Light-Trail-based Parallel Transmission for Image Sensor Communication

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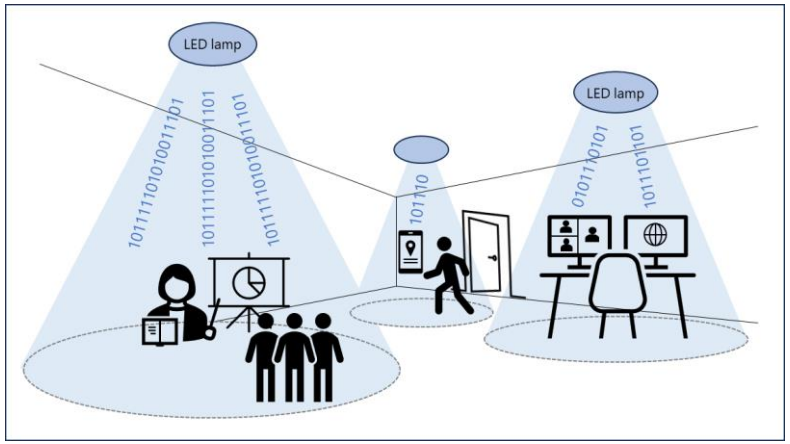
Outline

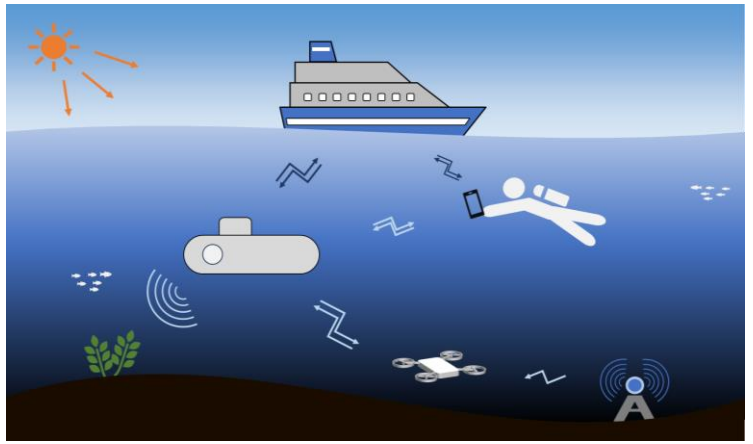
- Research Background
- Research Interests
  - Image sensor communication using linear light trails
  - Image sensor communication using circular light trails
- Conclusion

Visible Light Communication (VLC)

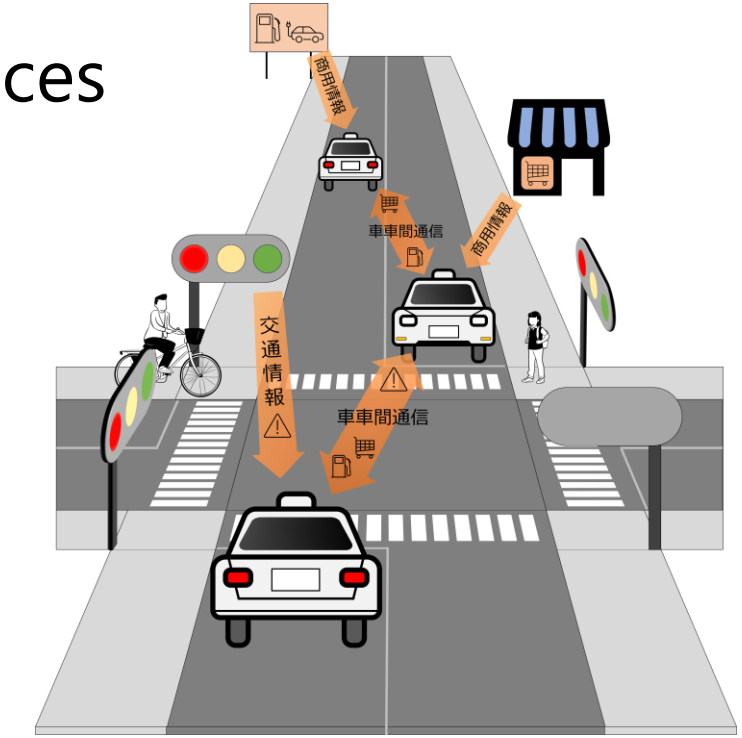
- Transfer data while providing light or visual services



Indoors



Underwater



Intelligent Transport System

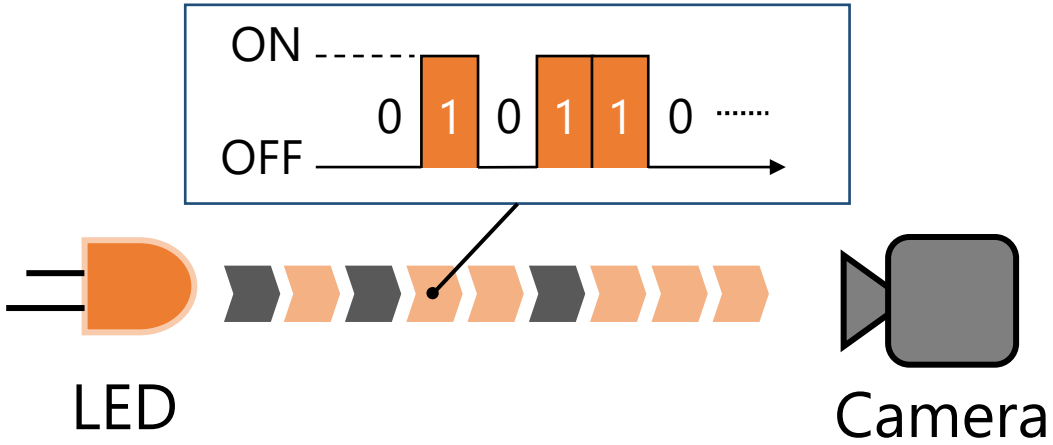
RXs: Photodiodes or image sensors (cameras)

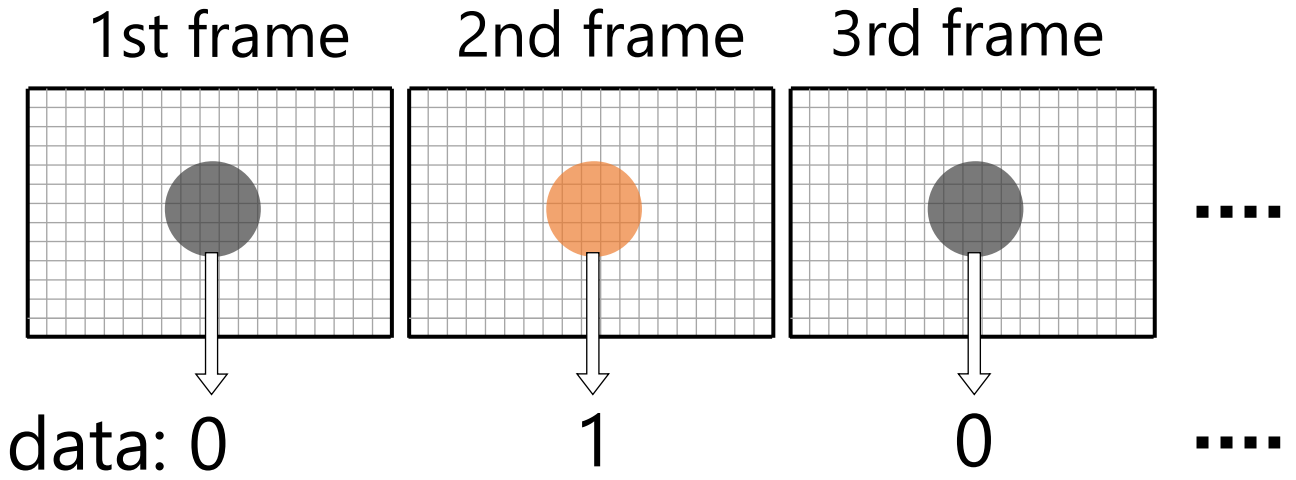
Image Sensor Communication (ISC)

- Proposed by Mr. Iizuka (CASIO) in 2009
- Same as Optical Camera Communication (OCC) standardized in IEEE 802.15.7 in 2012

Image Sensor Communication (ISC)

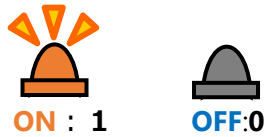
- Data Transmission and Recover





- **Transmitter**

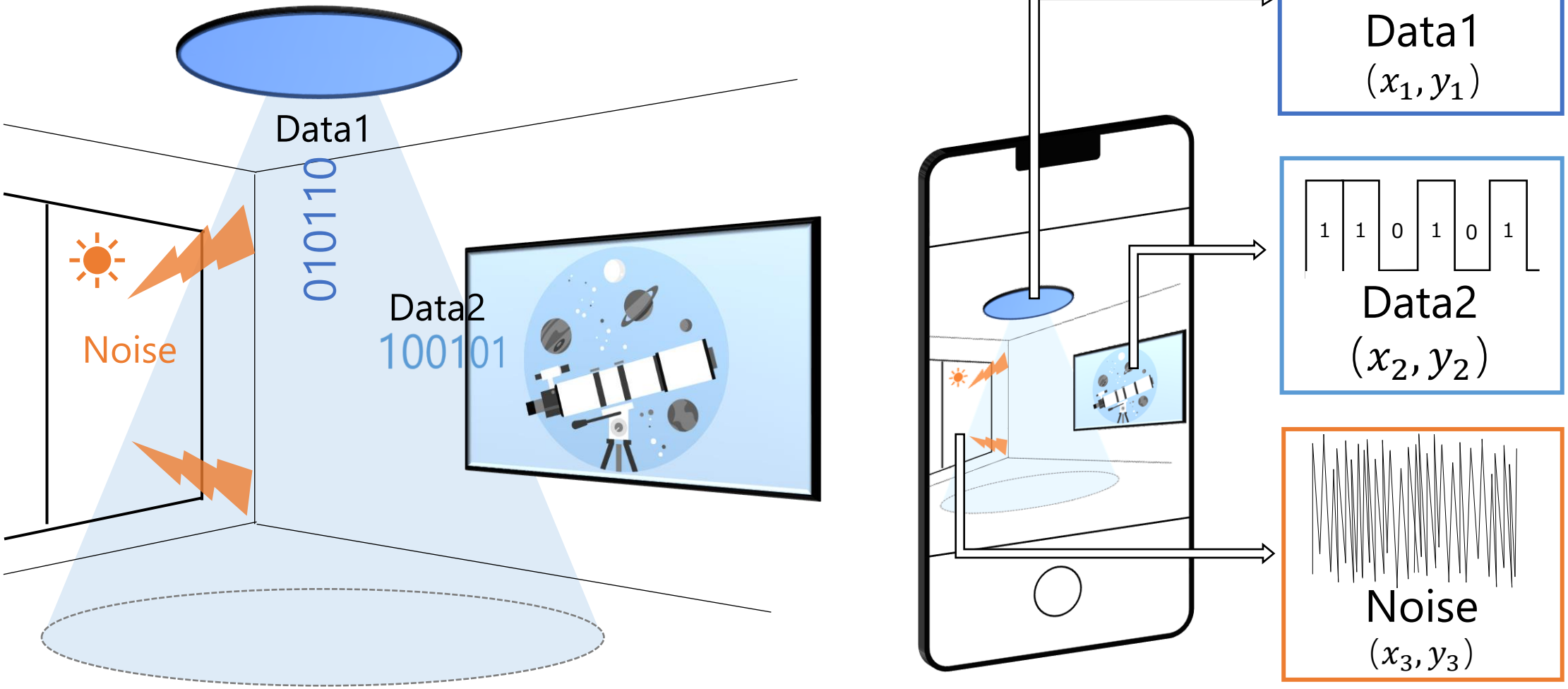
  sends data by **blinking LEDs**



- **Receiver**
  1. **Capture** blinking LEDs **as images**
  2. **Extract** LED luminance as **pixel values**
  3. **Recover** data based on extracted values

Superior noise immunity of ISC

The **spatial separation** capability of ISC

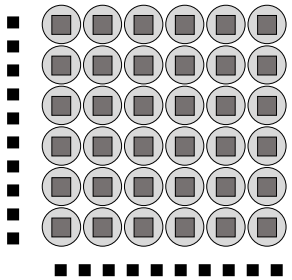


Parallel transmission in ISC

The **spatial separation** capability of ISC

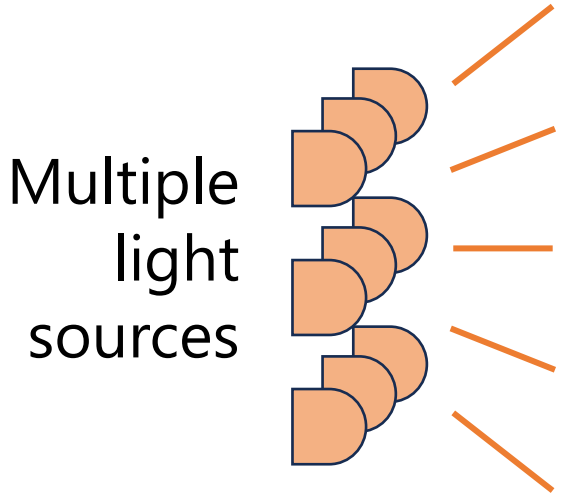
Image Sensor

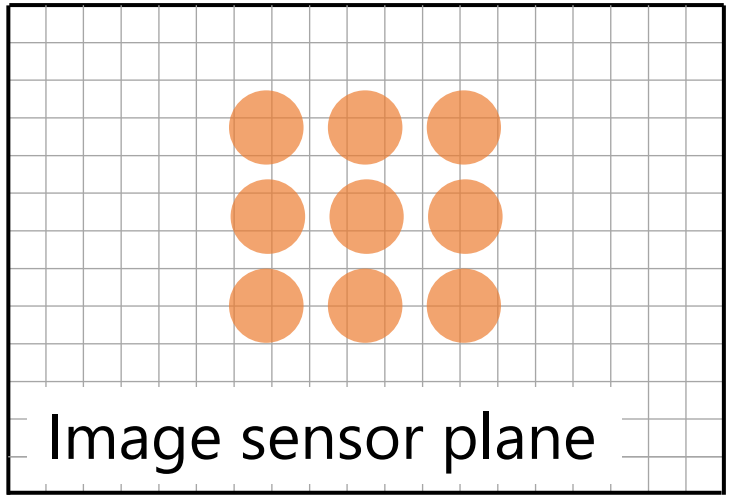
II



Huge number of receiving channels

- **The parallel transmission**





Multiple bits of data could be received within a frame

high-capacity parallel data transmission is desired in ISC

To achieve high-capacity transmission for ISC

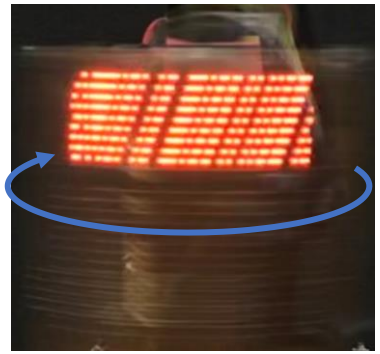
- Parallel transfer scheme

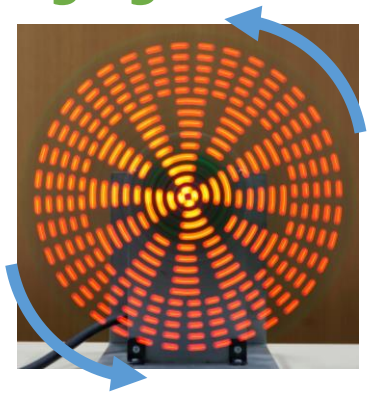
LED array-ISC

Display-ISC

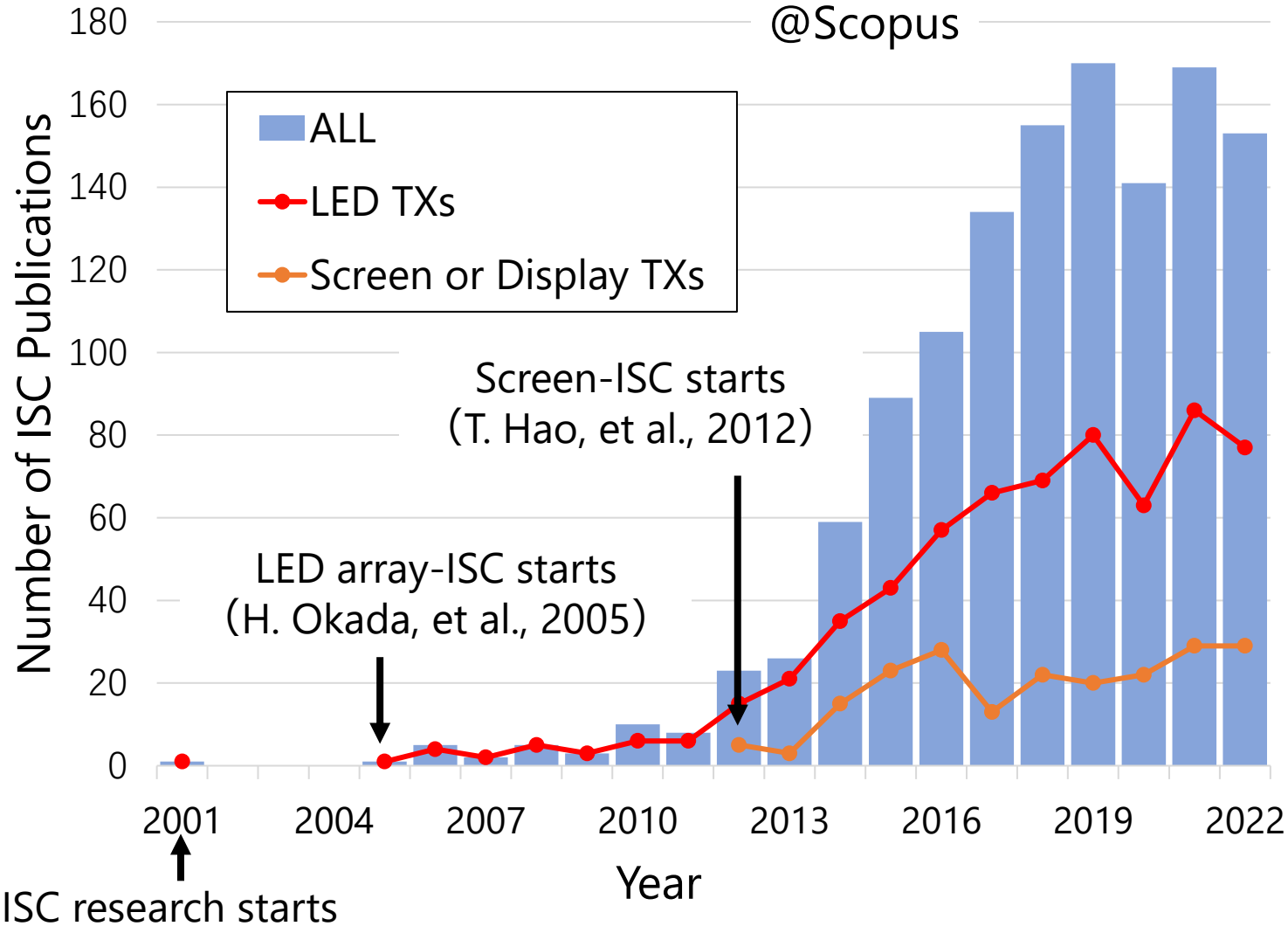
Previous studies: fixed lights

This study: moving lights





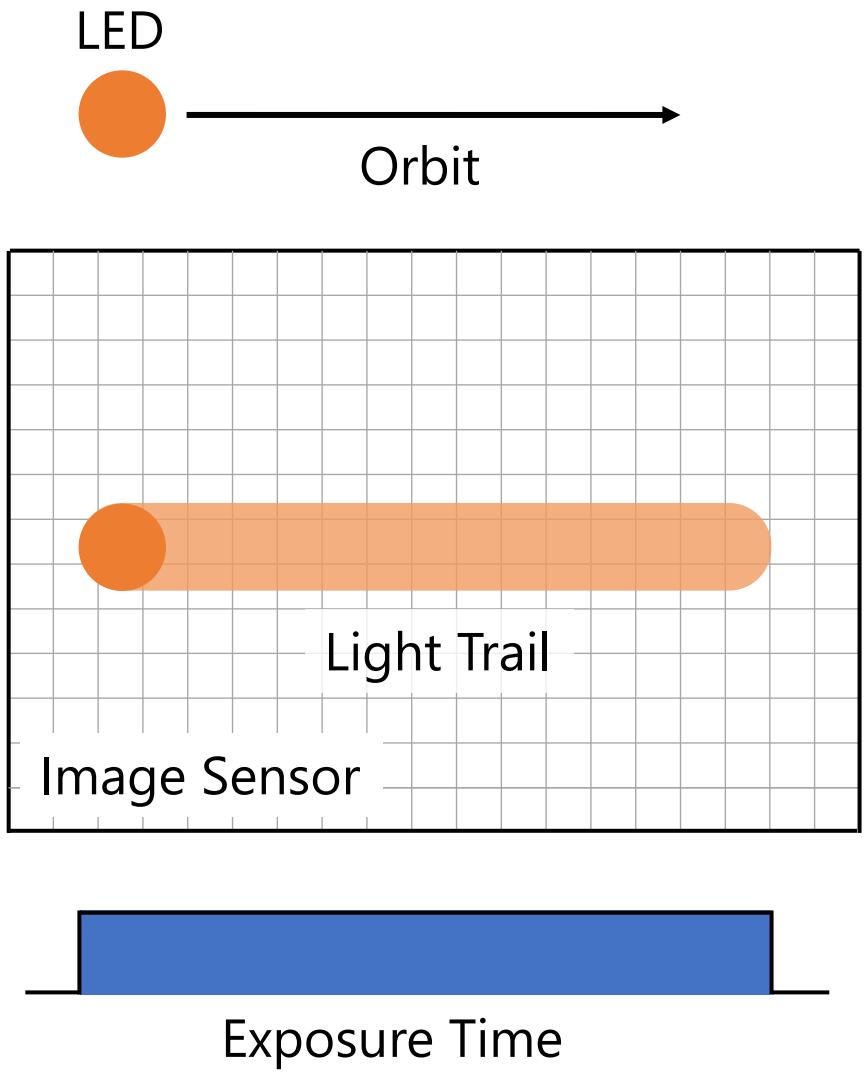
Virtual parallel transmission



An example of moving lights

https://ghpc.gsu.edu/2017/10/24/homeless-youth-lack-supports-maintain-physical-mental-well/man-at-subway-station-and-moving-train-2/

Using moving lights for ISC



Research Purpose

Realization of spatially high-capacity data parallel transmission using light trails

linear light trails

circular light trails

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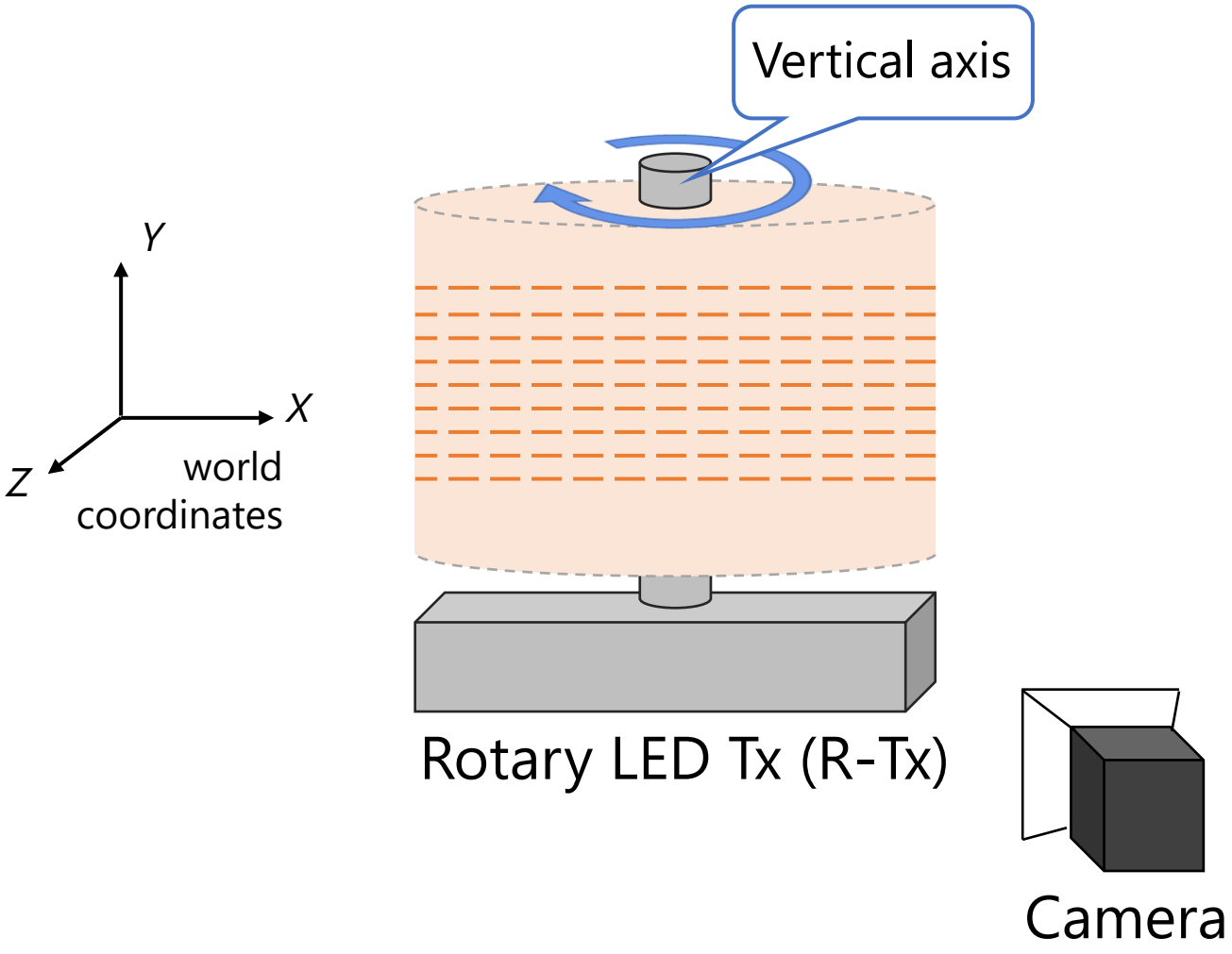
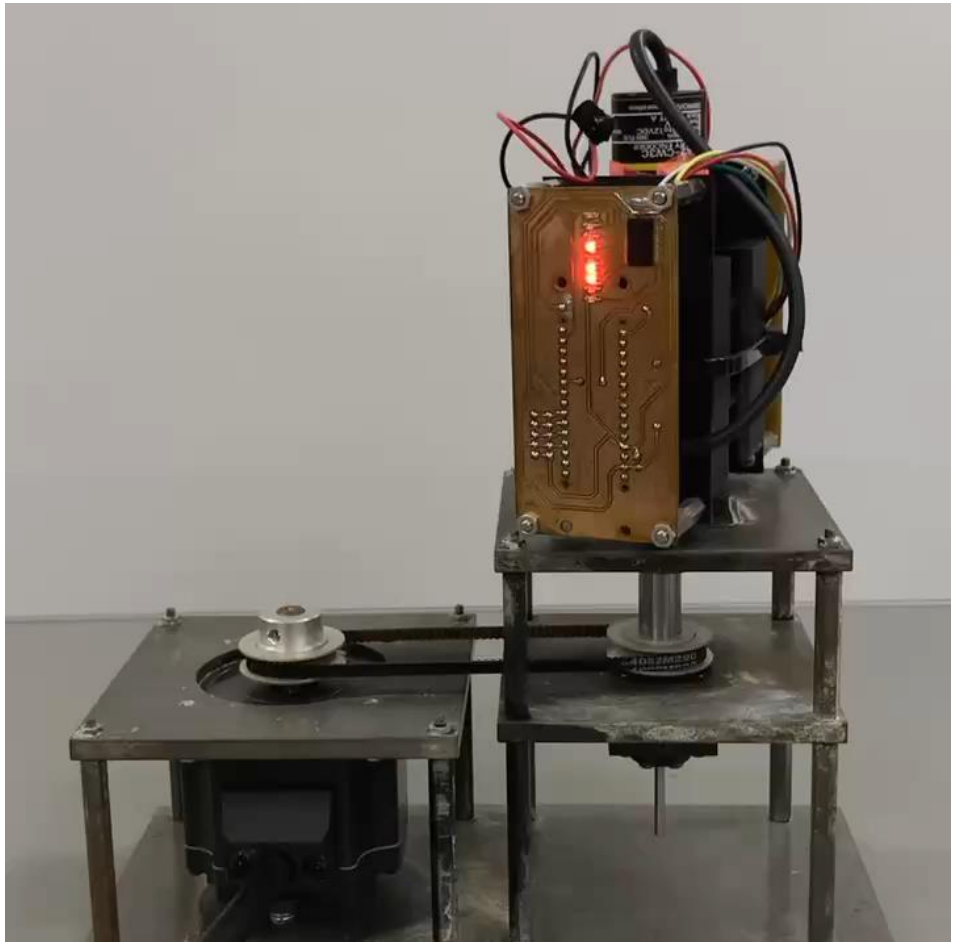
  - Image sensor communication using circular light trails
- Conclusion

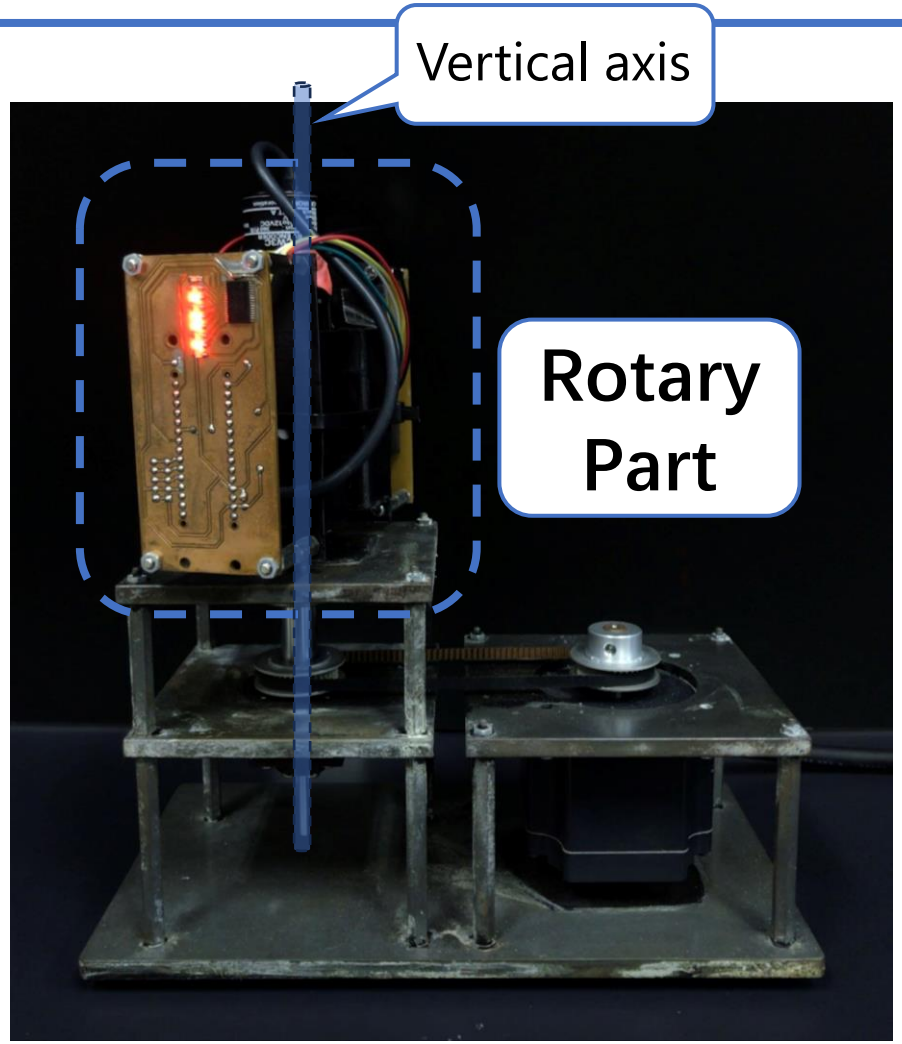
Rotary LED transmitter

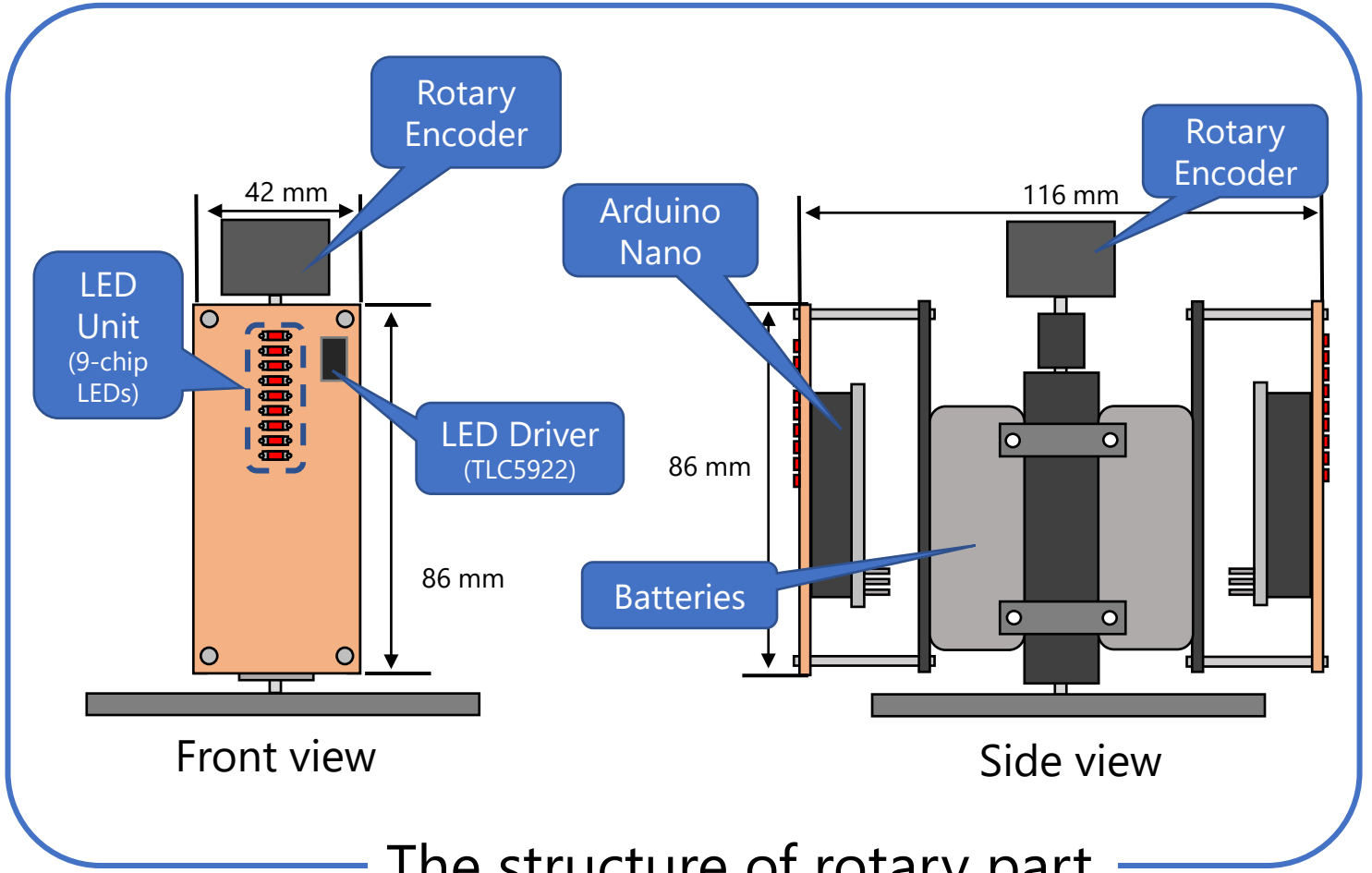




[1] S. Arai, **Z. Tang**, A. Nakayama, H. Takata, and T. Yendo, "Rotary LED Transmitter for Improving Data Transmission Rate of Image Sensor Communication," in *IEEE Photonics Journal*, vol. 13, no. 4, pp. 1-11, Aug. 2021.

Rotary LED Transmitter (R-Tx)

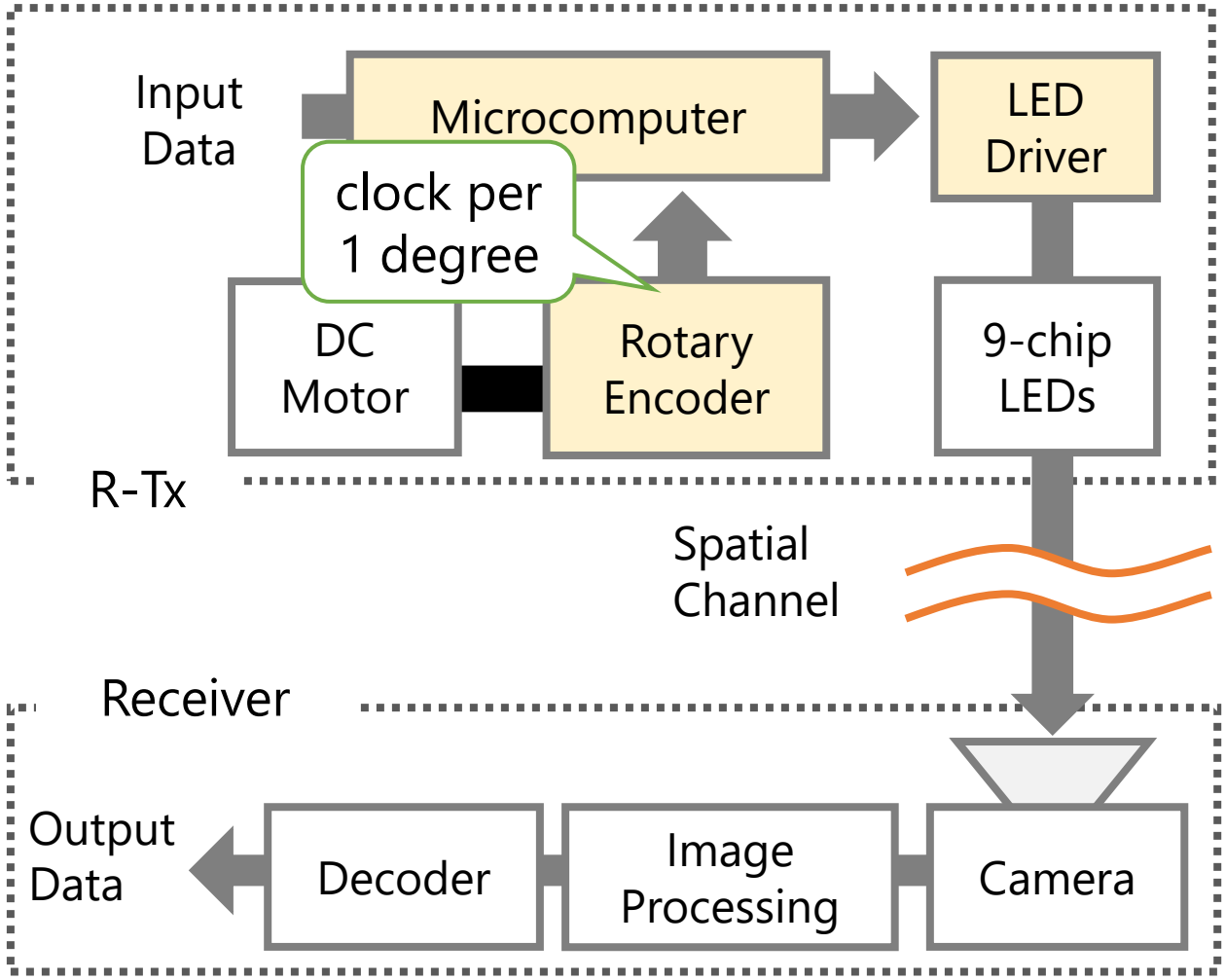




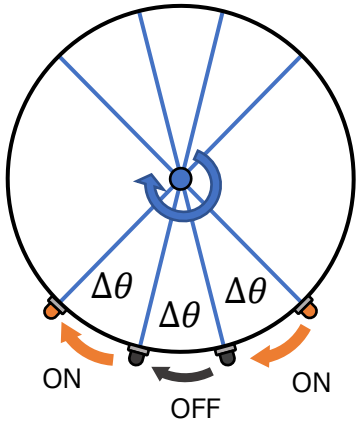
The structure of rotary part

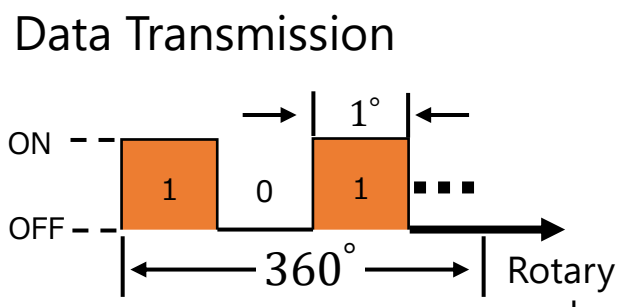
[1] S. Arai, **Z. Tang**, A. Nakayama, H. Takata, and T. Yendo, "Rotary LED Transmitter for Improving Data Transmission Rate of Image Sensor Communication," in *IEEE Photonics Journal*, vol. 13, no. 4, pp. 1-11, Aug. 2021.

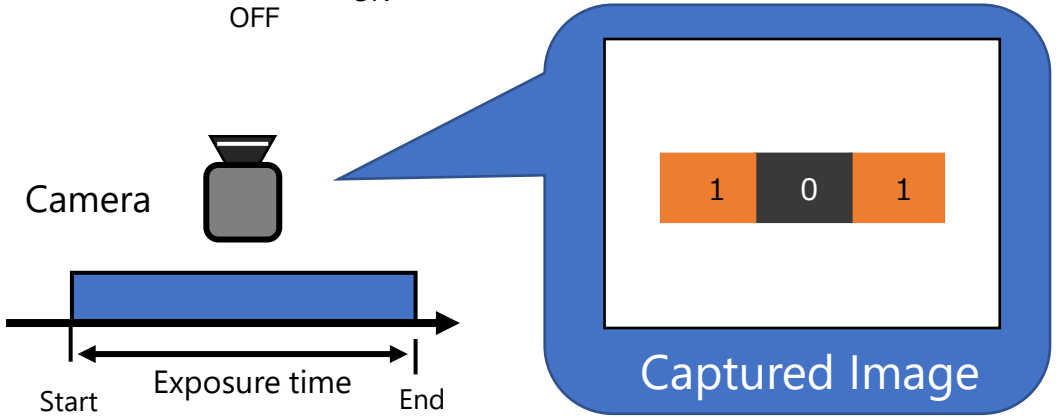
System Model



- Signal changes every 1 degree



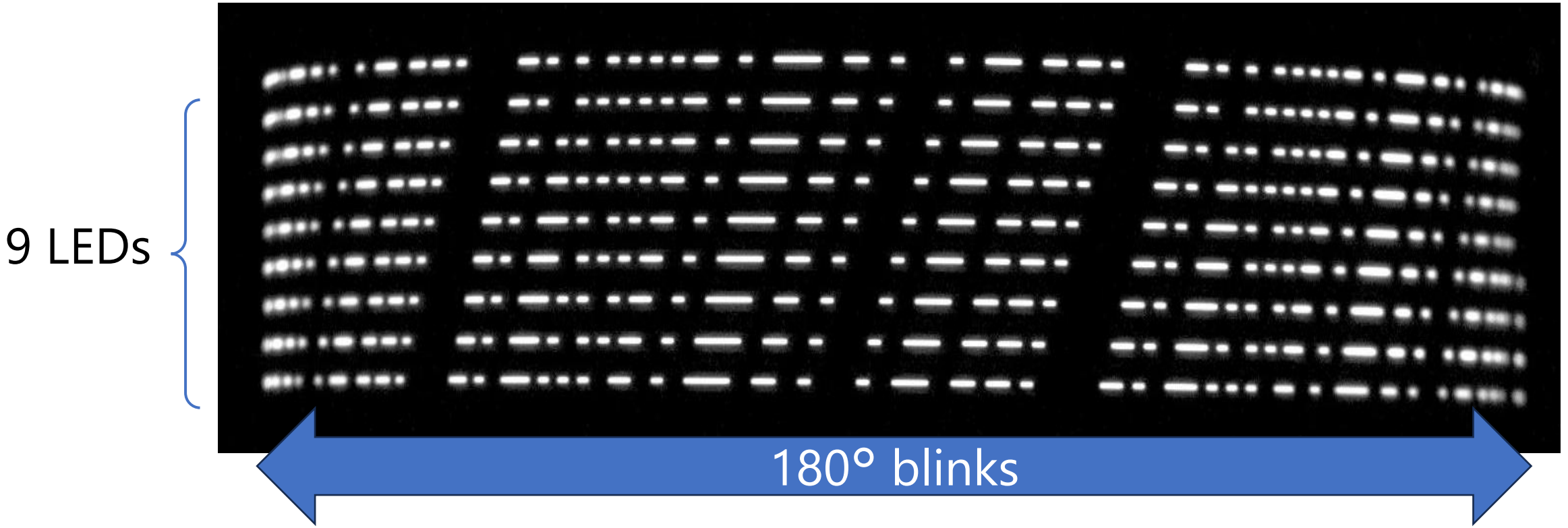




[1] S. Arai, **Z. Tang**, A. Nakayama, H. Takata, and T. Yendo, "Rotary LED Transmitter for Improving Data Transmission Rate of Image Sensor Communication," in *IEEE Photonics Journal*, vol. 13, no. 4, pp. 1-11, Aug. 2021.

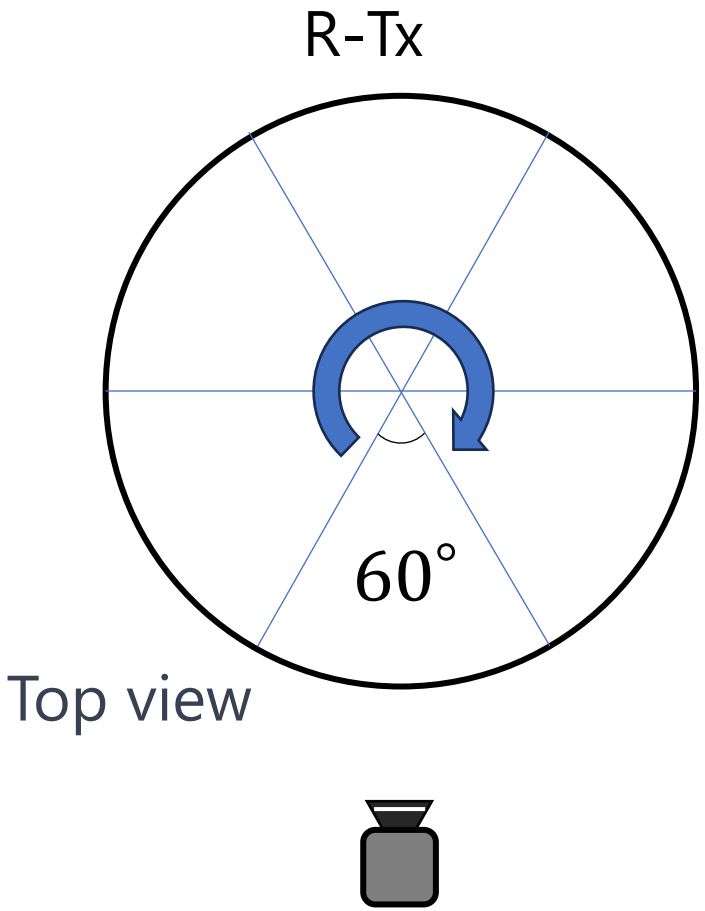
A captured image (5 fps)

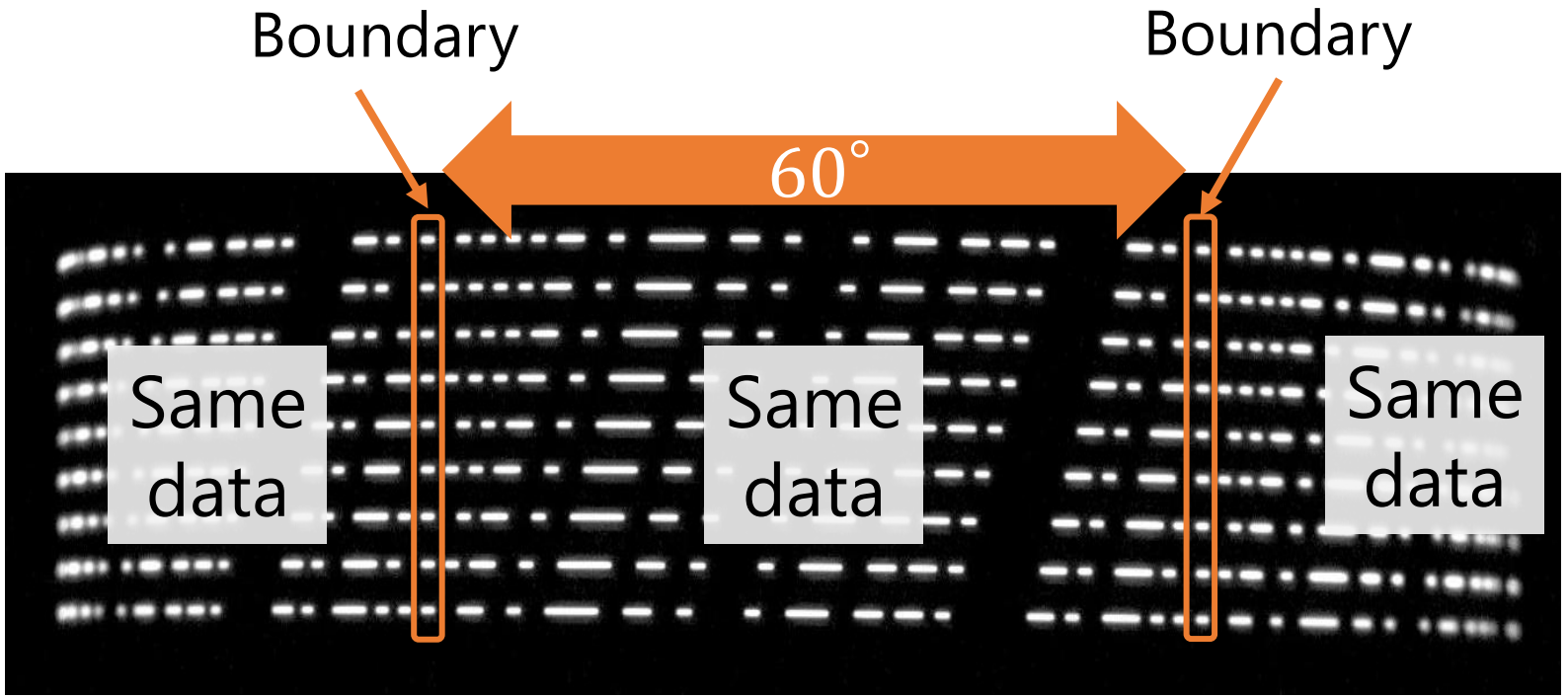
- Rotary Speed: 5 rps, Blinking angle: 1°



9 LEDs x 180 degrees = **1,620** blinks/image

Data angle range





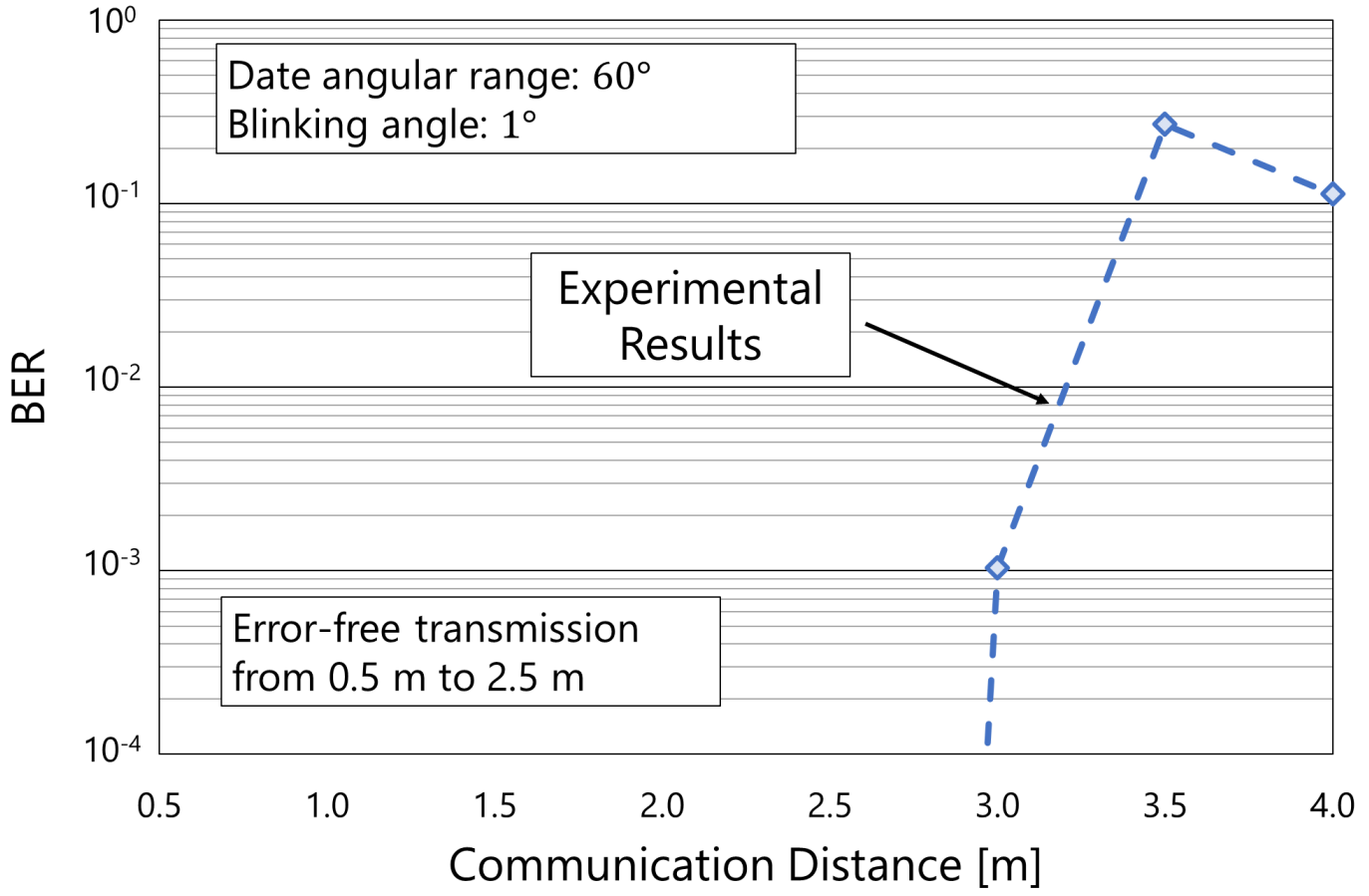
- Send the same data every 60 degrees

[1] S. Arai, **Z. Tang**, A. Nakayama, H. Takata, and T. Yendo, "Rotary LED Transmitter for Improving Data Transmission Rate of Image Sensor Communication," in *IEEE Photonics Journal*, vol. 13, no. 4, pp. 1-11, Aug. 2021.

Experiment and results

Experimental parameters

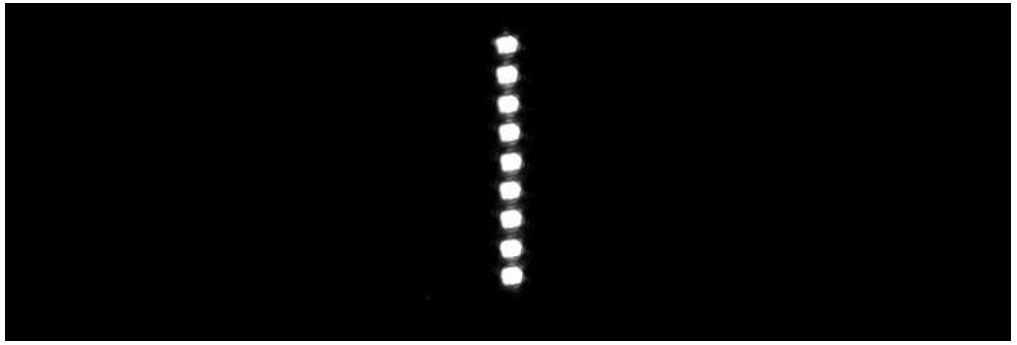
Environment	indoor
LED	SML-M13UTT86
# of LED	9
Blinking angle	1°
Data angle range	60°
Rotary speed	300 rpm
Modulation method	OOK
Camera	UI-3250ML
Frame rate	5 fps
Exposure time	0.2 s
Image sensor resolution	1,600 × 1,200
Aperture	F8
Lens filter	ND8



- Error-free data transmission (OOK) within 2.5 m

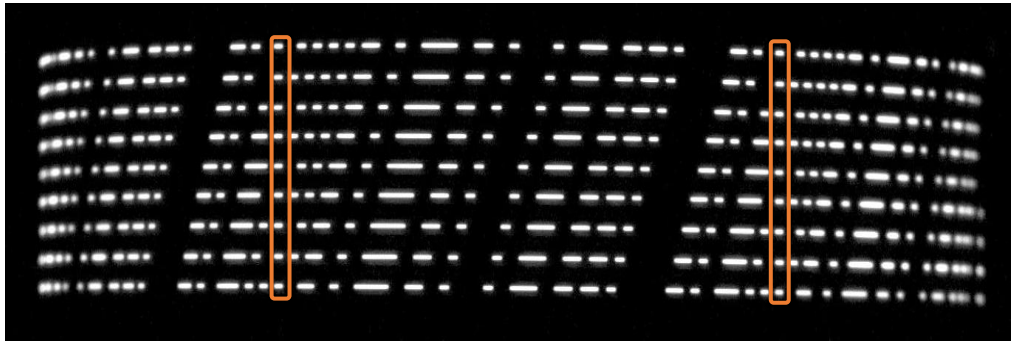
Improved data rate using light trails

Captured image of fixed lights



9 bits/frame

Captured image of light trails



9 LEDs x 60 degrees = **540** bits/frame

With the same LED lights and exposure time,

the data rate of our method is 60 times faster than the conventional method

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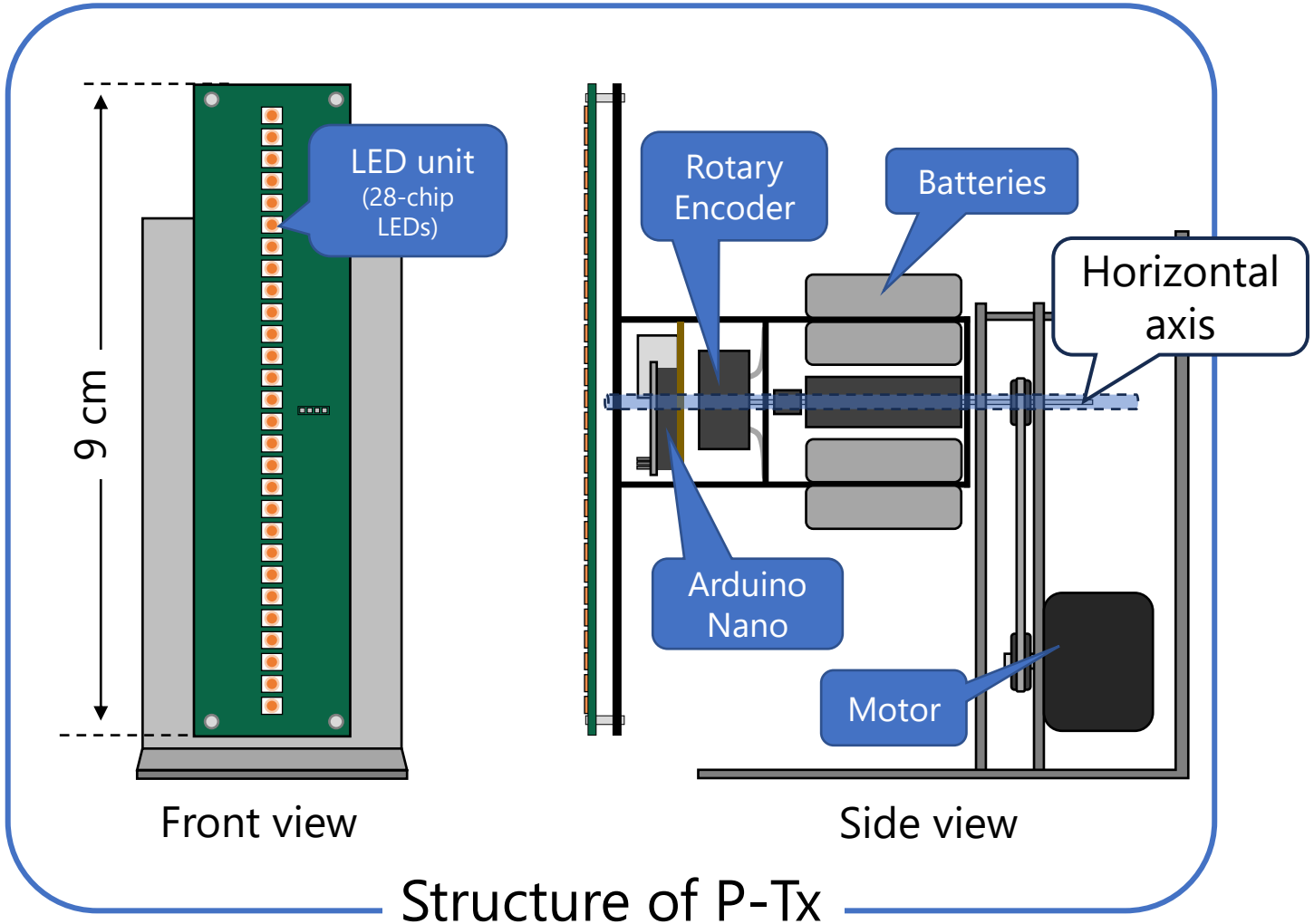
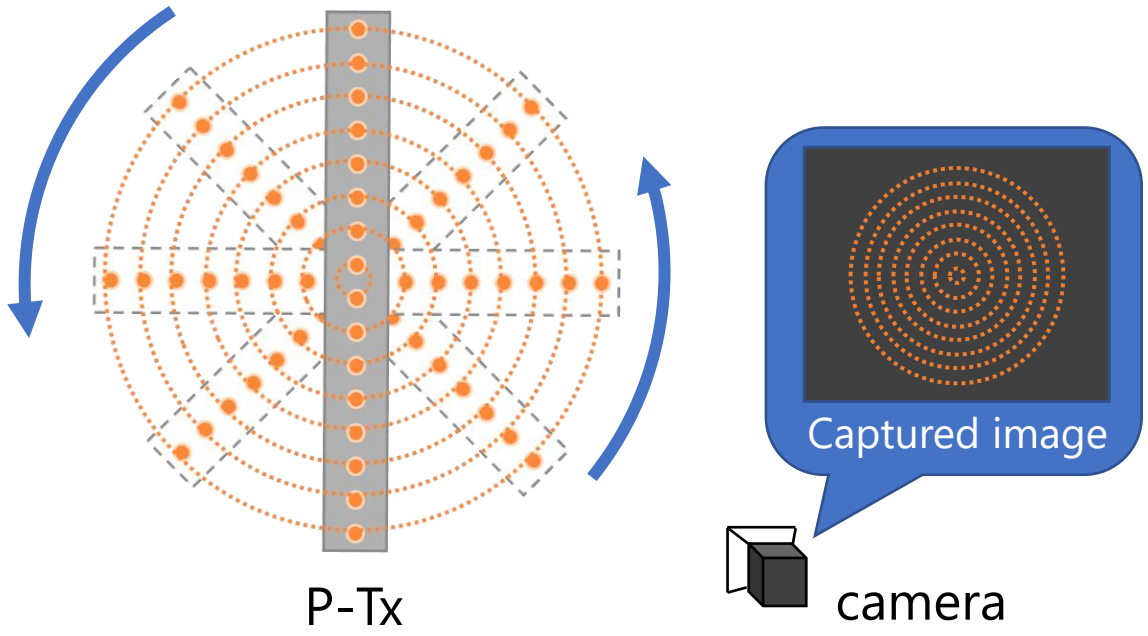
Propeller LED transmitter (P-Tx)

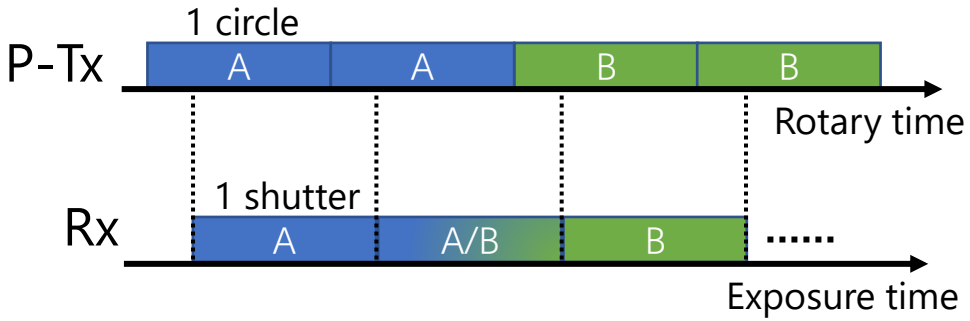


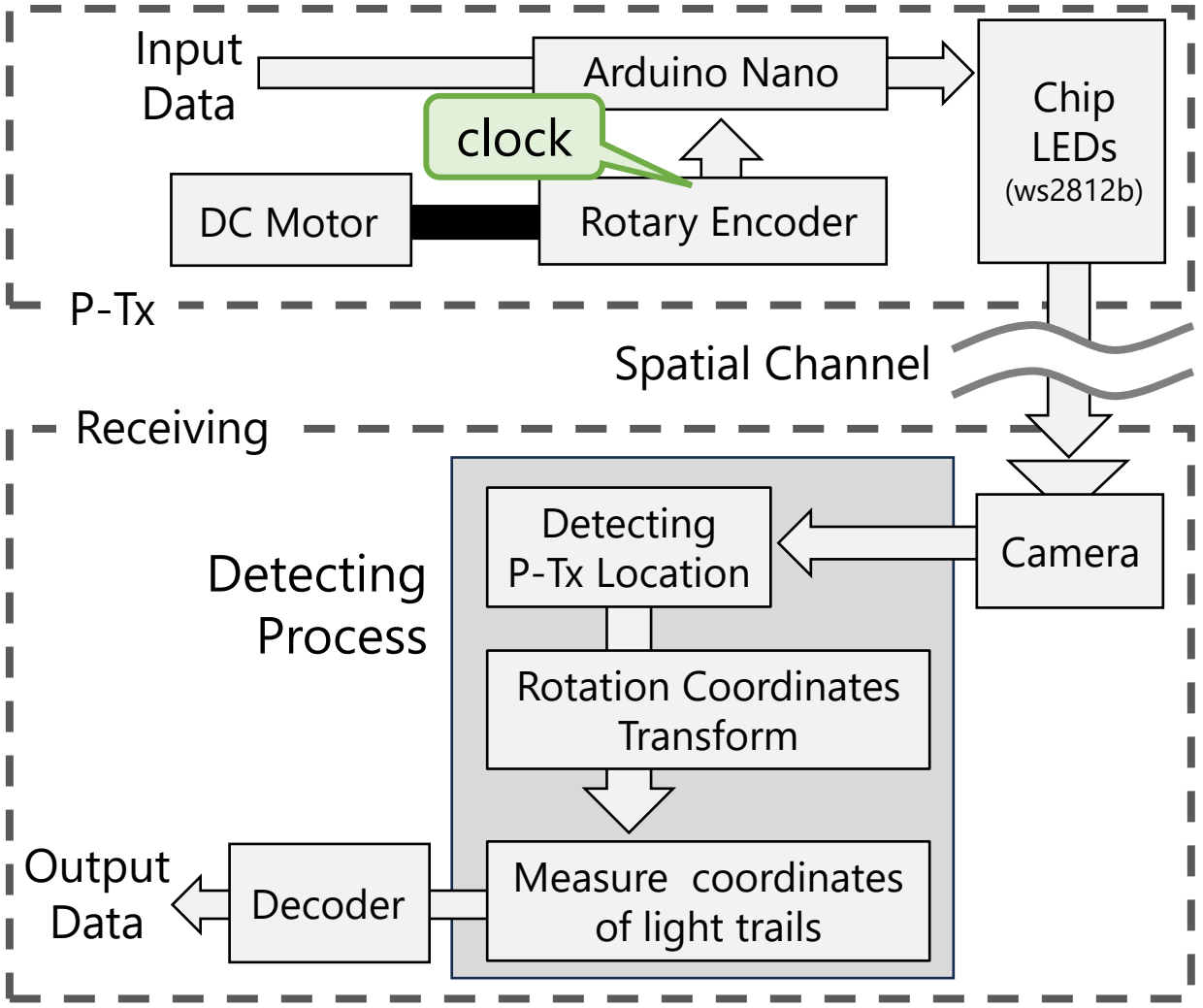
Structure of P-Tx

[2] **Z. Tang**, J. Zheng, T. Yamazato, and S. Arai, "Image Sensor Communication Via Light Trail Using Propeller LED Transmitter," in *IEEE Photonics Journal*, vol. 15, no. 5, pp. 1-12, Oct. 2023.

System model

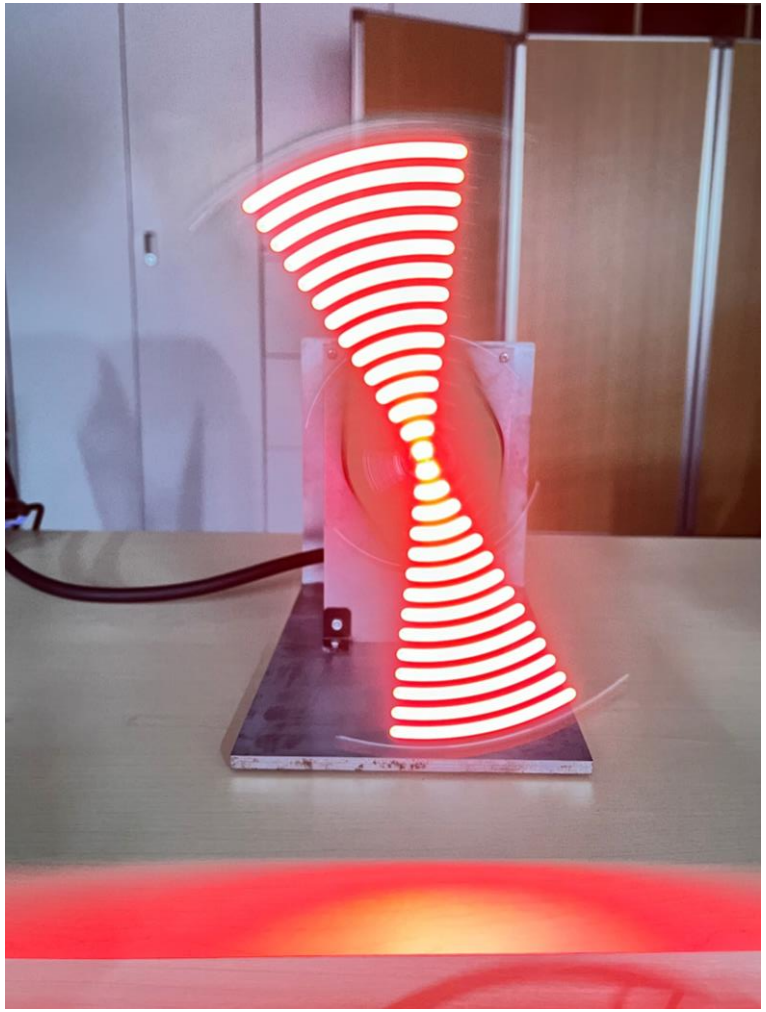




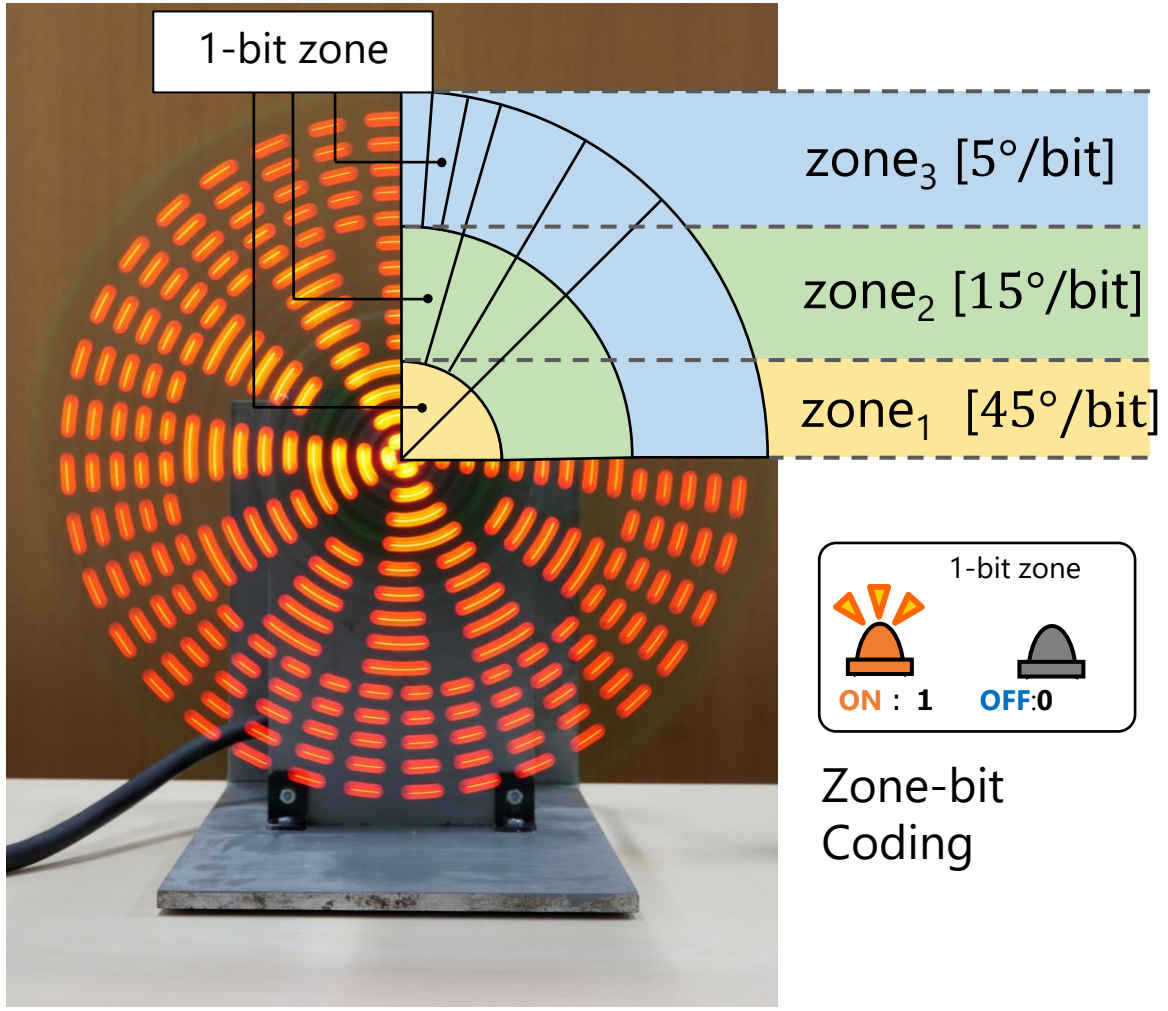


[2] **Z. Tang**, J. Zheng, T. Yamazato, and S. Arai, "Image Sensor Communication Via Light Trail Using Propeller LED Transmitter," in *IEEE Photonics Journal*, vol. 15, no. 5, pp. 1-12, Oct. 2023.

Segment circular light trails into several zones



Blinking based on the same angle



Blinking according to segmented zones

Segment circular light trails into several zones

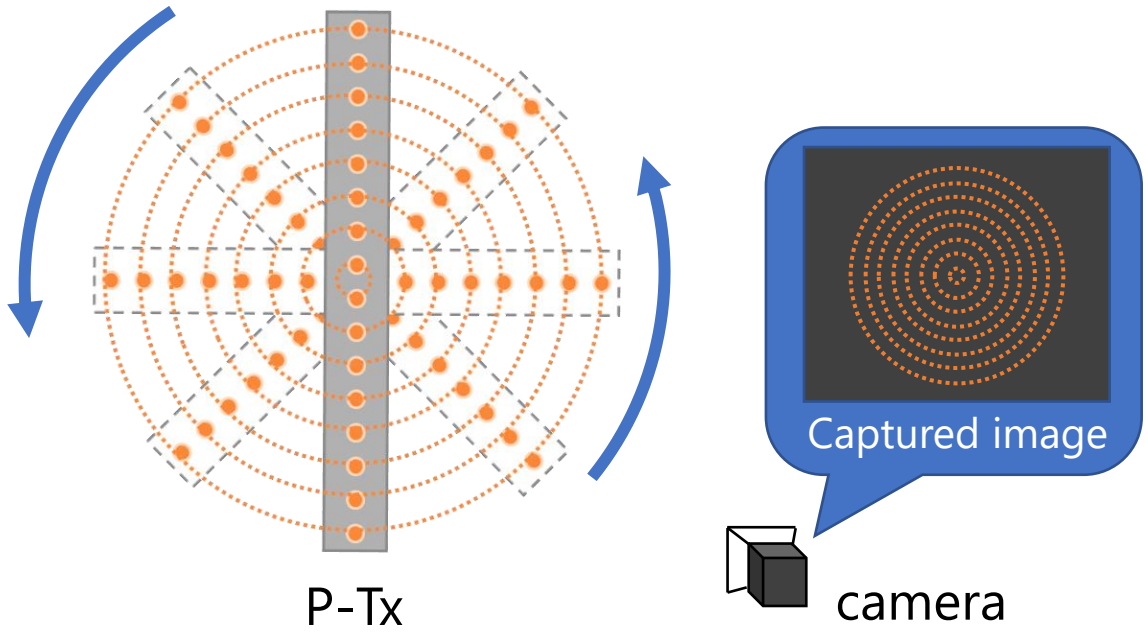
Outside zone

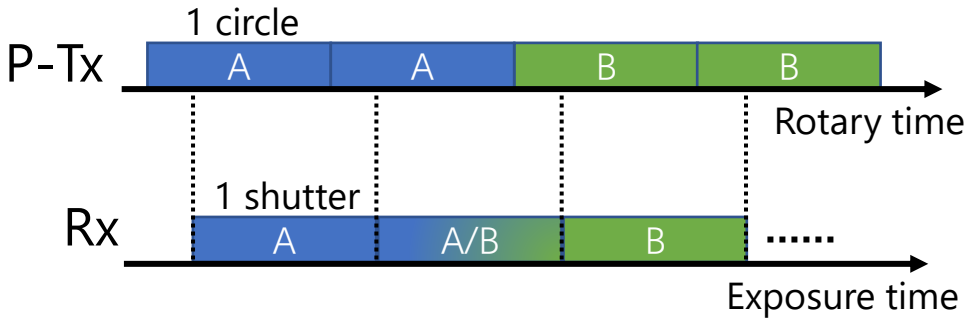
High-density light trails for
high-capacity transmission

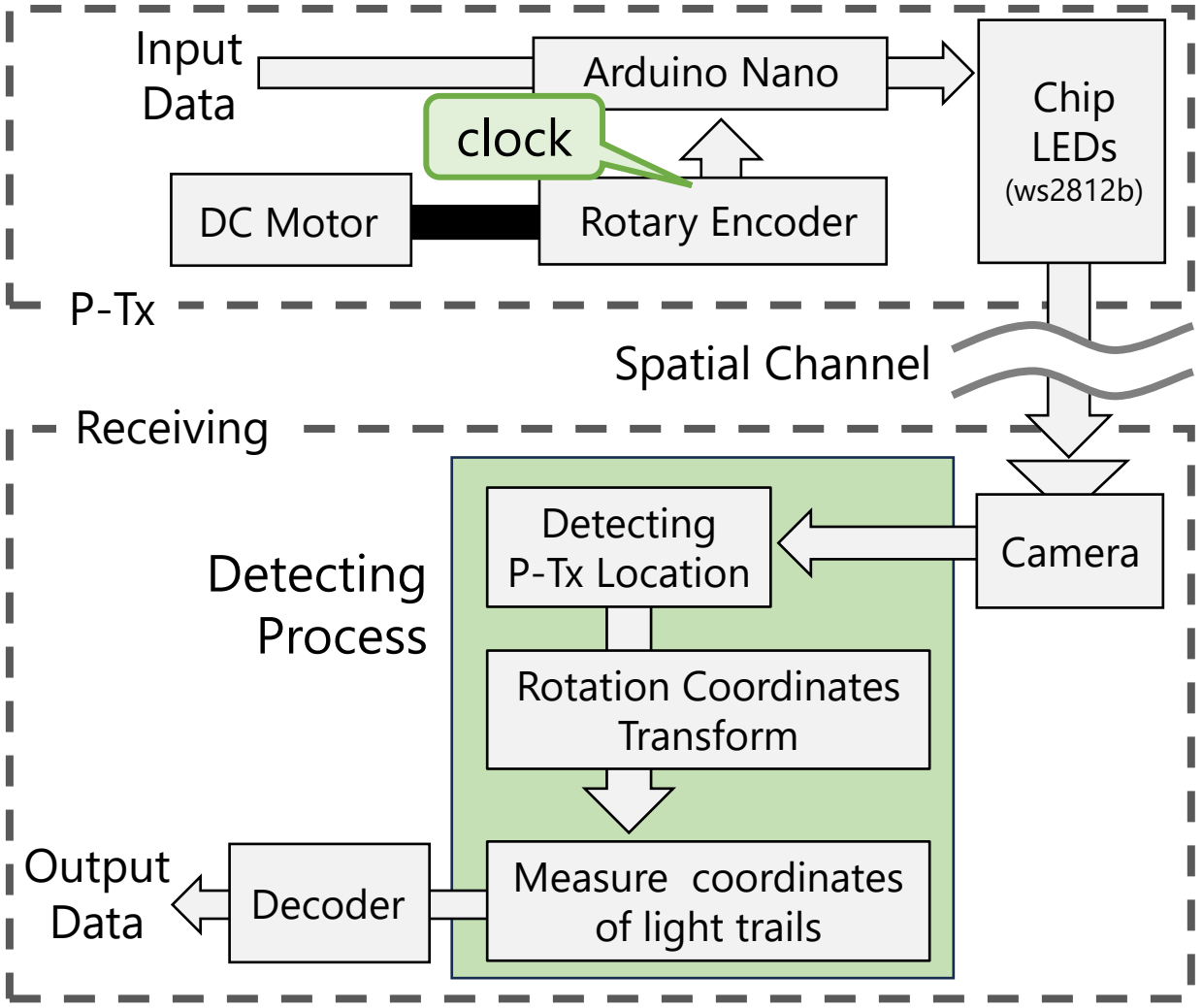
Inside zone

High-brightness light trails for
high-reliable transmission

System model



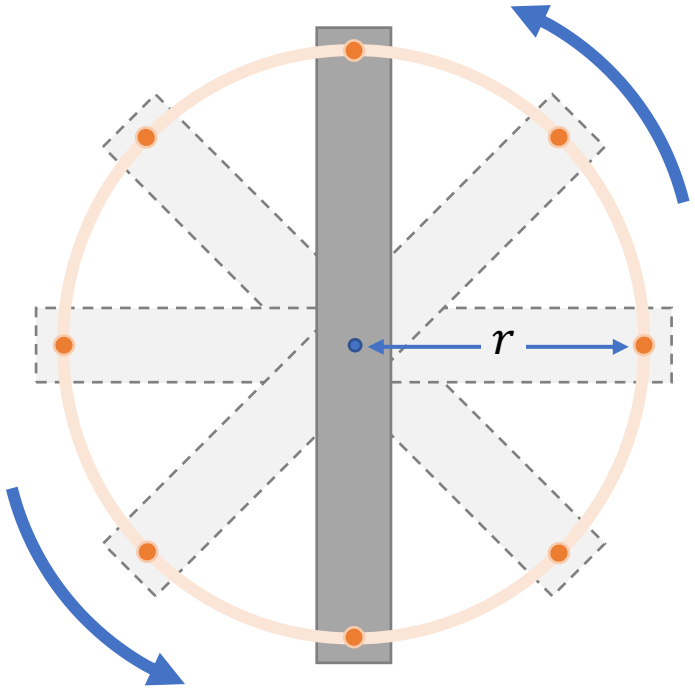




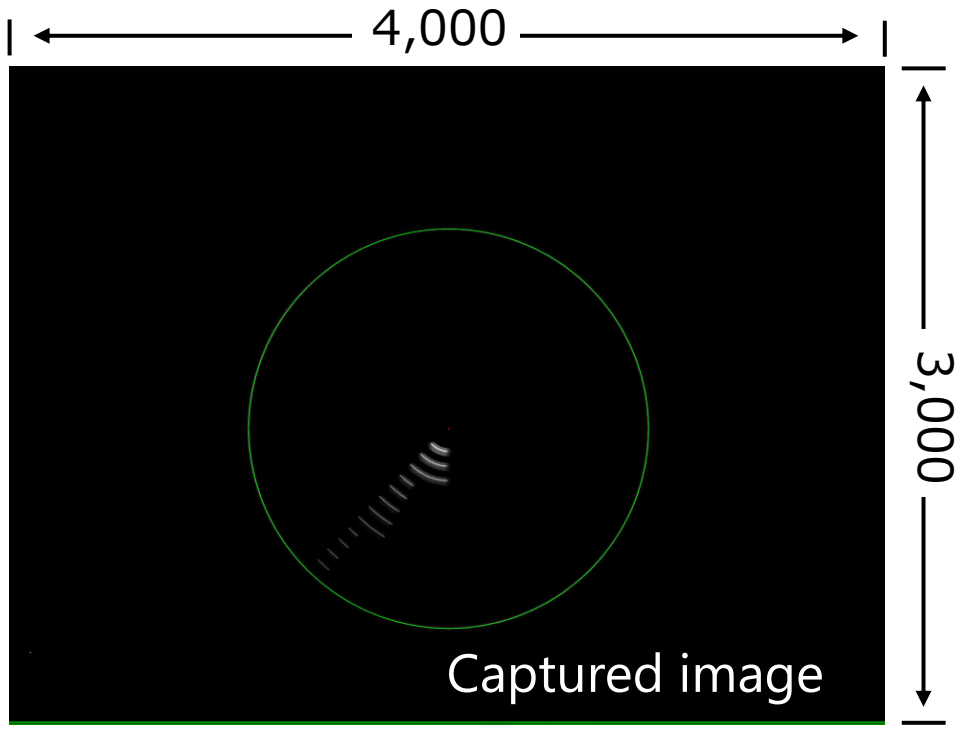
[2] **Z. Tang**, J. Zheng, T. Yamazato, and S. Arai, "Image Sensor Communication Via Light Trail Using Propeller LED Transmitter," in *IEEE Photonics Journal*, vol. 15, no. 5, pp. 1-12, Oct. 2023.

Localization the circular light trail

- Hough gradient method[a]



- Detection pattern
  - Turn ON the most outside LED

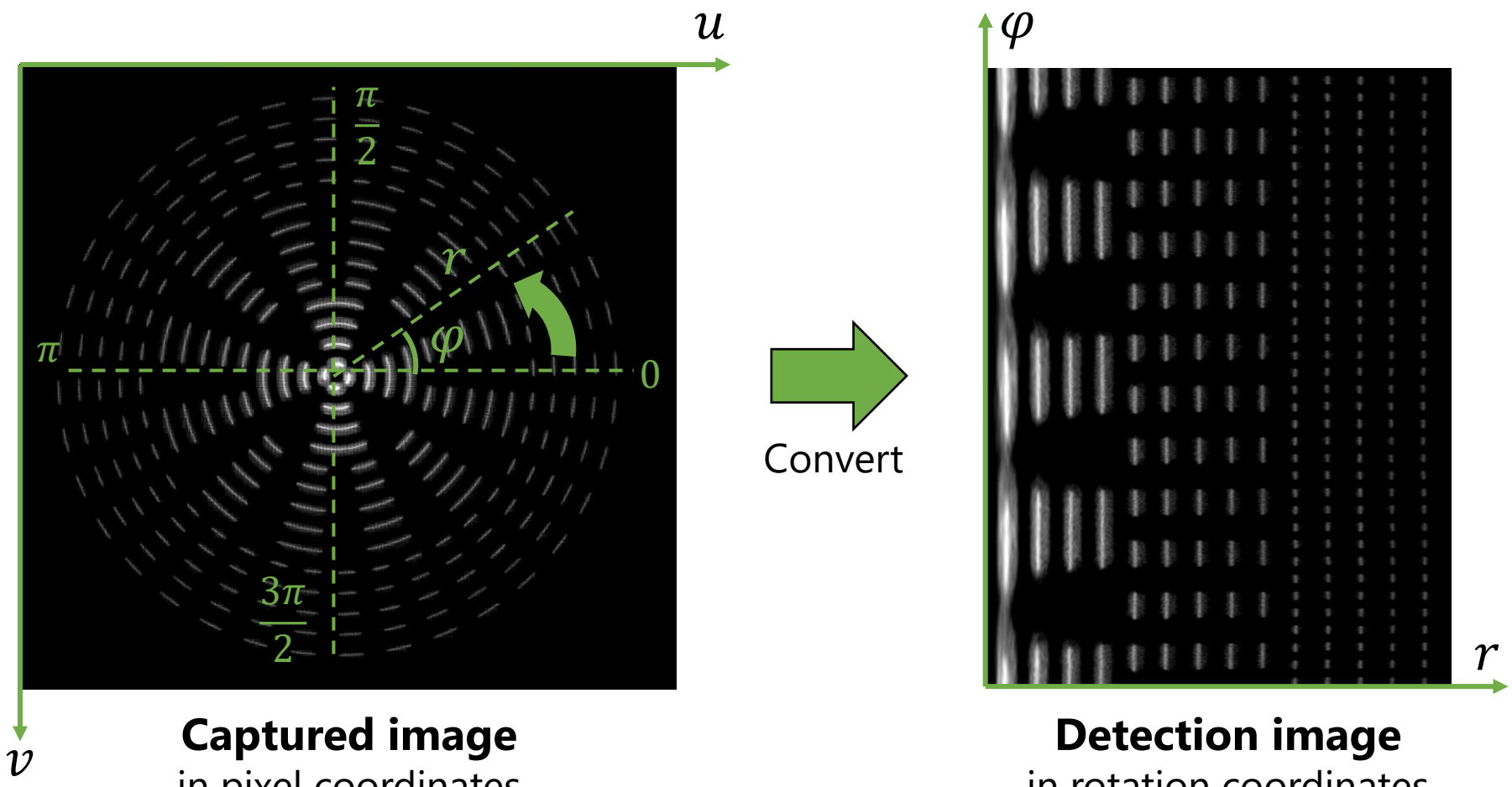


- Detection result

[a] J. Illingworth and J. Kittler, "The Adaptive Hough Transform,"
in *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. PAMI-9, no. 5, pp. 690-698, Sept. 1987.

Measure signal coordinates

- Rotation coordinates transform (Polar transform)

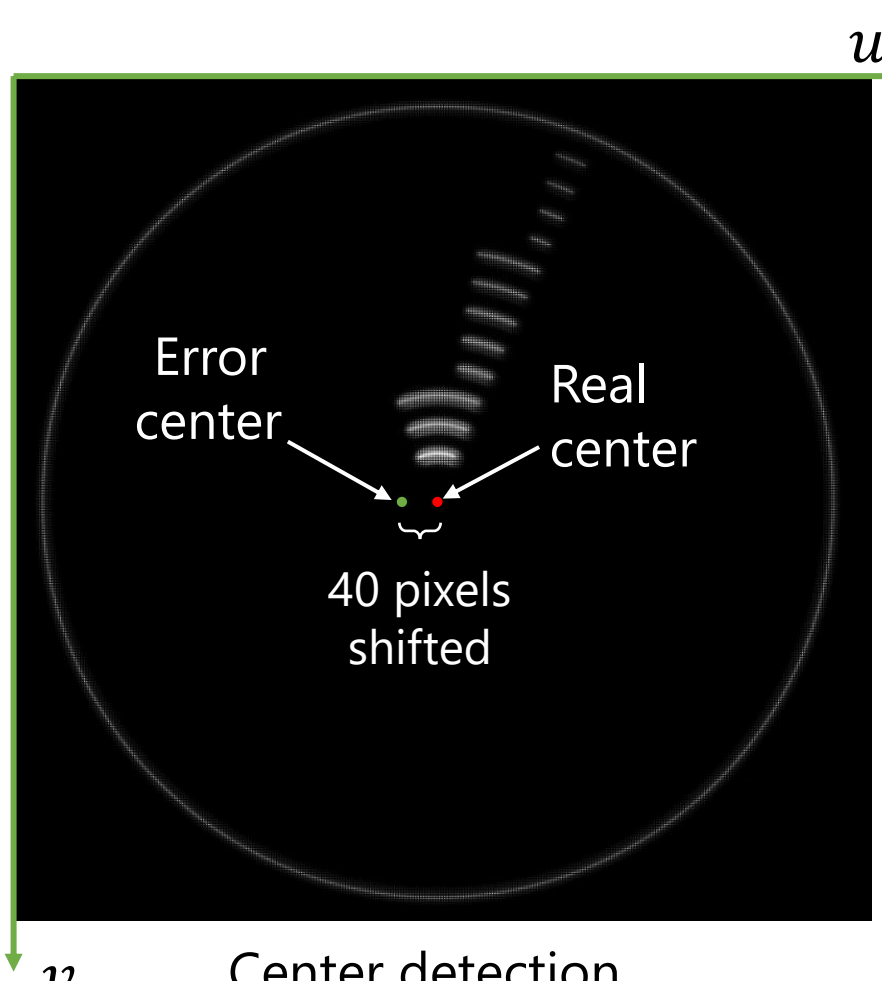


Captured image
in pixel coordinates

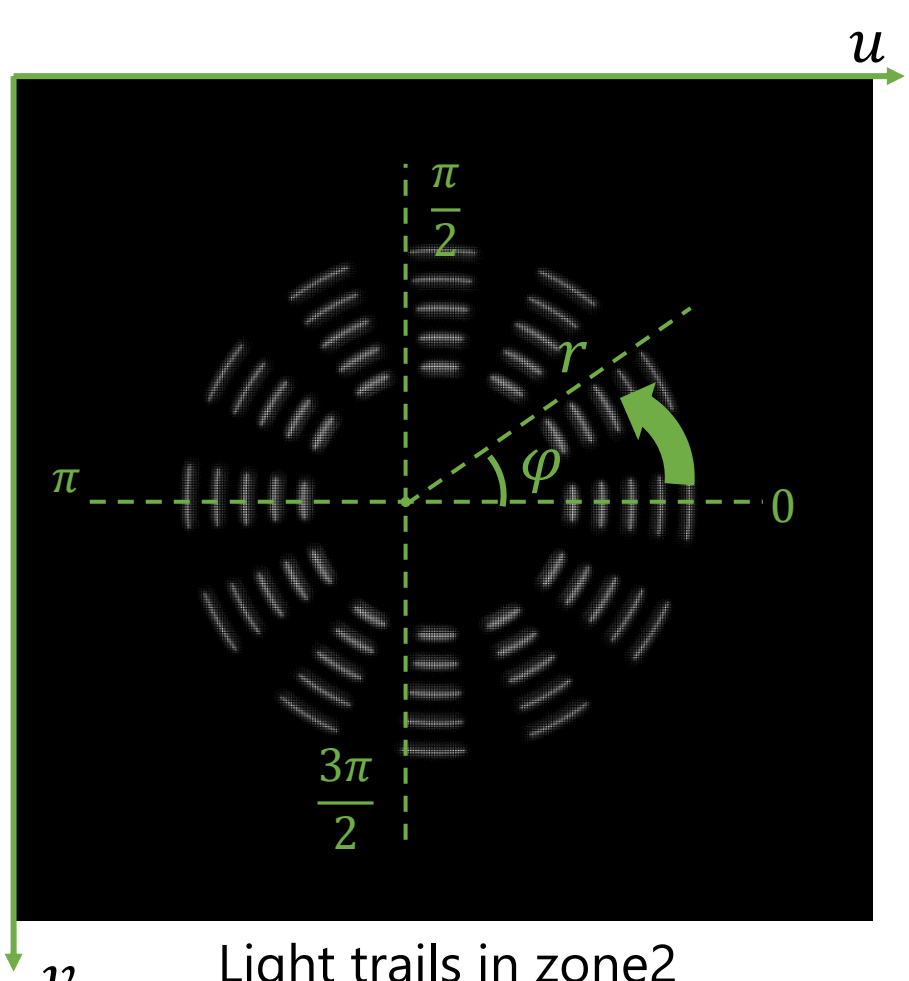
Detection image
in rotation coordinates

Why rotation coordinates?

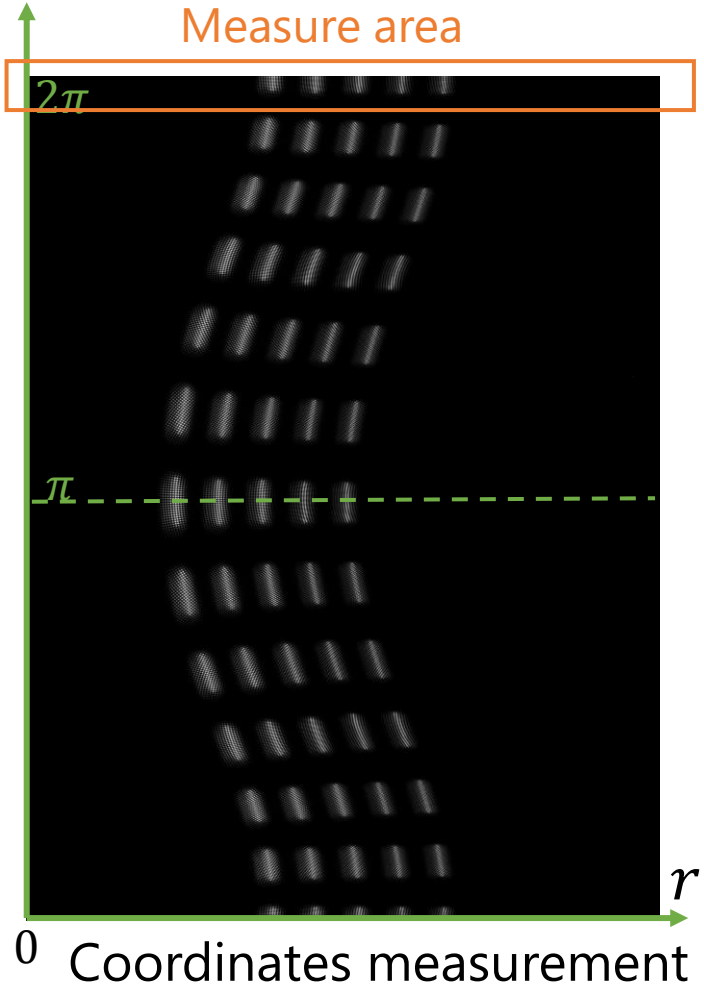
- For robust signal coordinates detection



Center detection



Light trails in zone2

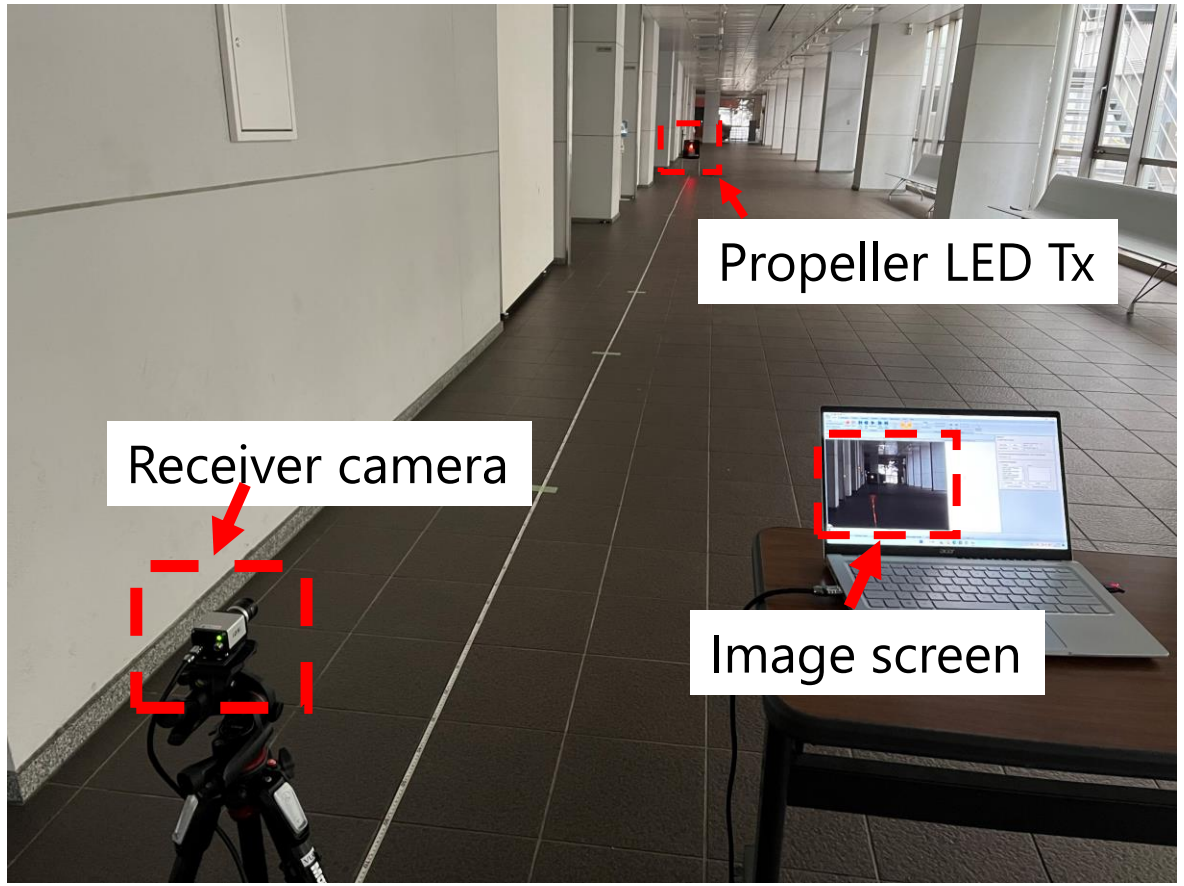


Coordinates measurement

Experiments

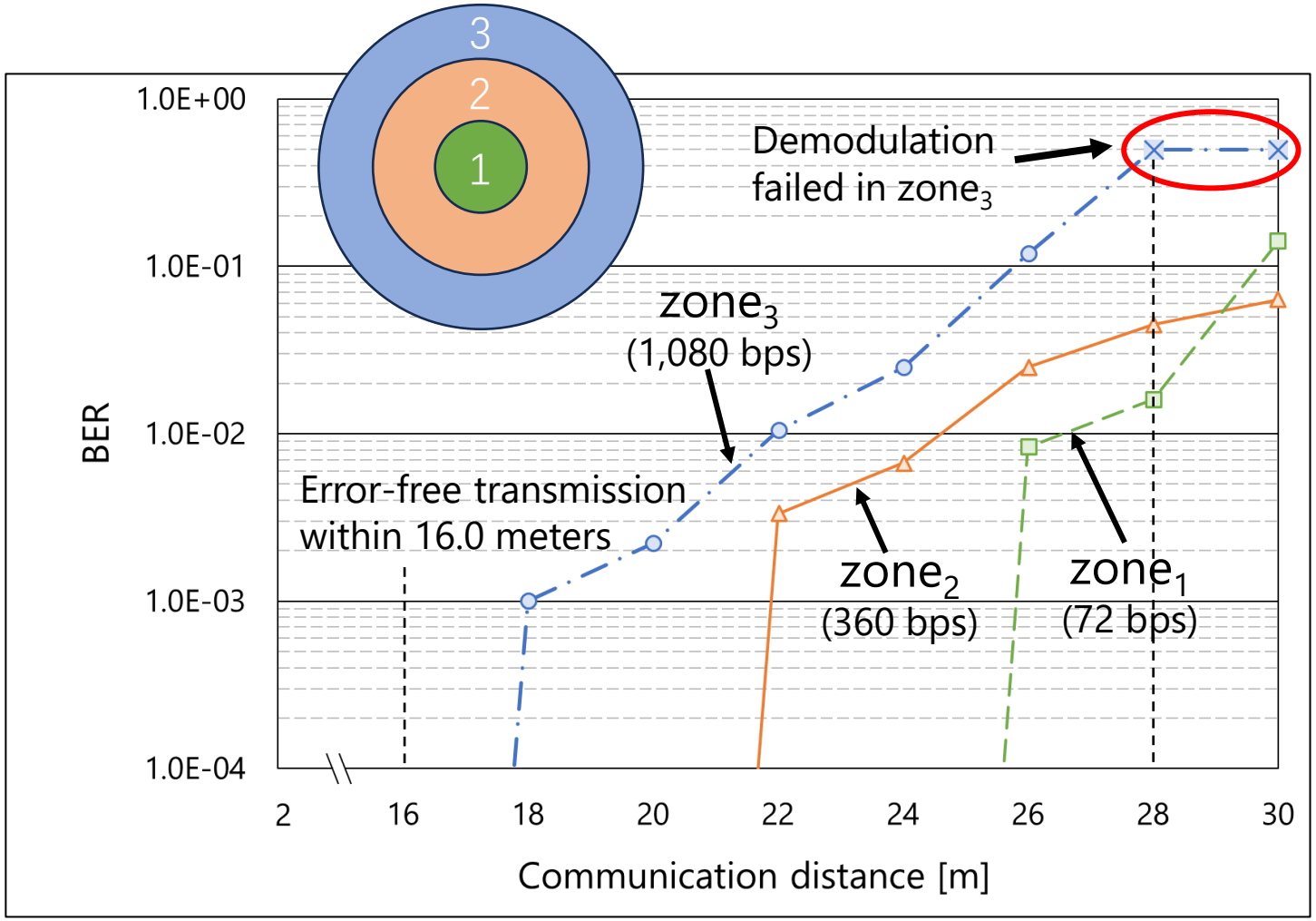
Experimental parameters

Experimental environment	Indoor
LED	WS2812b
Number of LEDs	14
Rotary speed	180 rpm
Switching angle for each zone	5°, 15°, 45°
Camera	IDS Peak family
Camera frame rate	3 fps
Exposure time	333,320 μs
Image sensor resolution	3,000 × 4,000
Focal length of Lens	35 mm
Aperture	F8
Filter	ND8
Communication distance	2.0 - 30.0 m

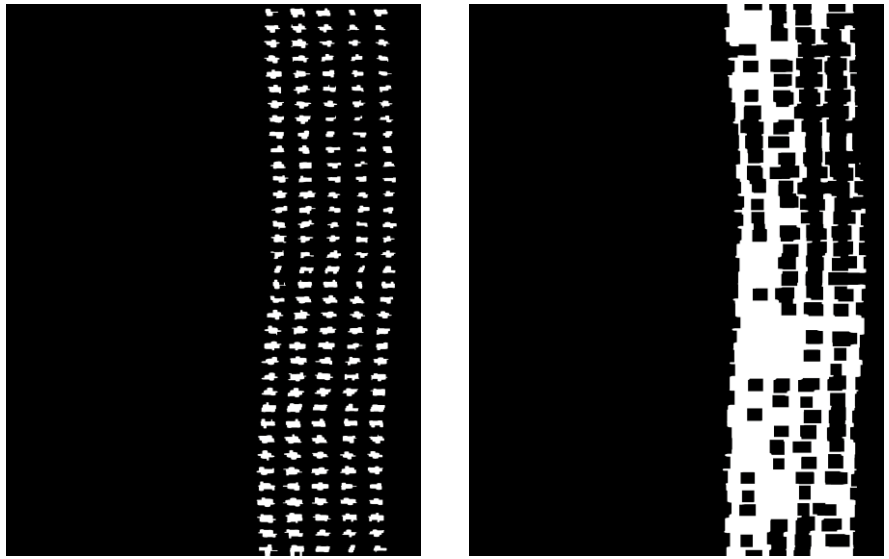


Experimental scene

Experiment result



Coordinates detection for $zone_3$



Captured at 20 m (Binarized)

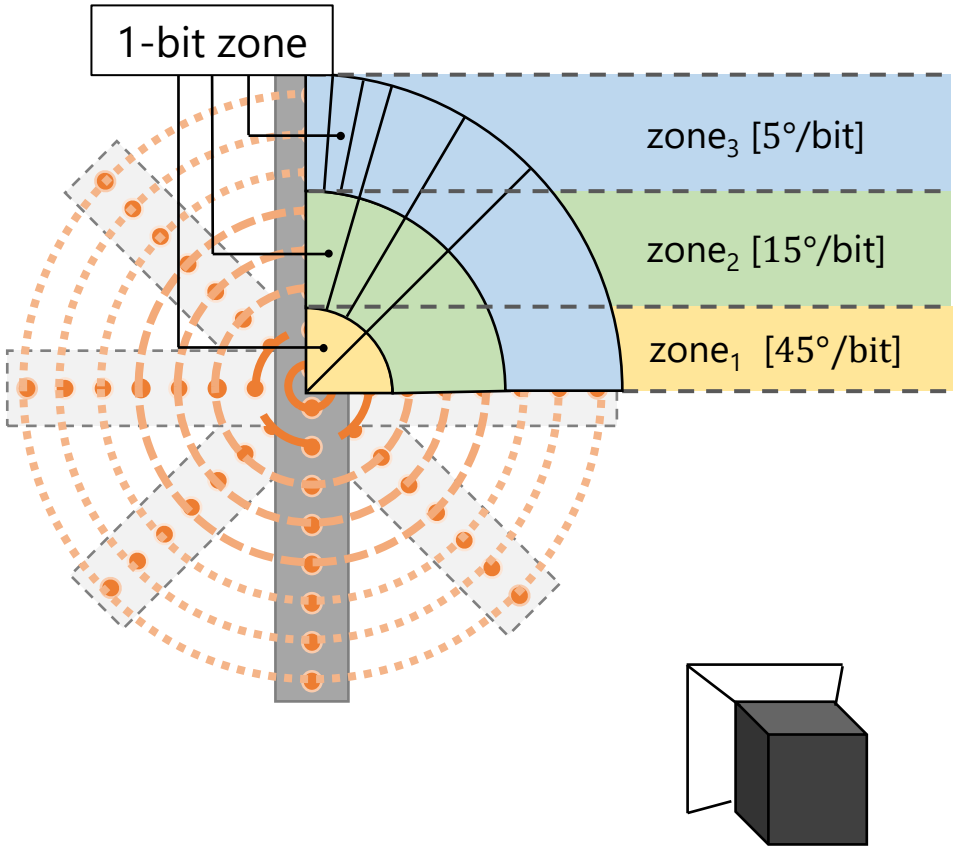
Captured at 28 m

- System error-free transmission at 16 m
  (in this experiment)
  - First error in $zone_1$ at 26 m
  - First error in $zone_2$ at 22 m
  - First error in $zone_3$ at 18 m

Performance

[2] **Z. Tang**, J. Zheng, T. Yamazato, and S. Arai, "Image Sensor Communication Via Light Trail Using Propeller LED Transmitter," in *IEEE Photonics Journal*, vol. 15, no. 5, pp. 1-12, Oct. 2023.

Experiment result



- Data rate in different zones

$$R_{\text{zone}} = N_L \frac{360°}{\theta_{\text{zone}}} \frac{S_r}{60}$$

N_L : # of LEDs
θ_{zone} [°]: rotation angle
S_r [rpm]: rotary speed

	zone$_3$	zone$_2$	zone$_1$	total
# of LEDs	5	5	3	**13**
Data rate [bps]	1,080	360	72	**1,512**
Error-free distance [m]	18	22	26	

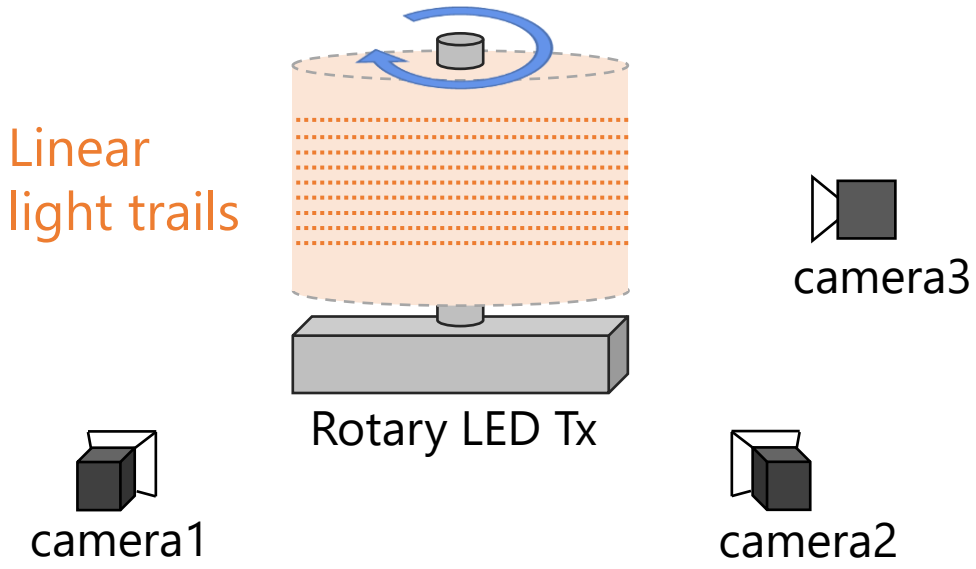
High flexibility of light-trail-based ISC

Outline

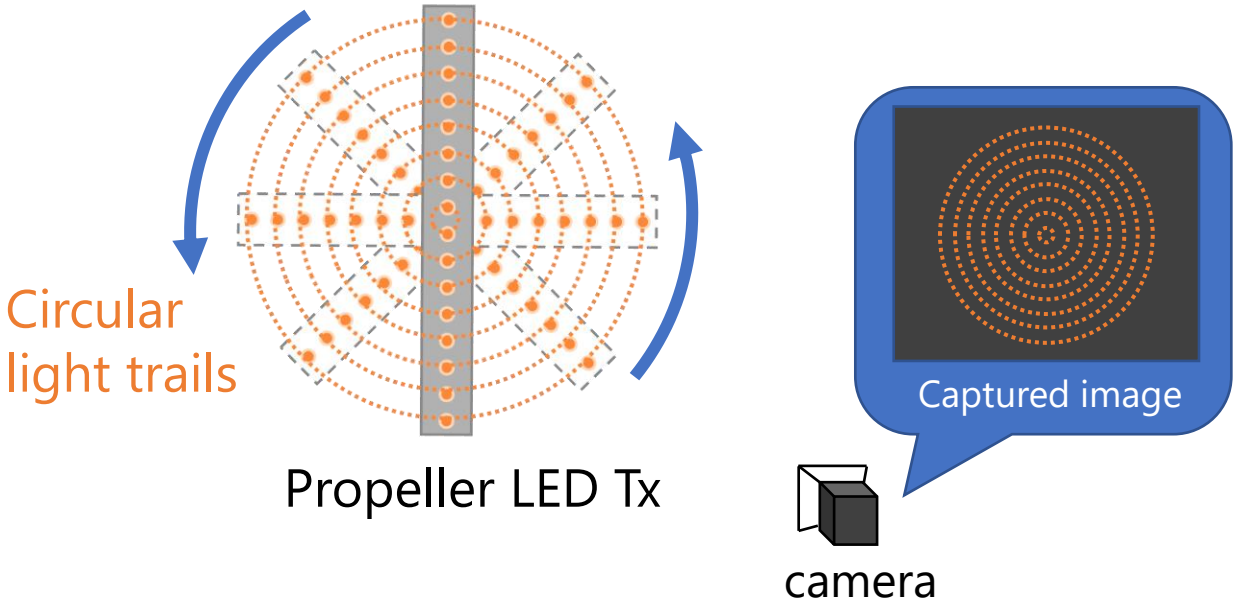
- Research Background
- Research Interests
  - Image sensor communication using linear light trails
  - Image sensor communication using circular light trails
- Conclusion

ISCs using light-trails

Achieving high-capacity transmission using light trails of a limited # of LEDs



- Increasing data transmission rate
- Omni-directional (horizontal) transmission



- Further increased data rate
- High practicality （drone, wind turbine etc.）