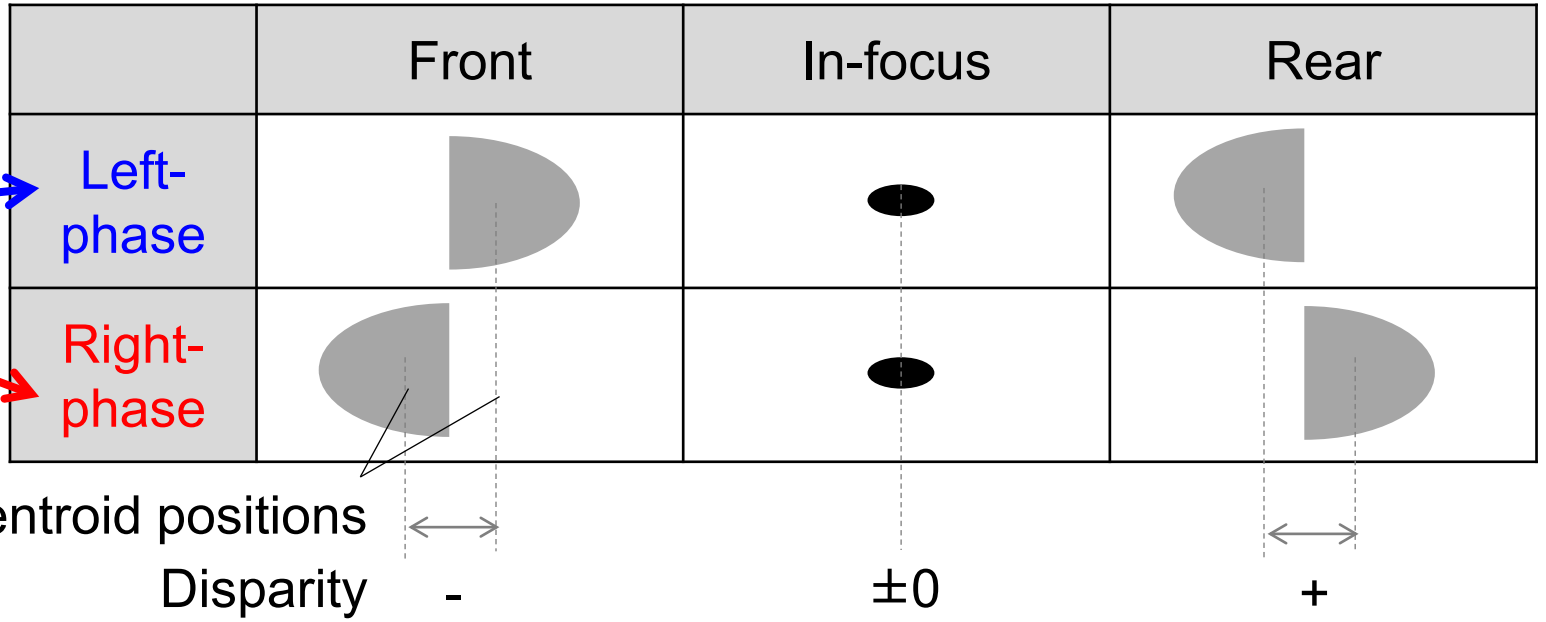
We have demonstrated the first ever 8K professional camera with AF.

(Appendix) Sensor-based PDAF

- Detecting focus position from disparity between PD pixels
- PDAF uses disparity regarding:
  - ✓**sign** to determine moving direction of lens's focus
  - ✓**magnitude** to determine moving speed

Example of
PD pixel array





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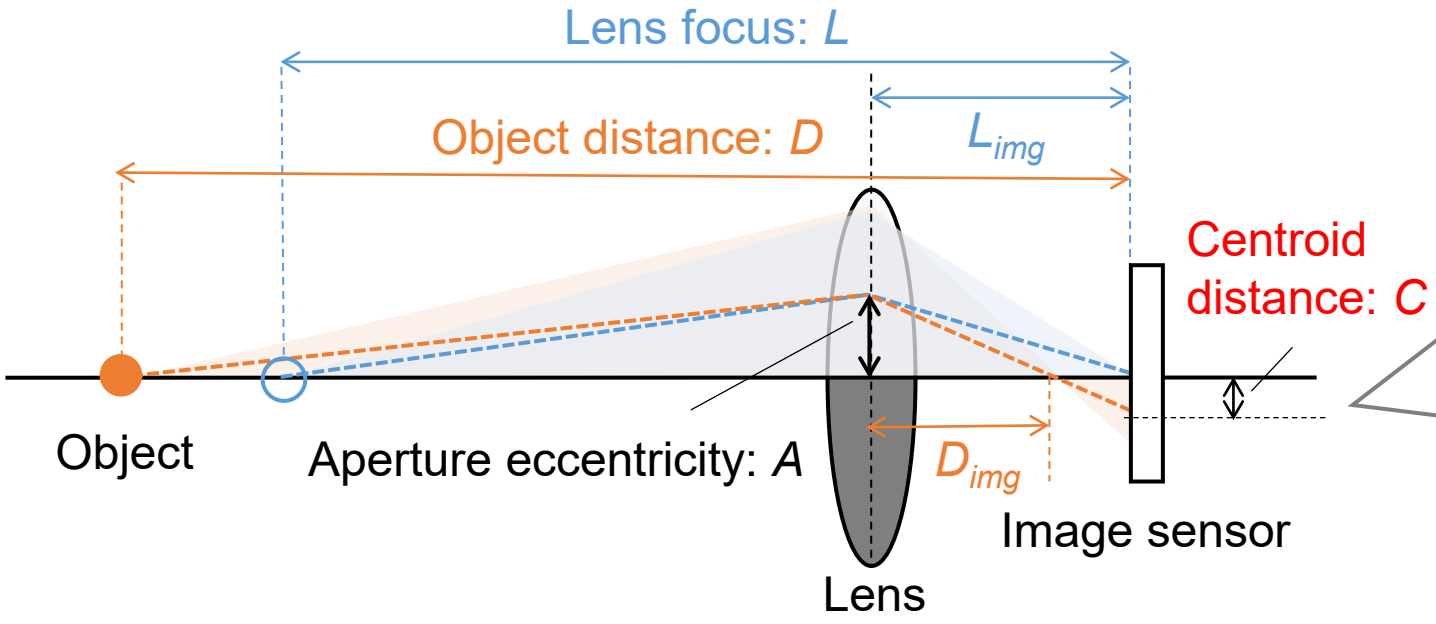

$$C(L) = A\left(\frac{L_{img}(L)}{D_{img}(L)} - 1\right)$$

$$\therefore Disparity = 2 \times \frac{C(L)}{Pixel\ pitch}\ [\text{pixels}]$$

(Appendix) Disparity calculation results

- Proposed method achieves robust disparity calculation.