MICHIGAN STATE UNIVERSITY

RAINBOWROW FAST OCC

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RainbowRow: Fast Optical Camera Communication

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Outline

Background

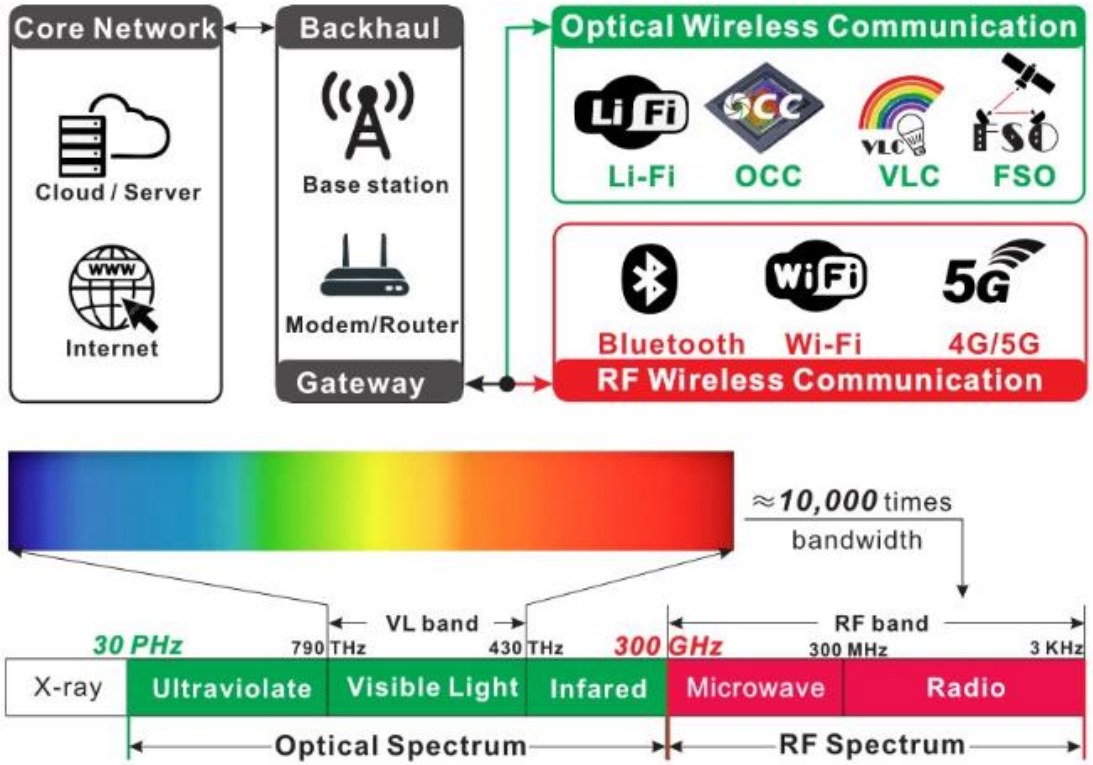
Concepts and Preliminaries

RainbowRow: High-speed OCC

Performance Evaluation

Conclusion

Background



Application scenarios of OCC system.

Optical wireless communication and RF based wireless communication.
Optical spectrum has broader bandwidth than RF spectrum.

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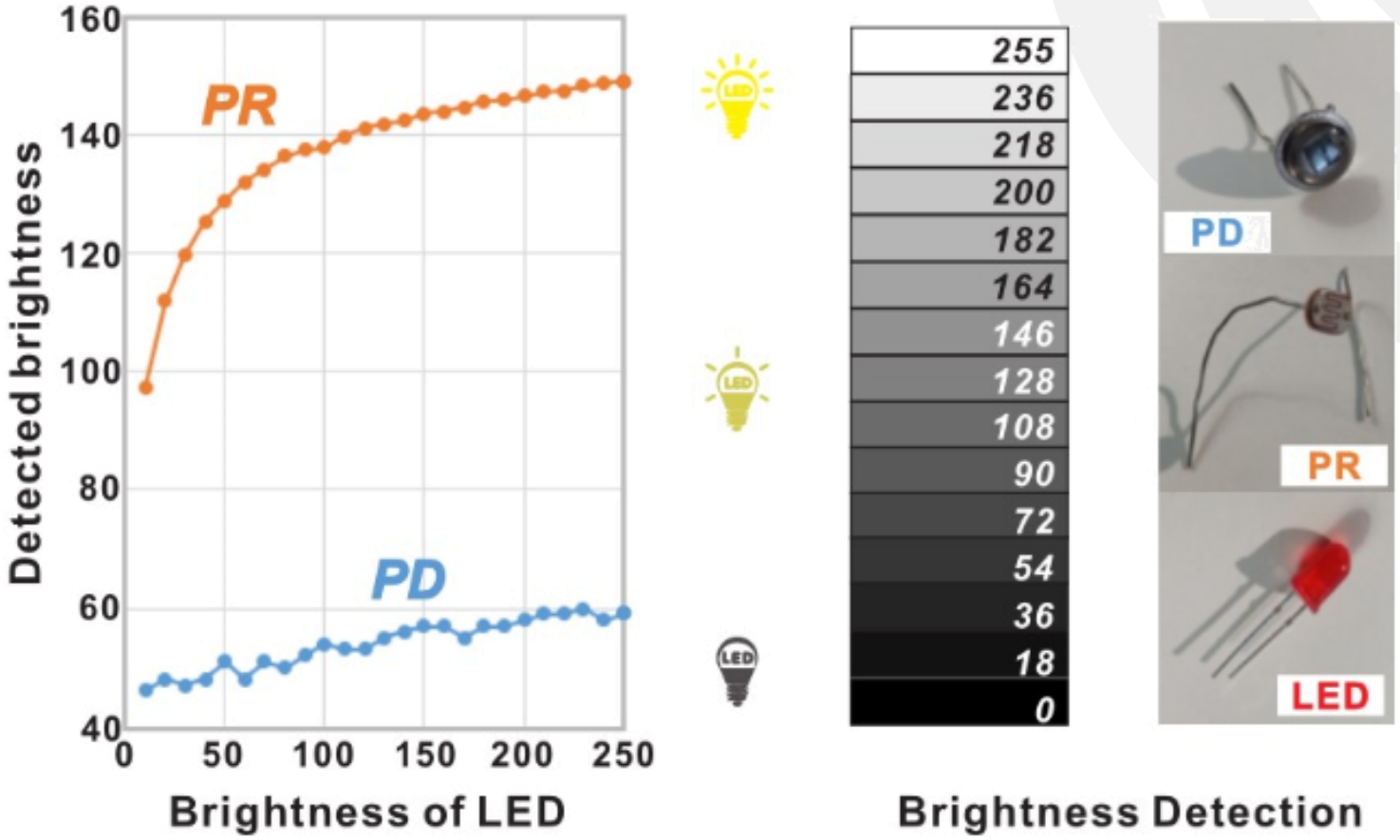
Concepts and Preliminaries

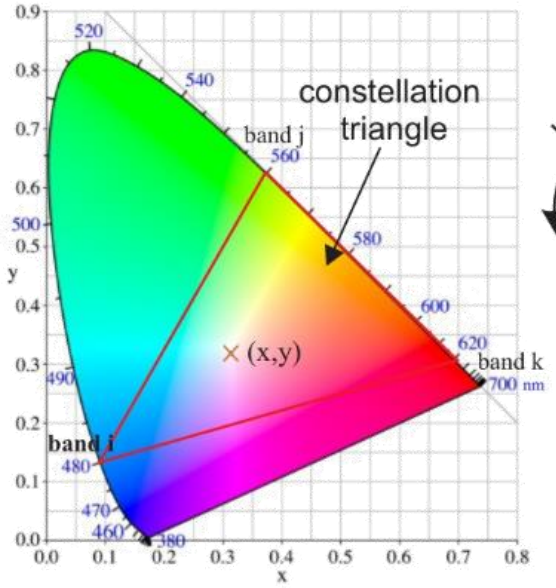
Amplitude diversity: brightness and grayscale



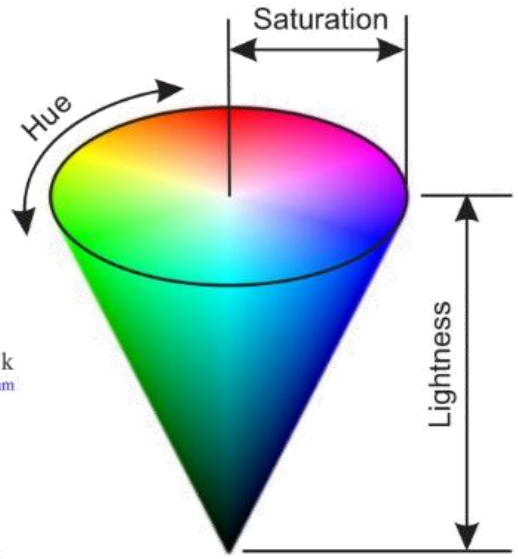
Amplitude diversity generated by different brightness of LED and measured by light sensors as grayscale. Two light sensors PD and PR perform differently.

Concepts and Preliminaries

Spectrum Diversity: Color Generation and Detection



RGB model (CIE 1931)



HSL model

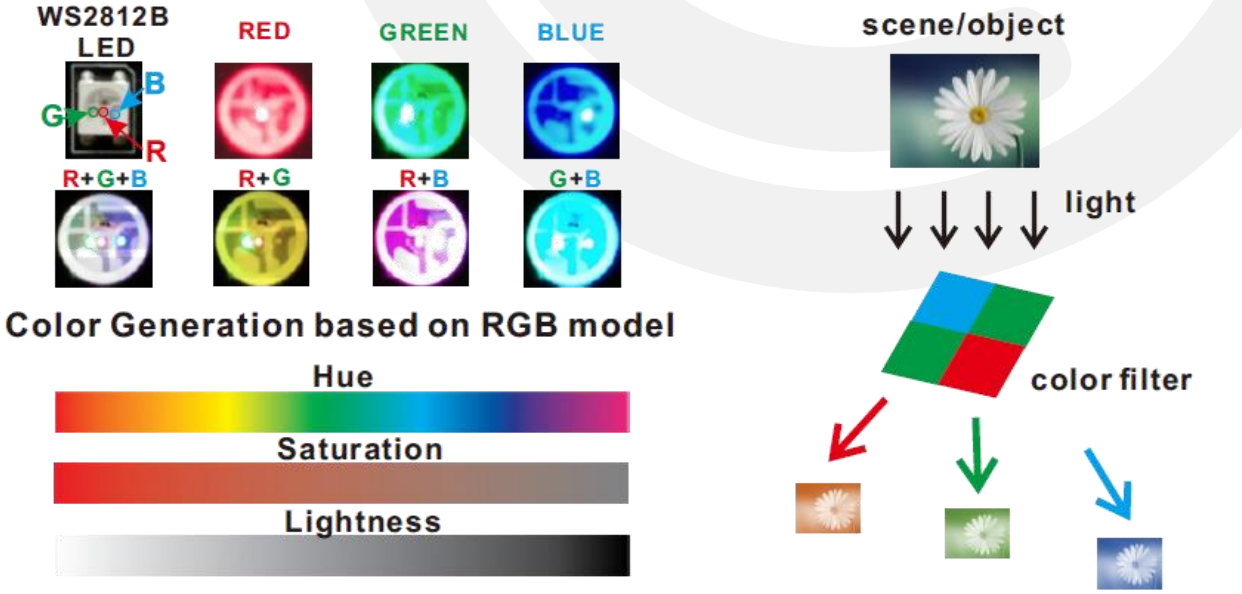
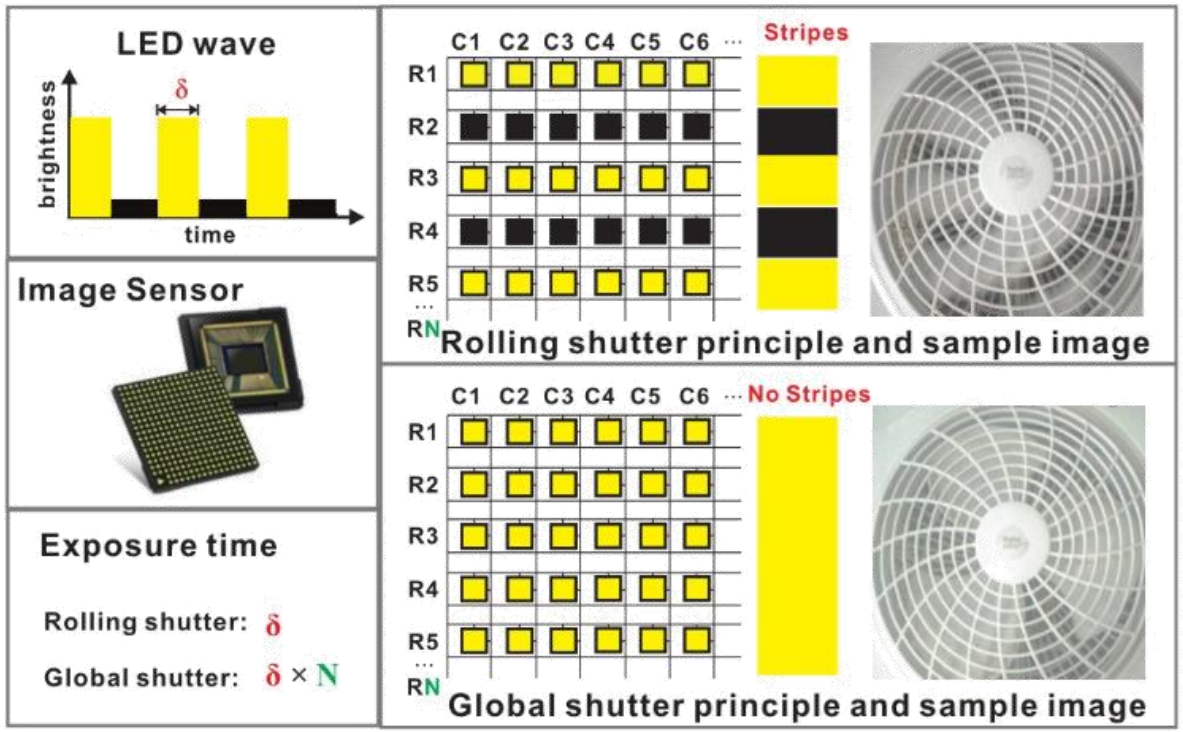
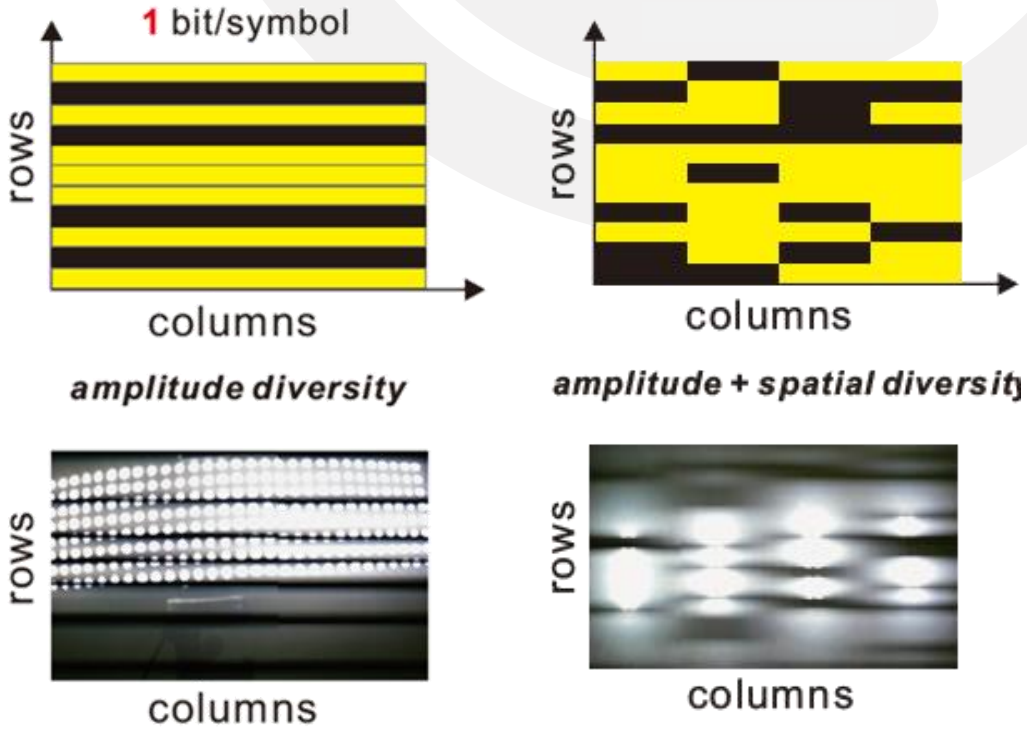


Illustration of color generation principle (RGB) in Tri-LED and detection principle (HSL) via color filter.

Concepts and Preliminaries

Spatial Diversity: New Insight





Rolling shutter stripe effect and contrast with global shutter in camera imaging.

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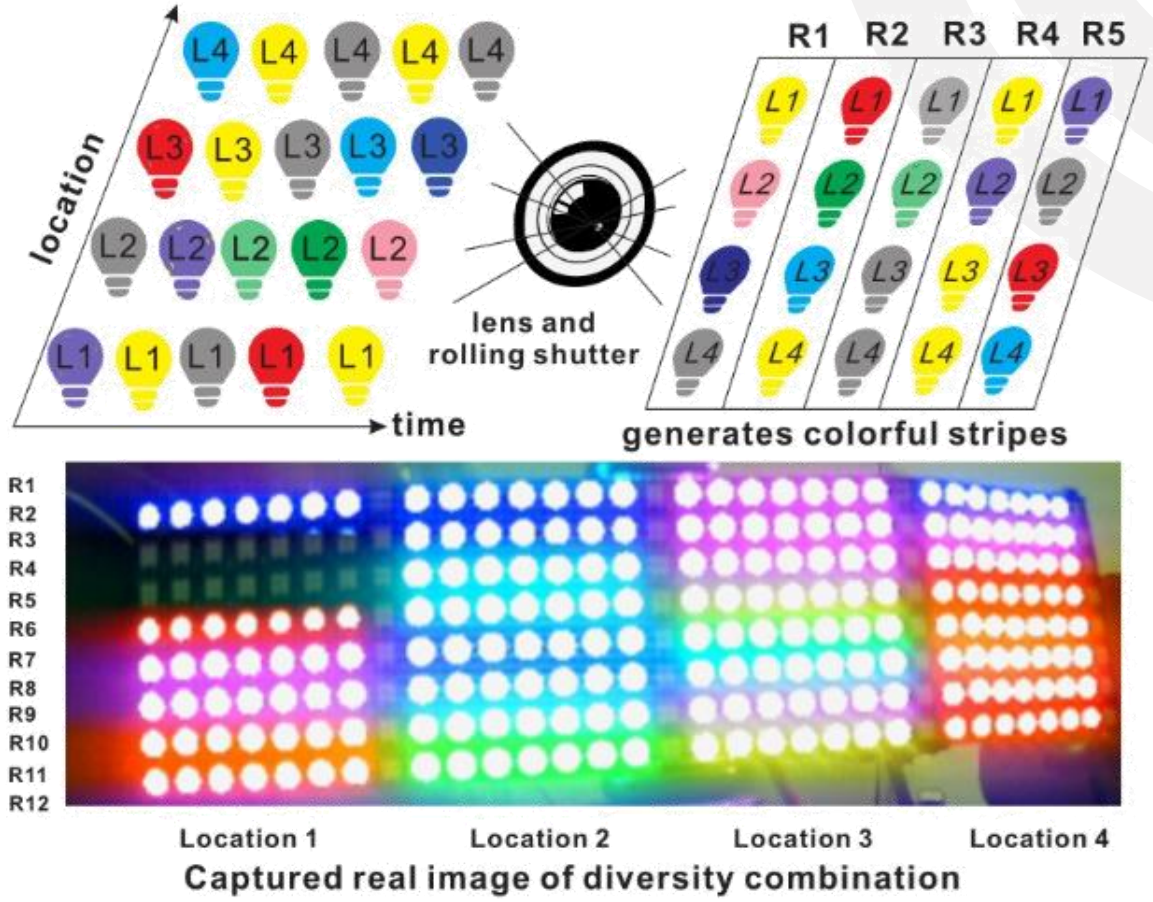
RainbowRow: High-speed OCC

Diversity Combination: Principle and Benefit

Let A denotes amplitude diversity,
S1 denotes spectrum diversity,
S2 denotes spatial diversity in each row.

$$B = S_2 \times \log_2 (A \times S_1)$$



Diversity combination illustration: the light from different LED elements is projected on the different pixels on the camera's image sensor via lens.

RainbowRow: High-speed OCC

Modulation Protocol Design

Let A denotes amplitude diversity,
S1 denotes spectrum diversity,
S2 denotes spatial diversity in each row.

$$B = S_2 \times \log_2 (A \times S_1)$$

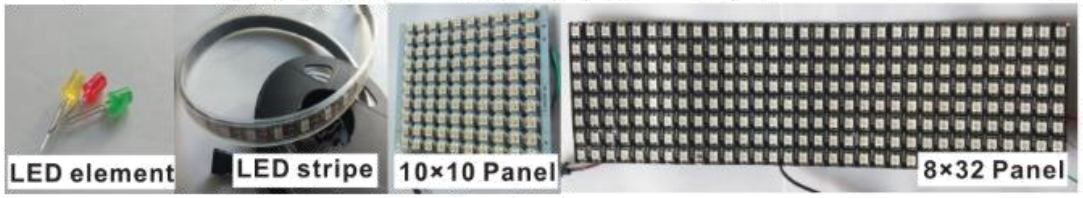
TABLE I: Symbol coding table for RainbowRow

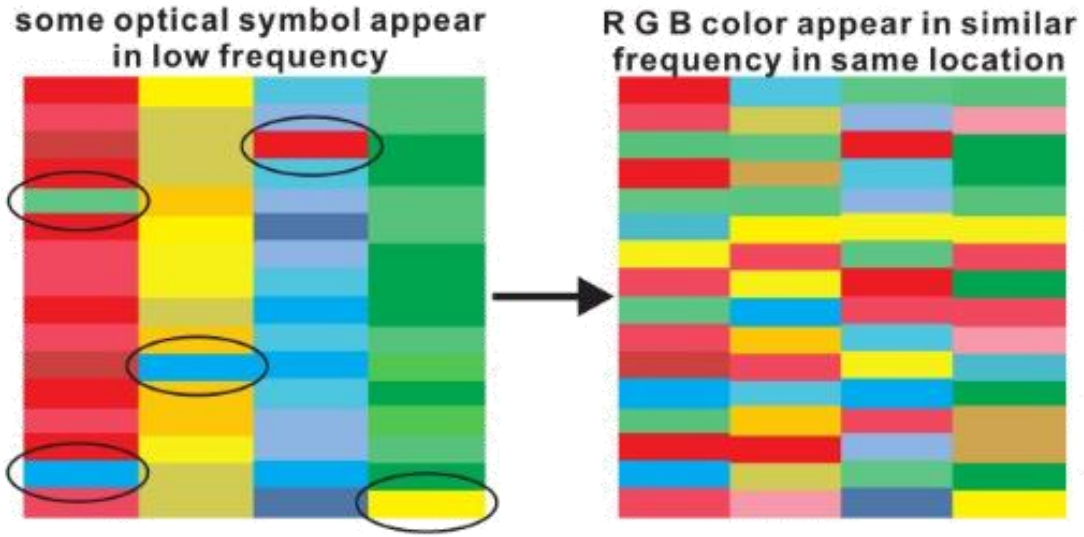
Color	Brightness	Location			
		L1	L2	L3	L4
RED	1	0000	0000	0000	0000
	2	0001	0001	0001	0001
	3	0010	0010	0010	0010
	4	0011	0011	0011	0011
GREEN	1	0100	0100	0100	0100
	2	0101	0101	0101	0101
	3	0110	0110	0110	0110
	4	0111	0111	0111	0111
BLUE	1	1000	1000	1000	1000
	2	1001	1001	1001	1001
	3	1010	1010	1010	1010
	4	1011	1011	1011	1011
YELLOW	1	1100	1100	1100	1100
	2	1101	1101	1101	1101
	3	1110	1110	1110	1110
	4	1111	1111	1111	1111

RainbowRow: High-speed OCC

System Implementation

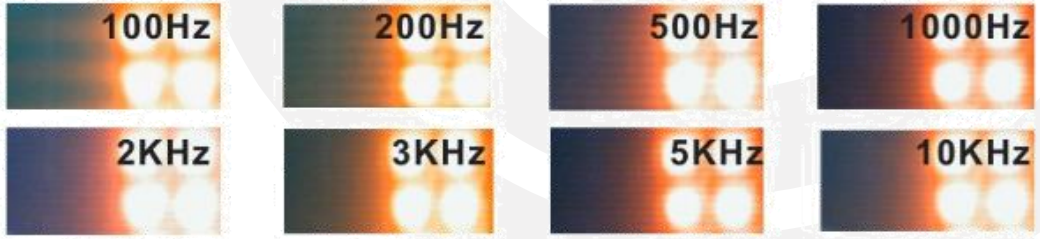
1) A low-cost LED-based Transmitter Design





Optical symbols with low appearance frequency cause flickers. We mitigate flickering by coding data with colors in the same possibilities.

2) Real-time Camera-based Receiver Design



Stripes generated in different frequency

Algorithm 1: RainbowRow Demodulation Algorithm

Input: O; // Optical RainbowRow Symbols
Output: D; // Decoded data bits
1 Initial Hue and Lightness thresholds H1-H3 and B1-B3 based on the measurement of Preambles;
2 Initial ROI size and location based on captured stripes;
3 $\lambda \leftarrow 0$; // Allowed H or B variation of same symbol
4 **while** $\triangle H$ *or* $\triangle B < \lambda$ **do**
5 Detect H and B of O; *// Four ROI in one Row*
6 **if** $\triangle H$ *or* $\triangle B > \lambda$ **then**
7 Go to line 1;
8 Demodulate O into D based on Table I;

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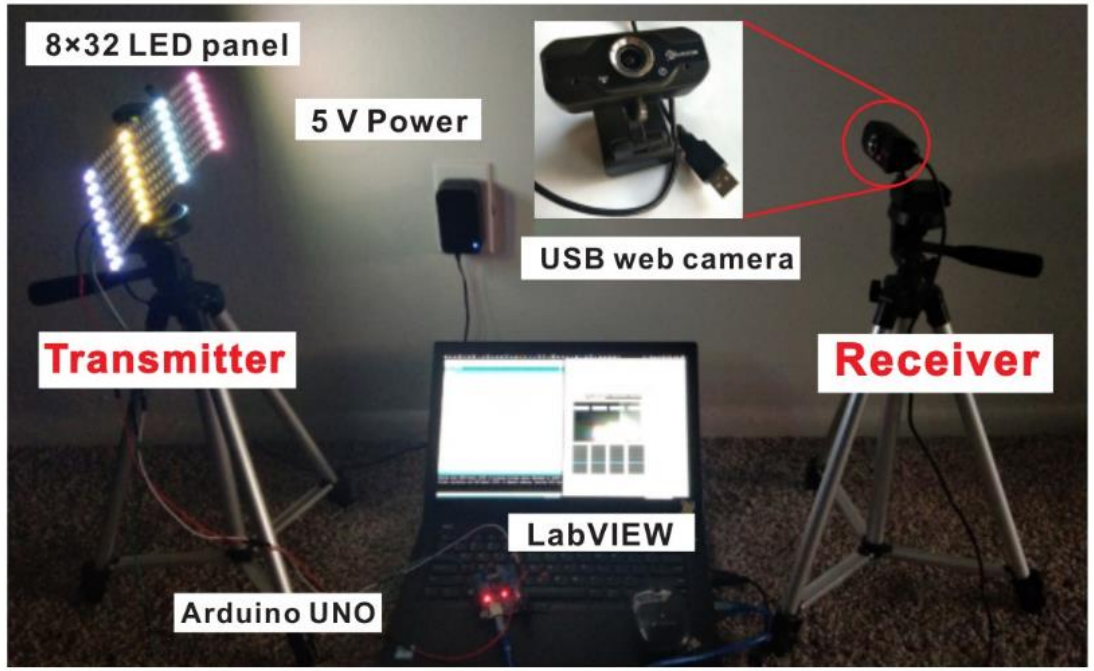
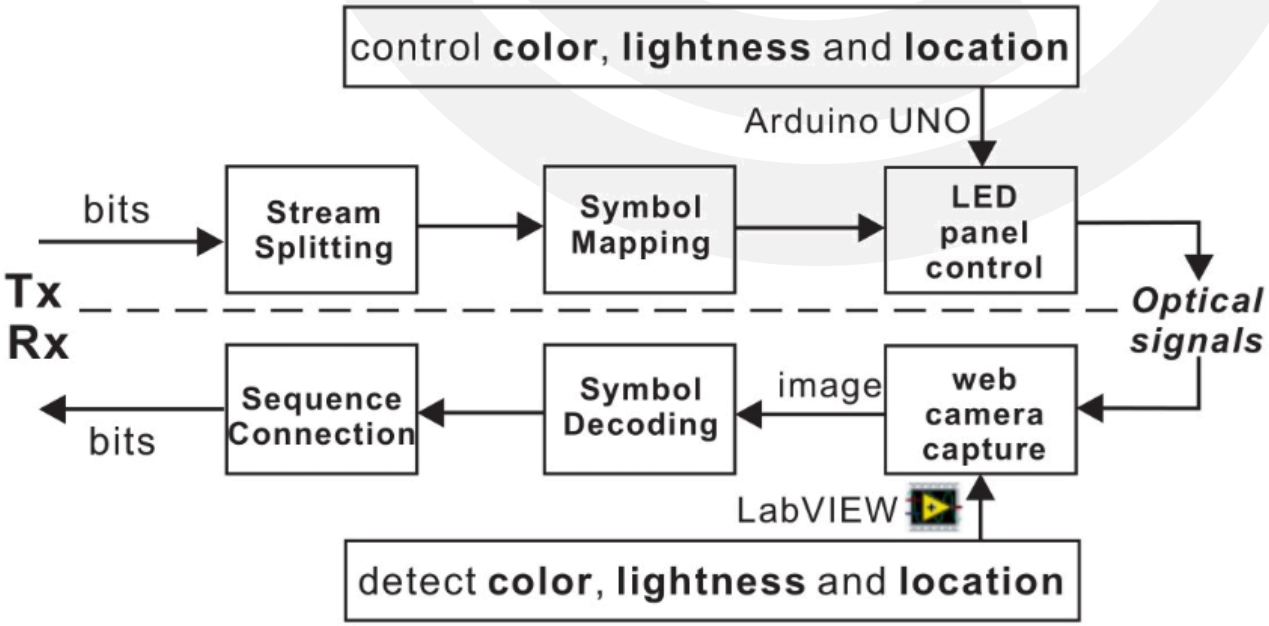
RainbowRow Testbed



The transmitter is a Tri-LED panel combined with Arduino UNO. The receiver is a regular web camera controlled by the LabVIEW program on PC.

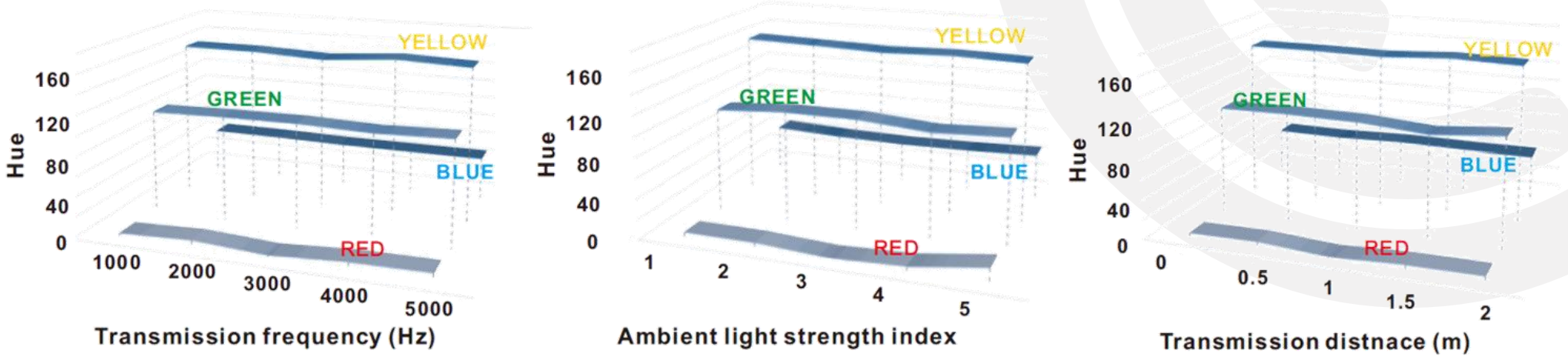


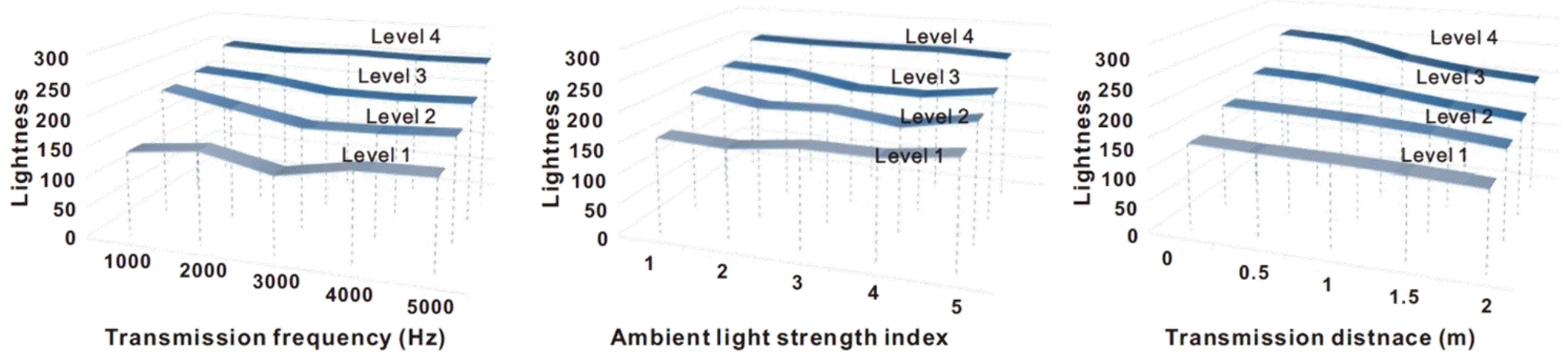
RainbowRow System Block Diagram

Performance evaluation

Diversity Reliability of Hue & Lightness

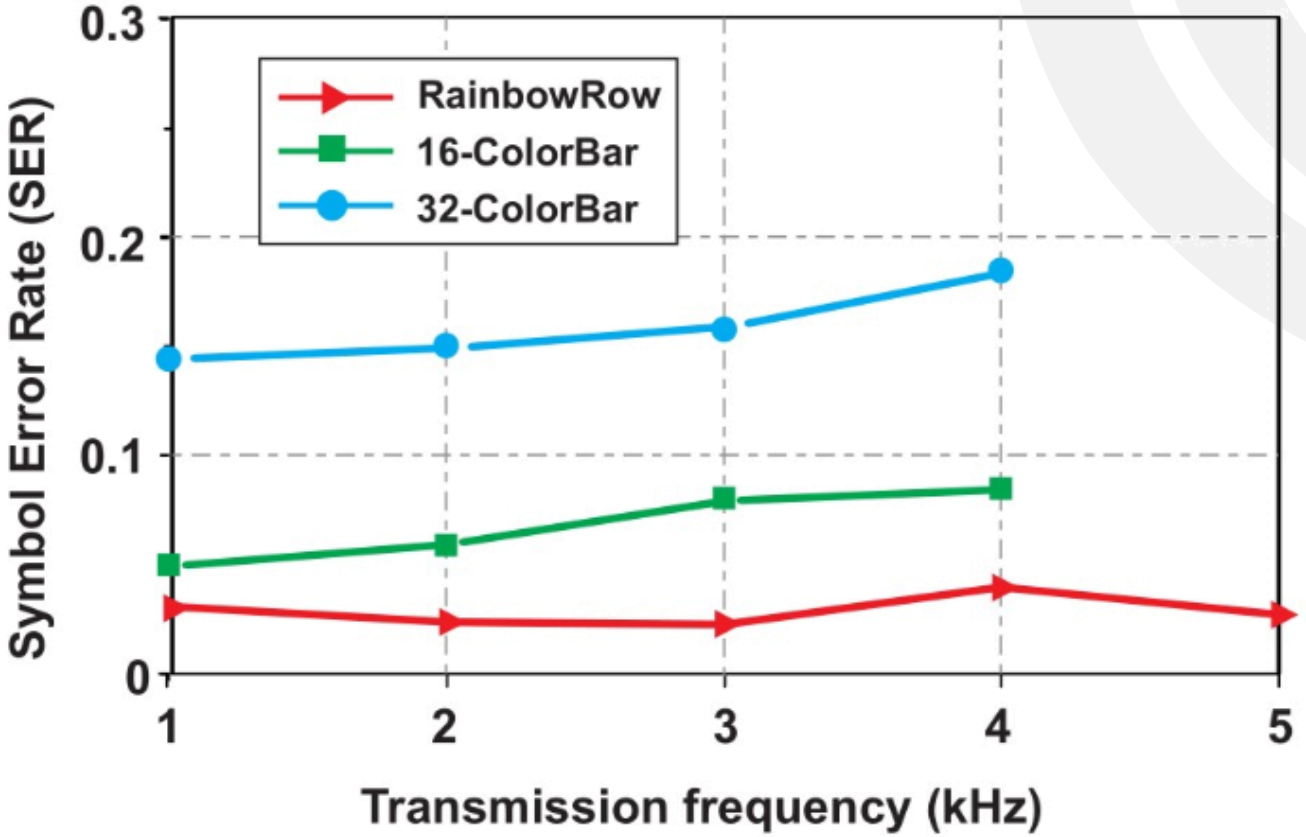
- *Hue & Brightness vs. transmission frequency*
- *Hue & Brightness vs. ambient light strength*
- *Hue & Brightness vs. transmission distance*





Performance evaluation

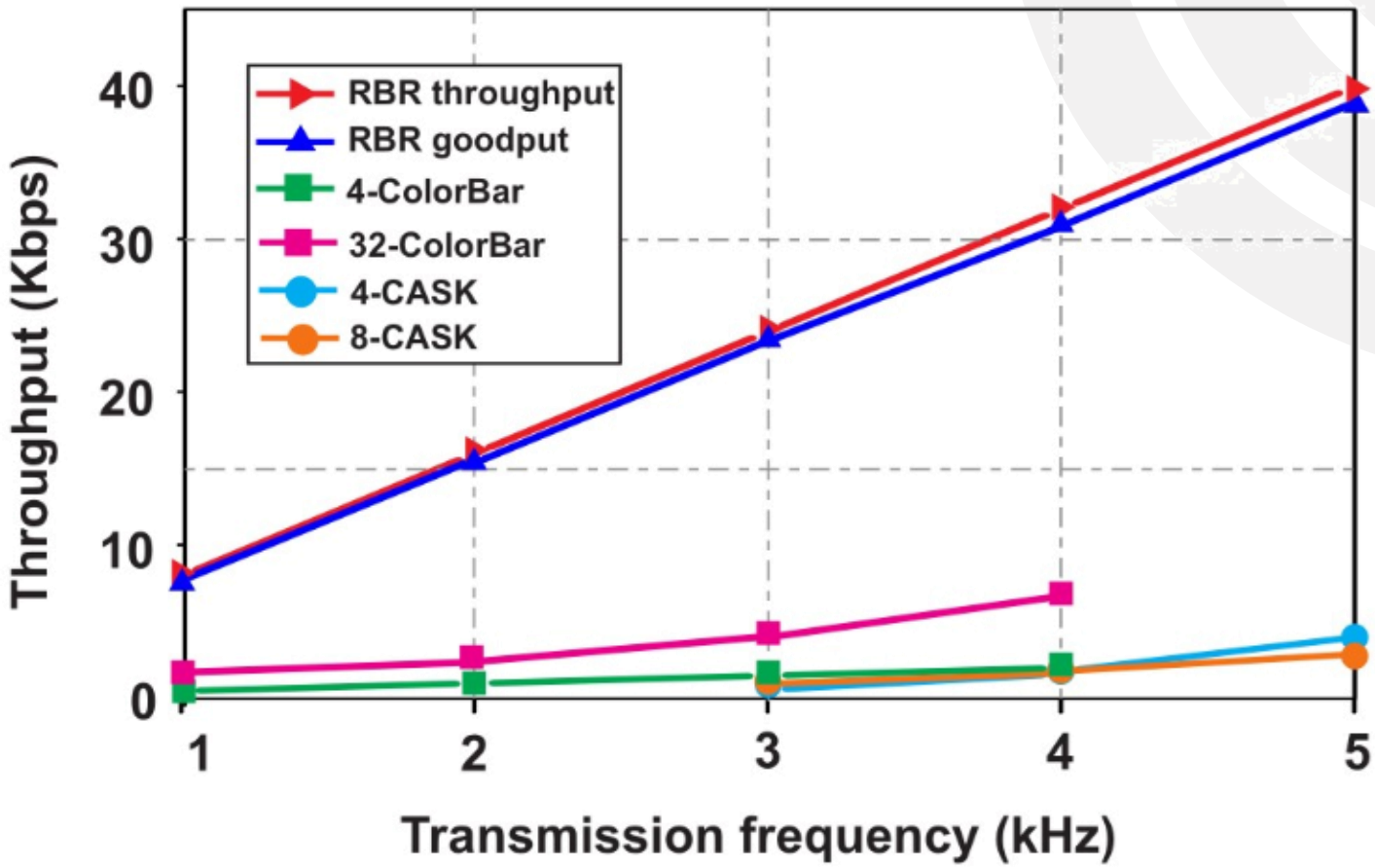
SER Reduction



RainbowRow's SER significant reduction compared with state-of-art high-order modulation ColorBar.

Performance evaluation

Throughput Improvement



RaibowRow's throughput improvement compared with state-of-art high-order modulation methods: ColorBar and CASK.

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- **Exploring spatial diversity in camera imaging for improving OCC**
- **Combine spatial diversity with amplitude & spectrum diversity for modulation**
- **Develop robust and practical OCC system RainbowRow and confirm its efficacy**
  - achieve the SER less than 0.05
  - achieve the throughput up to 40Kbps at 1 m
  - significantly improvement than state-of-art

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Q & A

THANK YOU

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