woven by TOYOTA

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Real-world Event Camera Applications Towards Visible-Light Communication

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Company History

TRI-AD

Established in March 2018

woven planet

woven core

woven alpha

woven by TOYOTA

Since April 2023

Focus Area

Arene

- Software Development Platform
- New customer value through software

Woven City

- Test course for mobility
- Build the future fabric of life with various partners

AD/ADAS

- Safe and reliable AD/ADAS systems
- Human-centered mobility

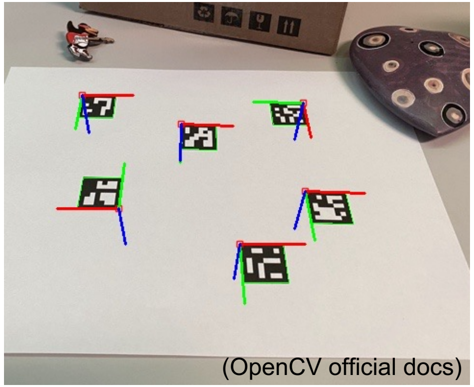
Woven Capital

- A growth-stage venture fund
- Investing in the future of Mobility and driving innovation

Local Communication In Daily Lives

Payment

Robot Localization



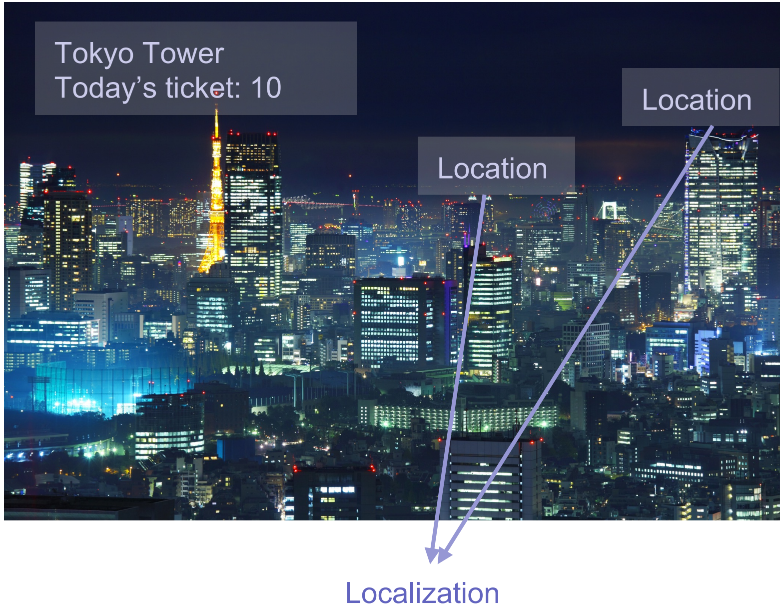
Advertisement

Important communication methods despite the widespread Internet

What is Visible Light Communication (VLC)?

VLC is a wireless communication based on modulations of visible lights (e.g., LED) at high frequency.

There are several protocols for data, such as using the blink and the intervals to encode data (i.e., binary).



Lights in Our Daily Lives and Their Potentials

Street light
Comm. from infra to car
Information for AR

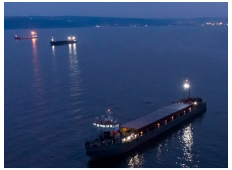
Traffic light
Detection
Sending signs (colors)
Surrounding info

Exit sign
Localisation (AR marker)

Factory alerts
Operation monitoring

Car
V-to-V comm.

Ship
P2P comm. under no Internet signals



Wireless communication and localization using our daily lights, without affecting radio-frequency bandwidth

Challenges in the VLC receivers

	Temporal resolution	Spatial resolution
	Data bandwidth	Signal contamination and localisation
Photodiodes	High (GHz)	Low
Frame cameras	Low (~60 Hz)	High (~1000 Mpix)
Event cameras	High (~MHz)	High (~100 Mpix)

We investigate communication and localization performance with event camera and VLC.

Our work at Woven by Toyota

1. Propose a dataset on mobile devices

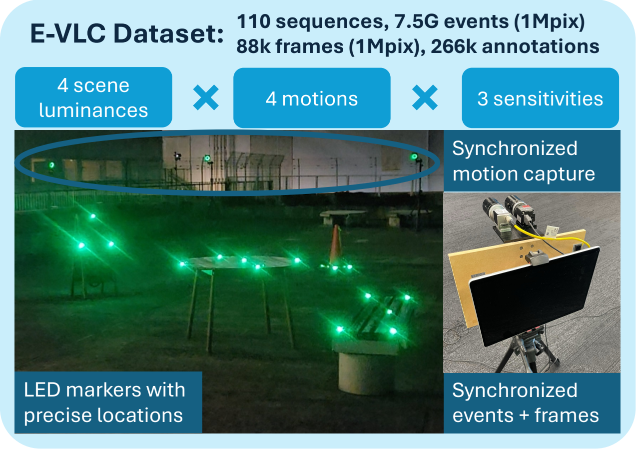
2. Propose an encoding on cars

3. Validation in outdoor environment with illumination

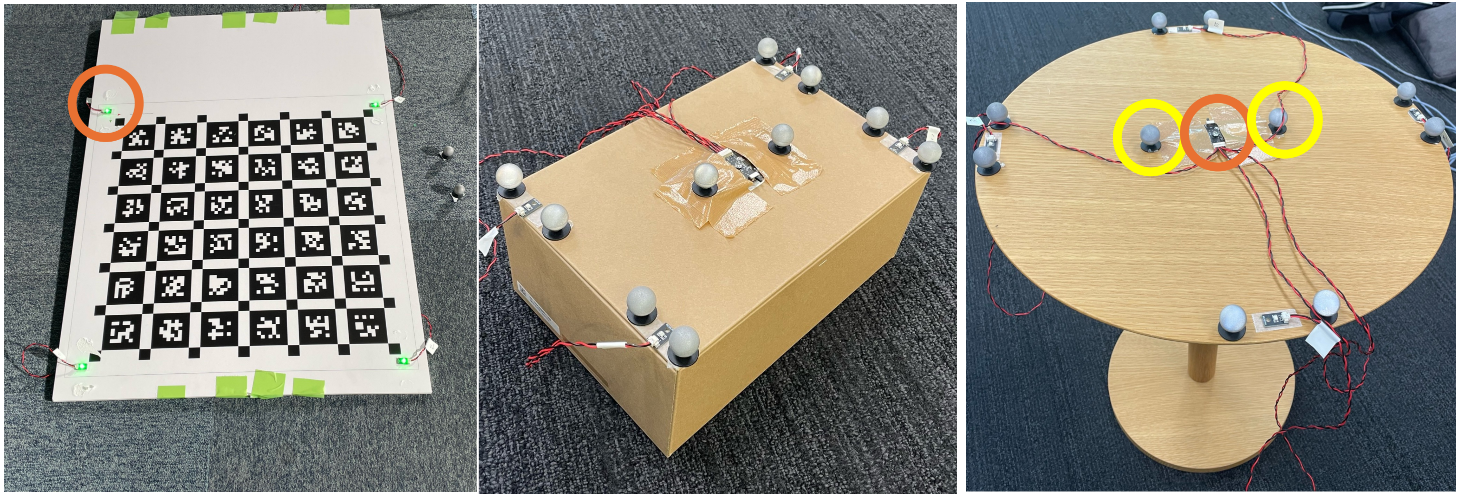
E-VLC Dataset

Problem There is no public dataset focusing on event-based VLC that is necessary for benchmark and improve algorithms.

This work We release E-VLC, consisting of synchronized frames, events, and motion capture, on various recording scenes.

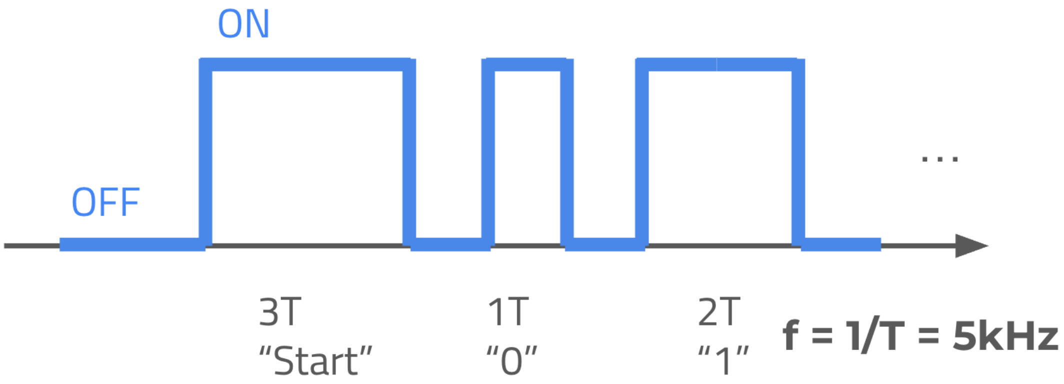


E-VLC Dataset | Transmitter



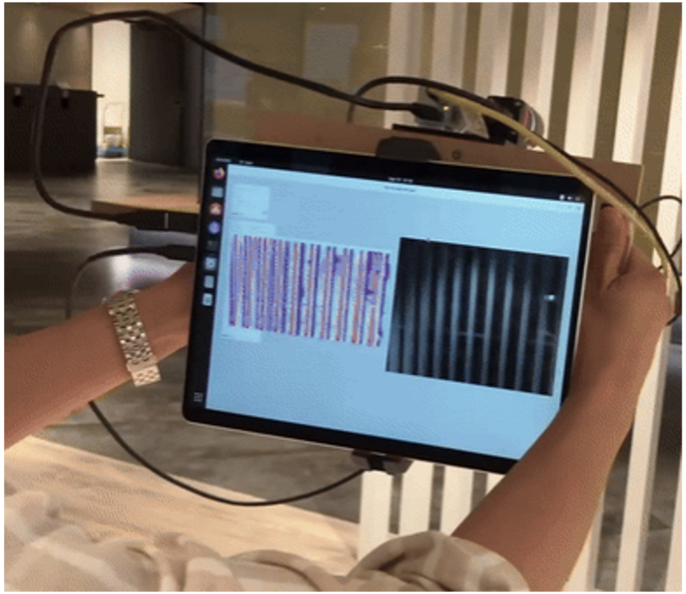
LEDs flicker at 5kHz and send different IDs from objects.

E-VLC Dataset | Protocol



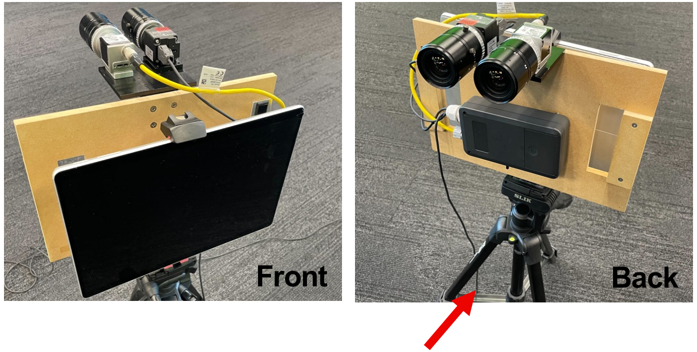
The encoding is based on the pattern (i.e., intervals) of the blink.

E-VLC Dataset | Receiver

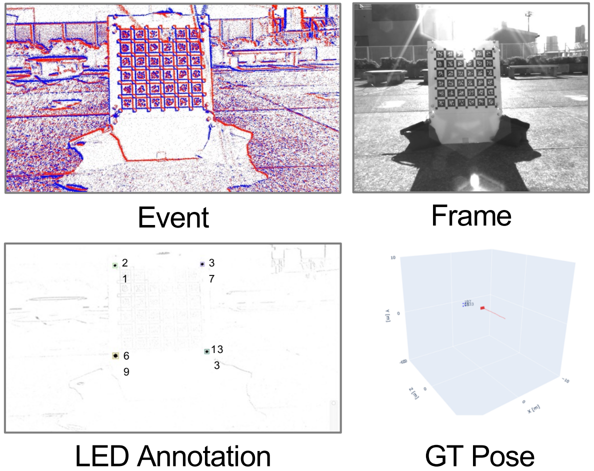


We build a custom receiver with a tablet, an event camera, a frame camera, and an external trigger box.

E-VLC Dataset | Receiver and Synchronization



Sync to motion capture



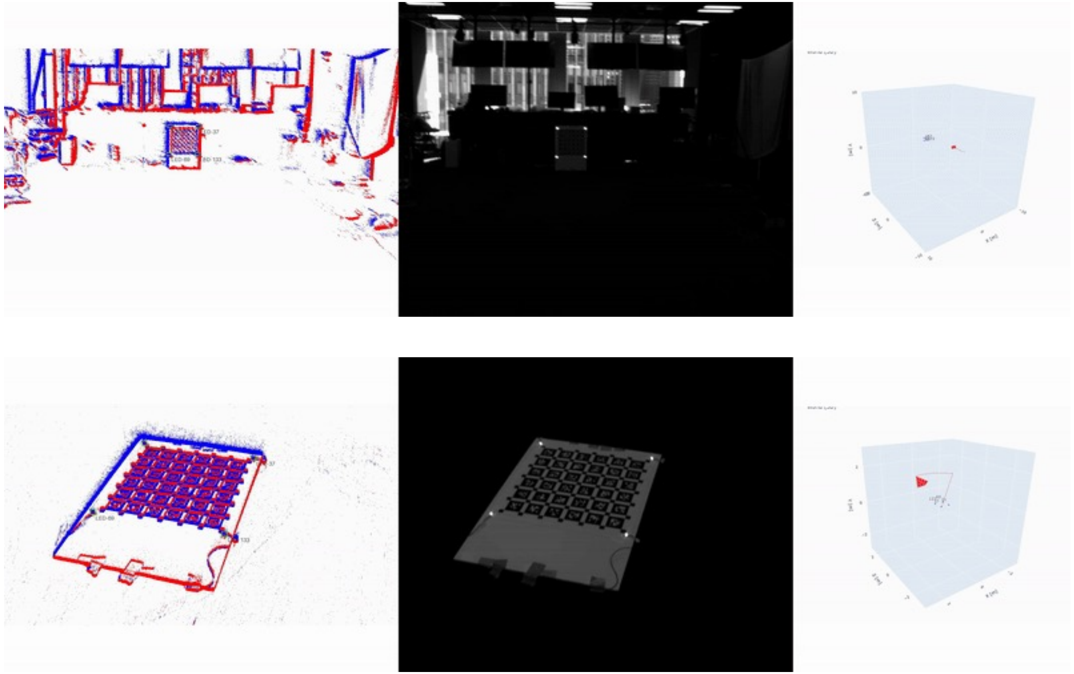
Example data

The external trigger box outputs the sync singals to an external motion capture (OptiTrack) . We also annotate LED IDs.

E-VLC Dataset | Recording Scenes

Data recording on different

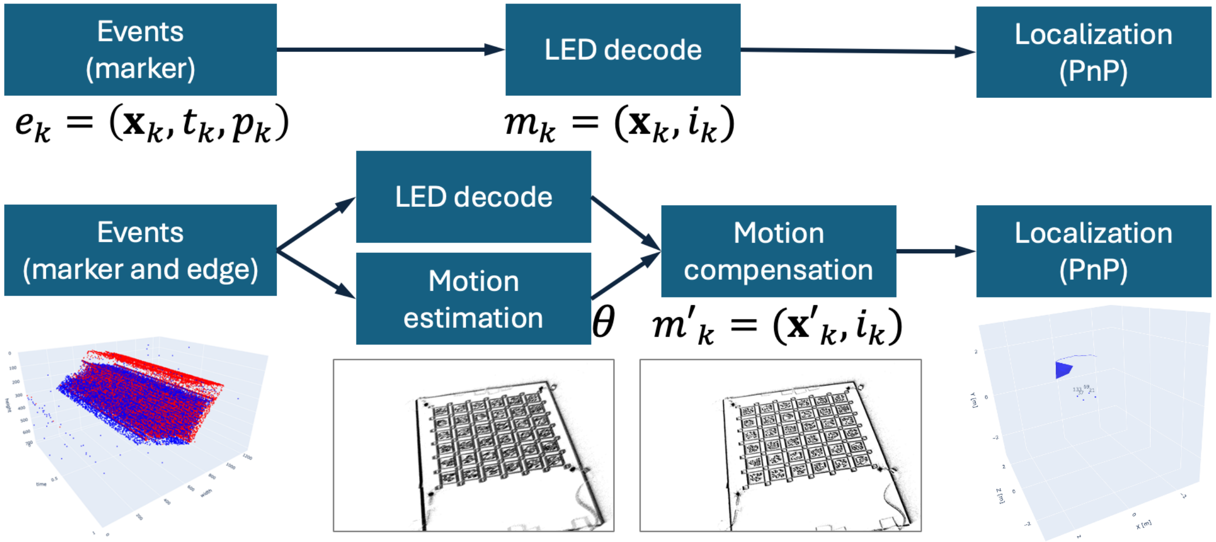
- Motion pattern
- Scene brightness
- Camera sensitivity



E-VLC Dataset | Details

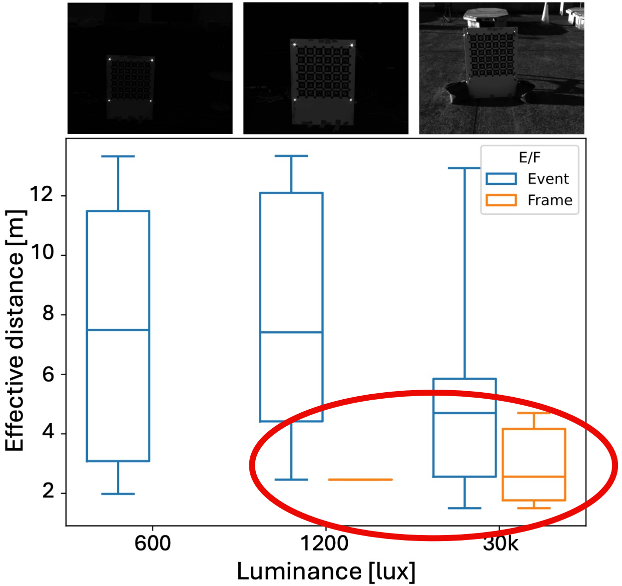
Motion	Luminance [lx]	Sensitivity	Sequences	Duration [s]	Events	Frames	Annotations
Static	600, 1200, 30k	Low	27	128.5	22M	2976	8928
		Medium	23	71.7	82M	960	2880
		High	23	107.8	225M	2148	6444
Translation	600, 1200	Low	6	378.4	41M	13629	40861
		Medium	4	242.7	1129M	8005	23997
		High	2	90.2	767M	3097	9284
Rotation	600, 1200	Low	4	168.9	25M	6376	19128
		Medium	4	208.7	1135M	6991	20973
		High	4	252.0	2031M	9092	27276
Dynamic	10, 600, 1200	Low	5	356.1	62M	13400	40171
		Medium	5	386.0	983M	13954	41841
		High	3	221.0	978M	8139	24404
Total	10, 600, 1200, 30k	L, M, H	110	2612.0	7.5G	88.7k	266.2k

E-VLC Dataset | Motion Compensation



Contrast Maximization and motion compensation improve the decoding and localization accuracies.

E-VLC Dataset | Localization Accuracy



Event cameras can detect markers at larger distances (> 10m) than frames, regardless of the scene brightness.

	Detected frames ↑	Mean [m] ↓	Median [m] ↓
Event (H)	**4185**	0.184	0.181
Frame	1038	**0.171**	**0.178**
Event (M)	**3236**	0.196	0.191
Frame	755	**0.172**	**0.177**
Event (L)	**2871**	0.204	0.197
Frame	374	**0.171**	**0.173**

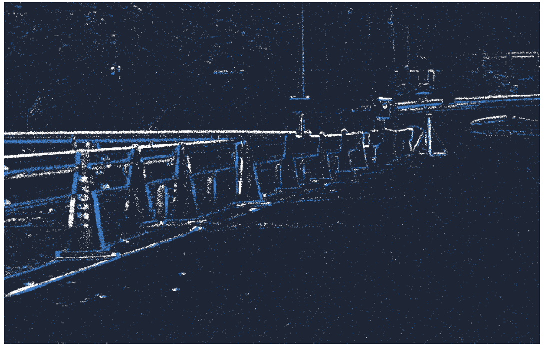
Within 4m, event cameras offer better detection rate (by 4x) and worse localization accuracy (by ~2cm).

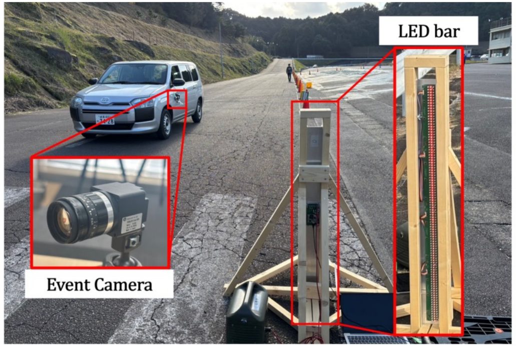
※Collaboration with Nagoya University and Toyota Motor Corporation.

Protocol with Walsh–Hadamard encoding

Problem What is a robust protocol when the camera (receiver) moves quickly, such as on vehicles?

This work We propose a new protocol using Walsh–Hadamard encoding for a camera mounted on a car (~50km/h).

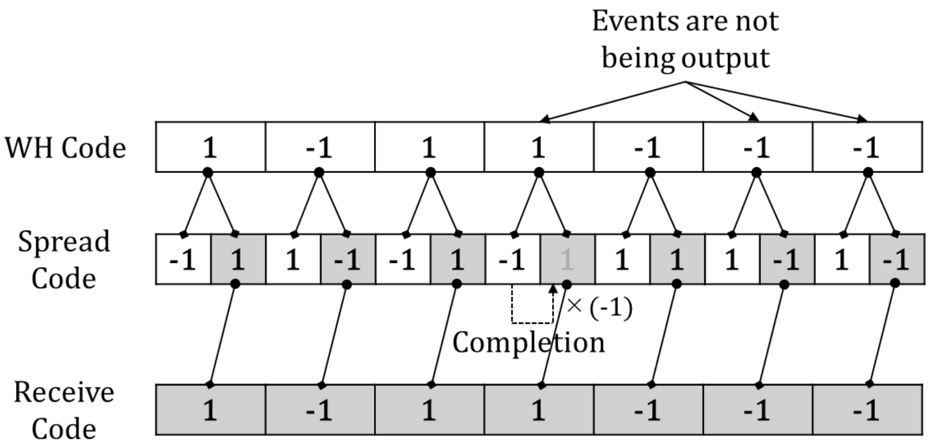




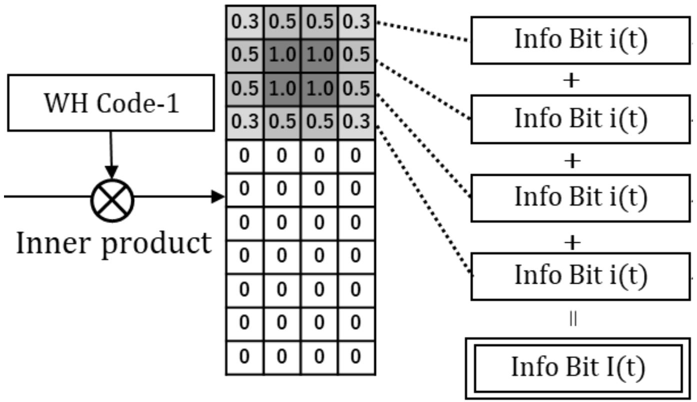
※Collaboration with Nagoya University and Toyota Motor Corporation.

Protocol with Walsh–Hadamard encoding | Encode and Decode

Encoding



Decode

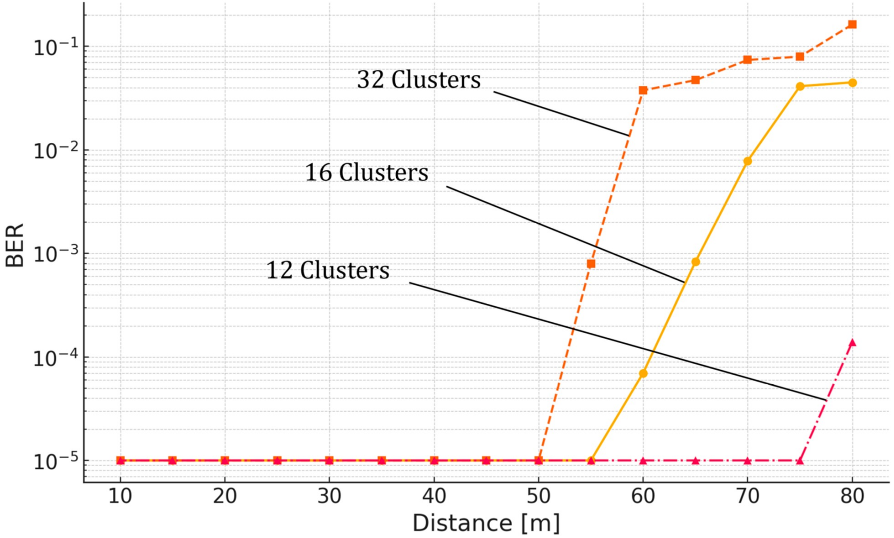


The entries of the Walsh-Hadamard (WH) matrix are either +1 or −1, and its rows/columns are orthogonal. e.g., $\begin{pmatrix} +1 & +1 \\ +1 & -1 \end{pmatrix}$

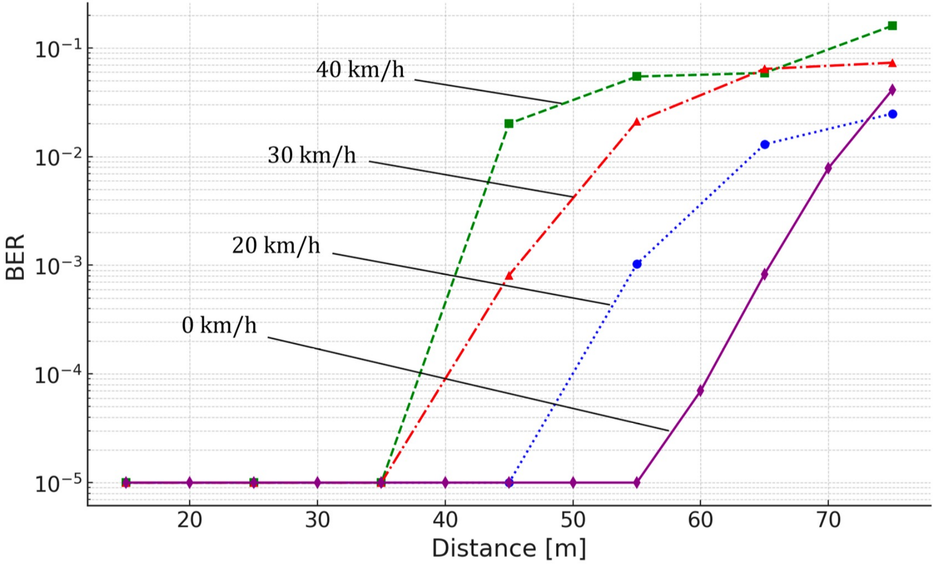
※Collaboration with Nagoya University and Toyota Motor Corporation.

Protocol with Walsh–Hadamard encoding | Results

Static receiver



Dynamic receiver



Error-free communication
20km/h: up to 50m, 40km/h: up to 40m

Validation in outdoor environment with illumination

We use the same microcontroller with actual illumination and outdoor environment to validate outdoor.

Illumination spec

Lumens	6500 lm
Power	82.5W
Color	White
Beam openings	30 deg

VLC controller

Summary, and Paper information

1. Propose a dataset on mobile devices

“E-VLC: A Real-World Dataset for Event-based Visible Light Communication And Localization”, Shiba S., Kong Q., Kobori N., CVPRW2025
“Augmented Reality Applications Using Active Markers With An Event Camera”, Shiba S., Kong Q., Kobori N., CVPRW2025
https://woven-visionai.github.io/evlc-dataset/

2. Propose an encoding on cars

”Evaluation of Mobile Environment for Vehicular Visible Light Communication Using Multiple LEDs and Event Cameras”, Soga R., Shiba S., Kong Q., Kobori N., Shimizu T., Lu S., Yamazato T, IEEE IV 2025.
”Distance Estimation in Outdoor Driving Environments Using Phase-only Correlation Method with Event Cameras”, Kobayashi M., Shiba S., Kong Q., Kobori N., Shimizu T., Lu S., Yamazato T, IEEE IV 2025.