Wanna block my light? No way!

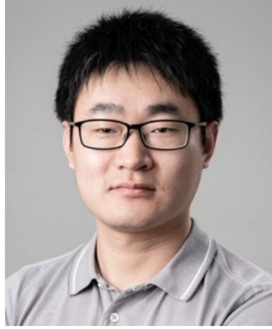
Embedded Systems Group, TU Delft

汪 庆

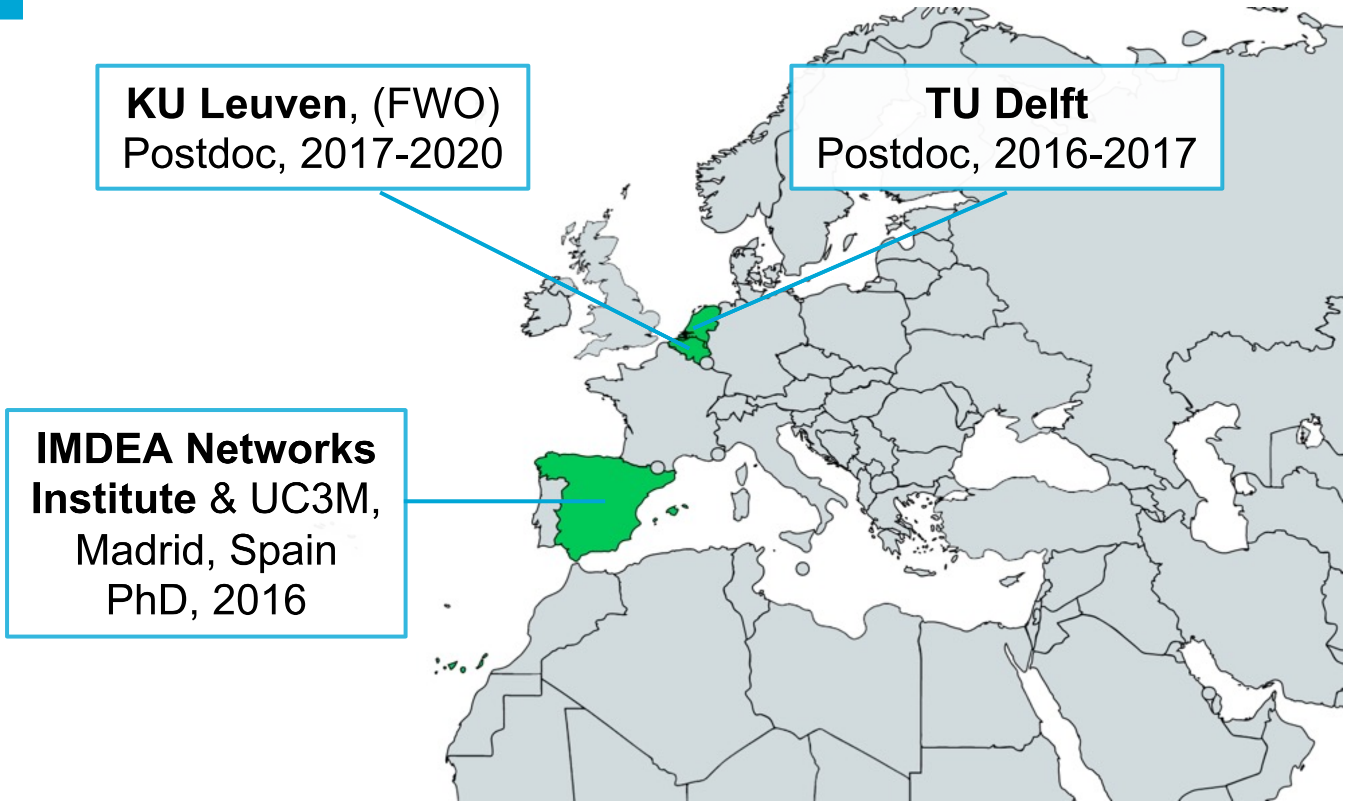
川渝前沿论坛第十期

Nov 28, 2022

About me



Current position: Tenured Assistant Professor @ Embedded Systems Group, TU Delft



Current research areas:

Visible light communication & sensing

Embedded AI for IoT

Wireless networking

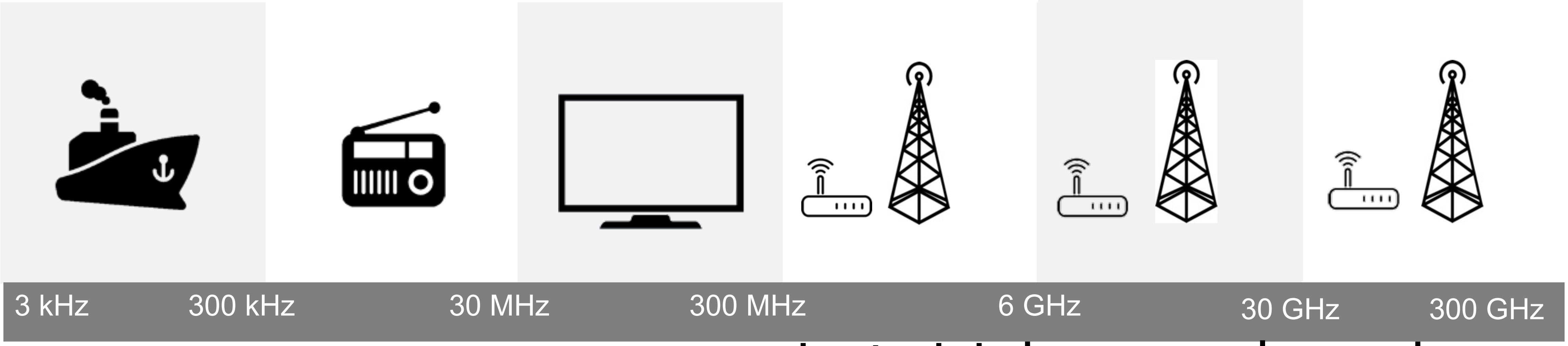
Co-founder:

TU Delft's **Embedded AI Lab**

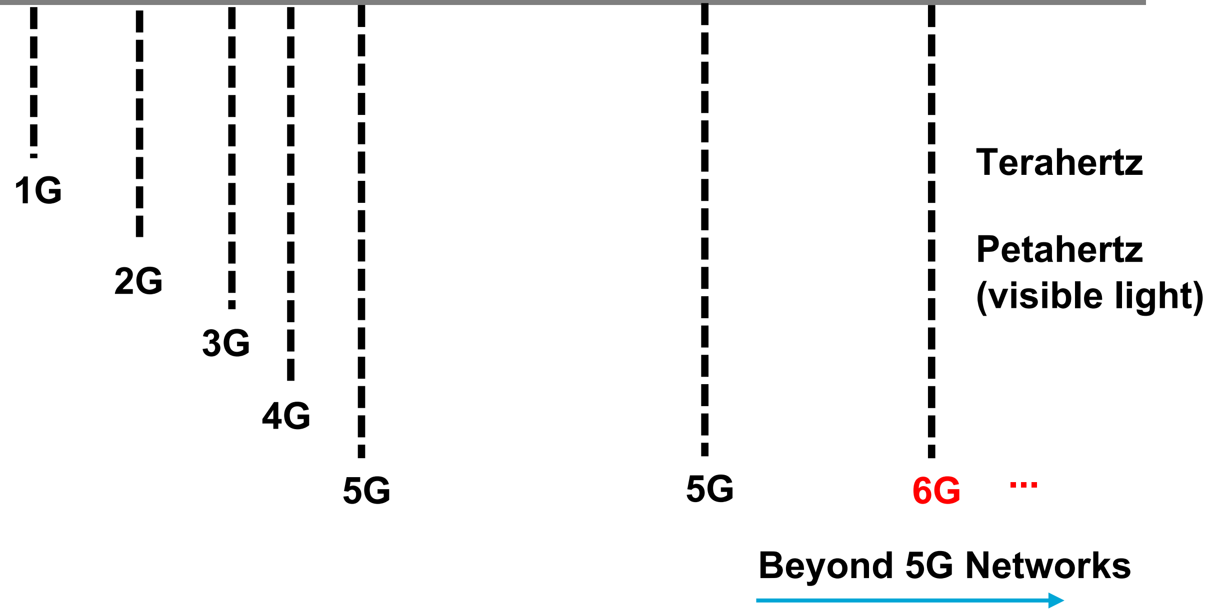
The **OpenVLC** project

www.openvlc.org

Evolution in wireless communications



- Ever-increasing demand for wireless capacity
- From low frequency band to high frequency band

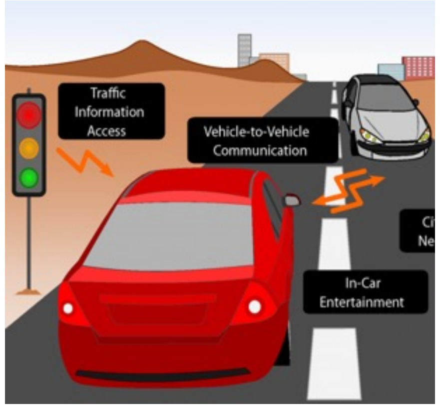


Visible Light Communication (VLC)

Transmitter: Modulate the light intensity of LEDs

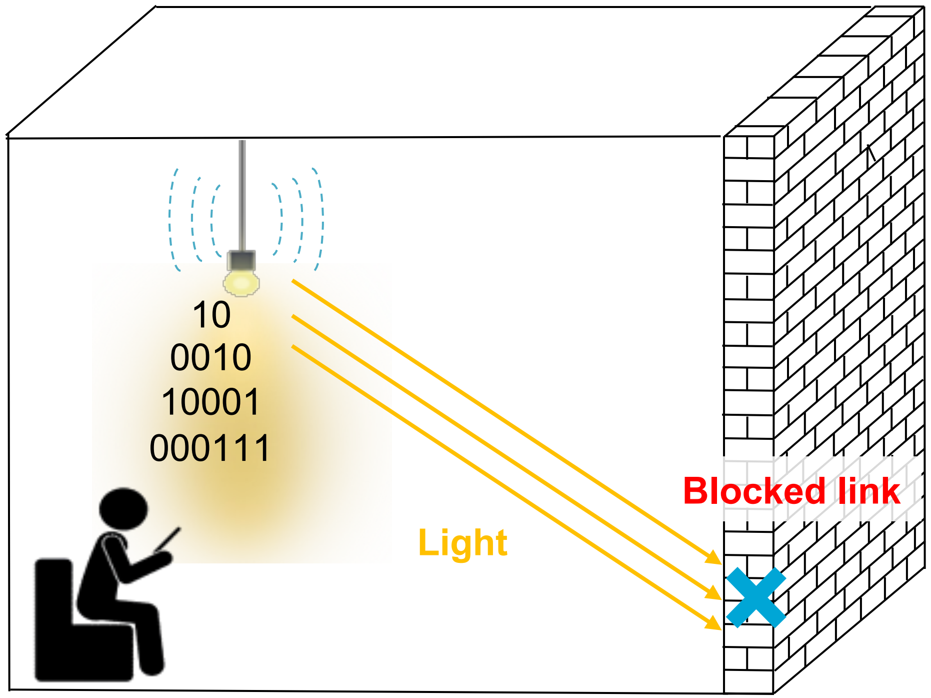
Receiver: Photodiode, Camera, etc.

Advantages: 10,000x bandwidth than RF, energy efficient, existing LED infrastructure, etc.

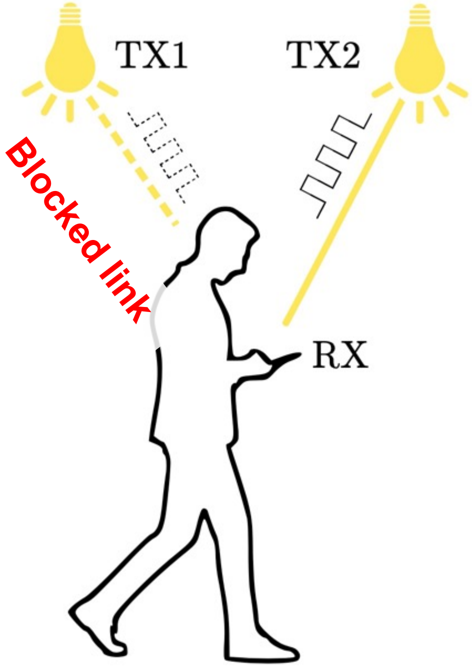


Applications: Li-Fi / Beyond 5G (6G) networks, Internet of vehicles, indoor positioning, secure communication, etc.

Challenge in VLC: not reliable due to blockages



Wall as blockage

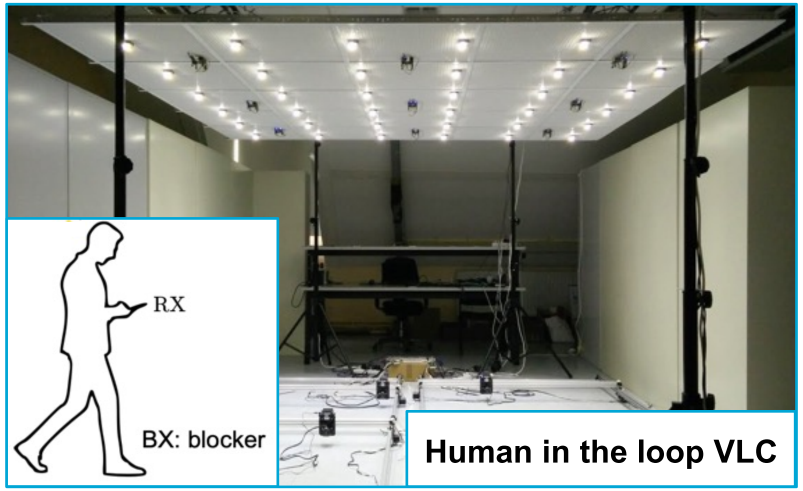


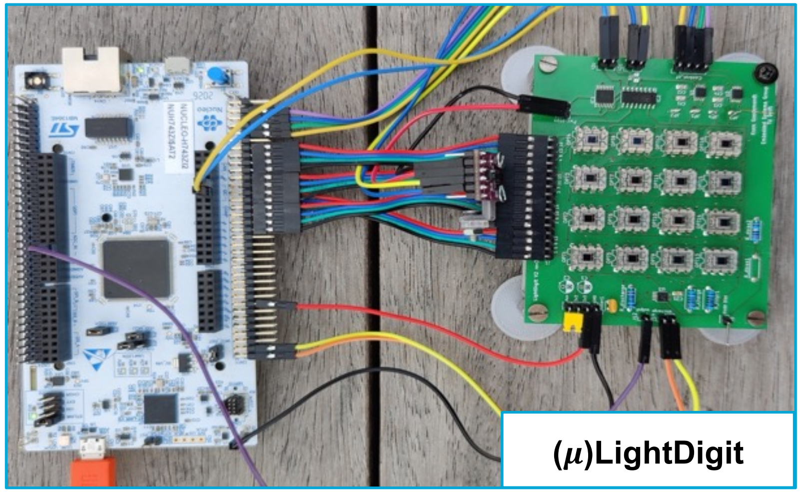
Human as blockage

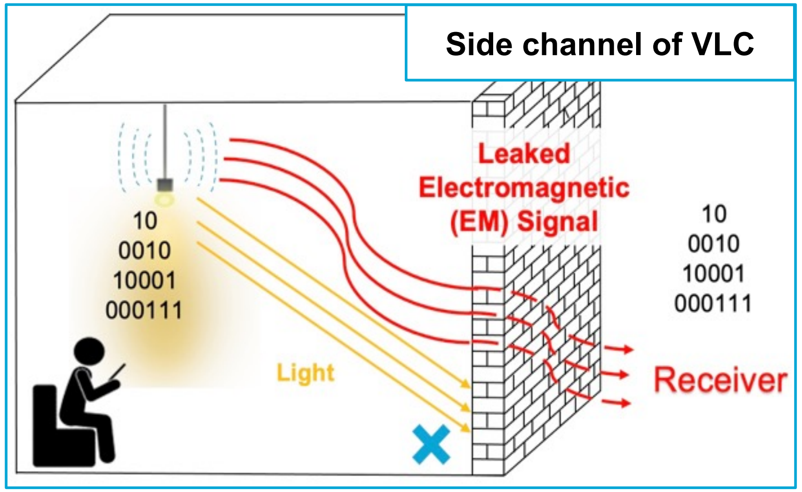
Screen becomes a blocker

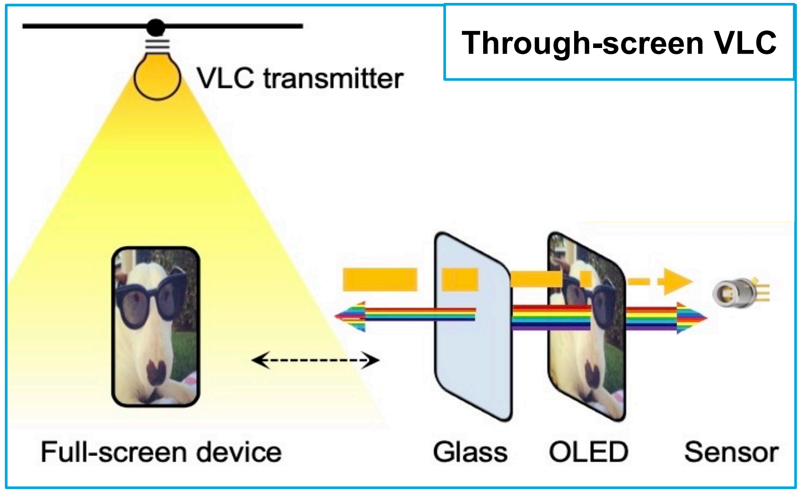
Outline of this talk

START HERE



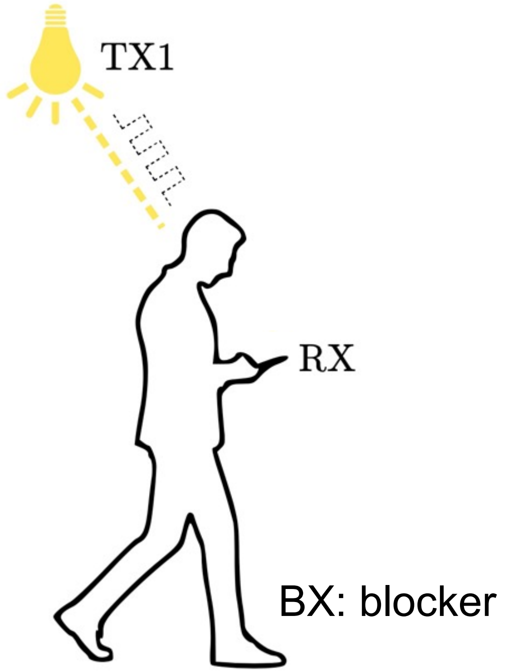


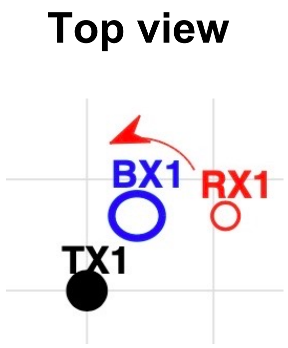


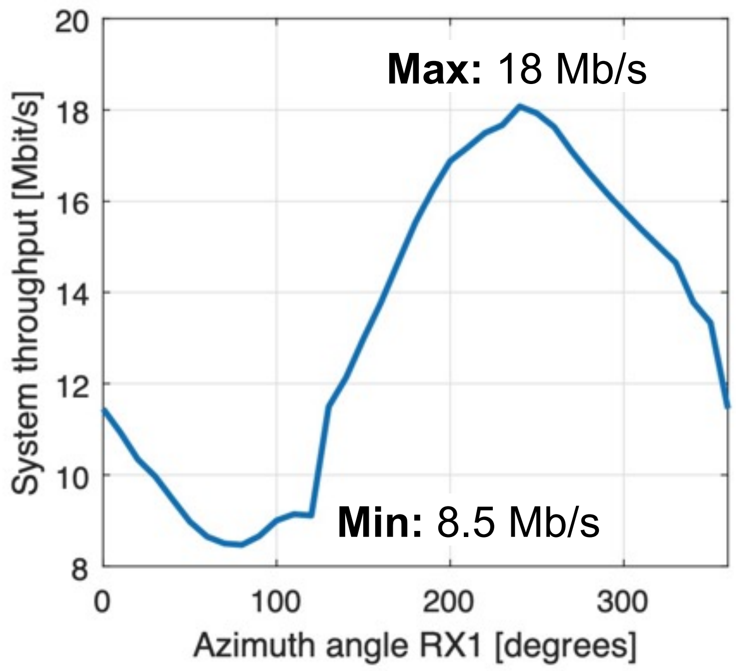


Solution 1: User-in-the-loop communication

User's participation plays an important role to tackle blockage issues.







Participation willingness

Would users be willing to **rotate themselves** to tackle blockage issues?

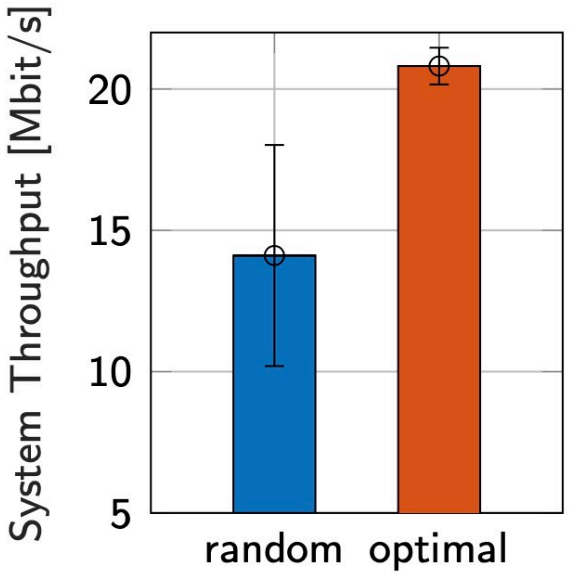
Could be, because:

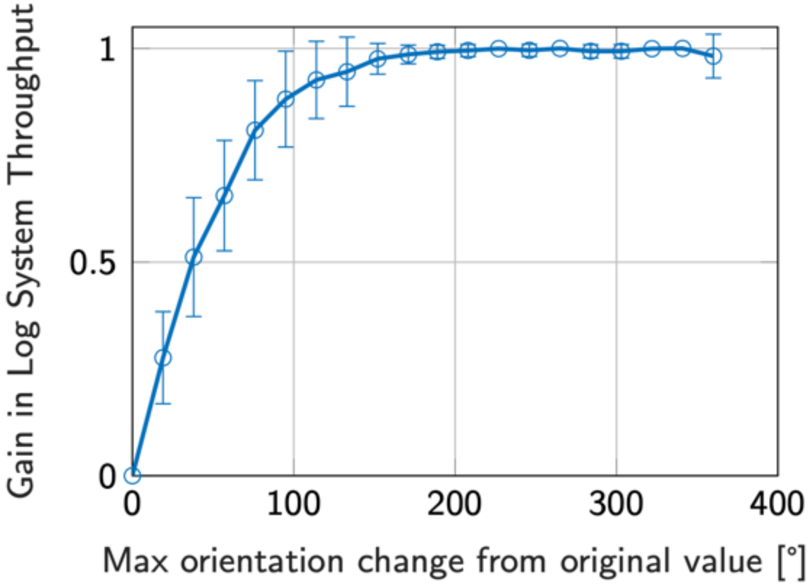
- Visible light can be captured by our eyes → Spontaneous action to rotate towards the light
- Smartisan released a smartphone featuring an infinity screen for disruptive experience

Research challenges

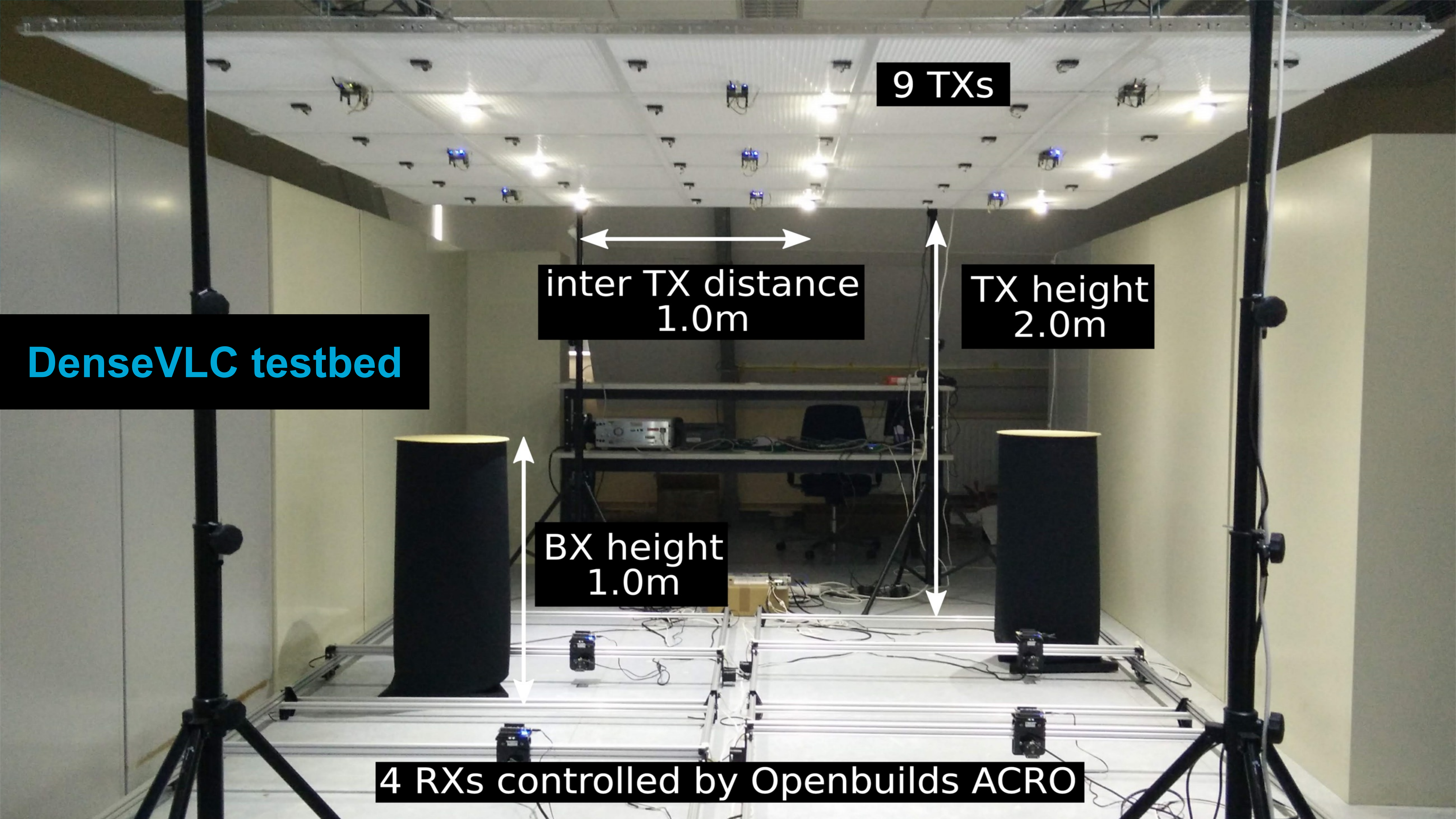
Challenge 1: Optimal user orientation
How can we identify the optimal user orientations?

Challenge 2: Tradeoff between rotation and gain
With a constraint on the maximal user orientation, can we still improve the performance?



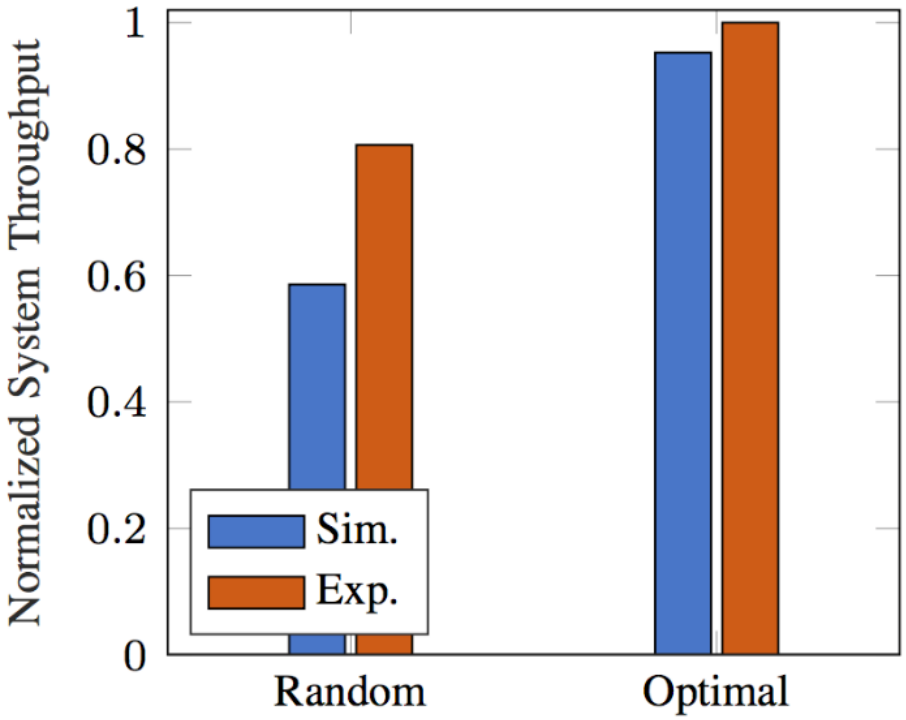


Some simulation results


9 TXs
inter TX distance
1.0m
TX height
2.0m
DenseVLC testbed
BX height
1.0m
4 RXs controlled by Openbuilds ACRO

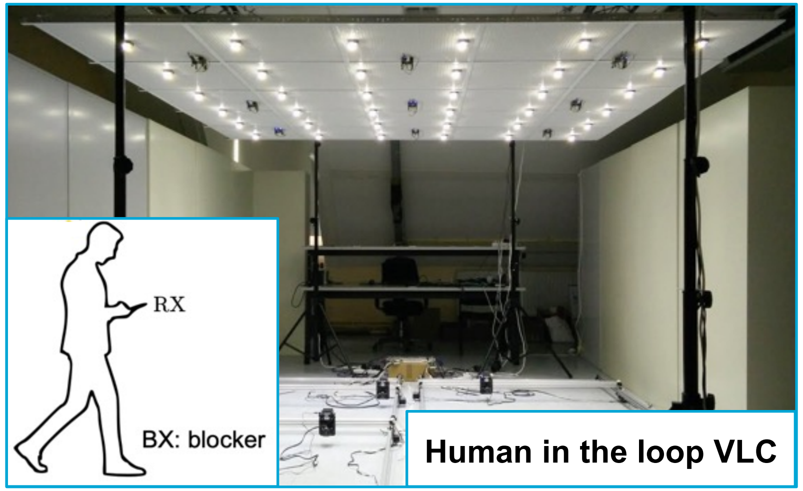
Experimental result

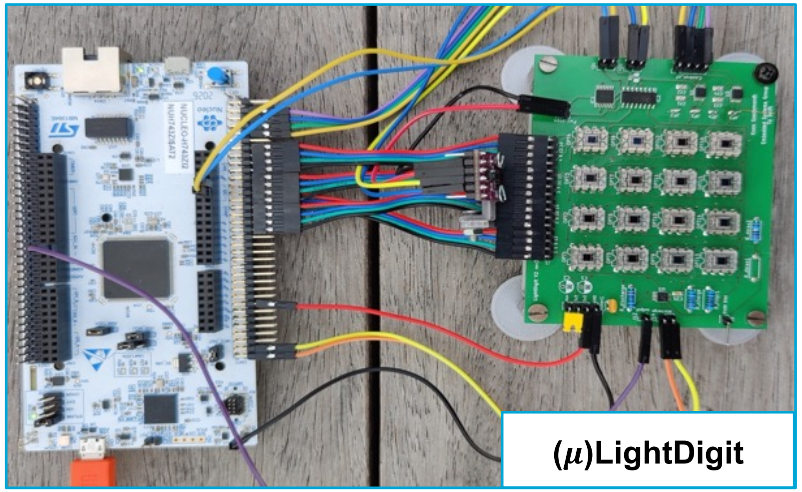
- User-in-the-loop VLC does help!
- Throughput in the experiment is higher (reflections)



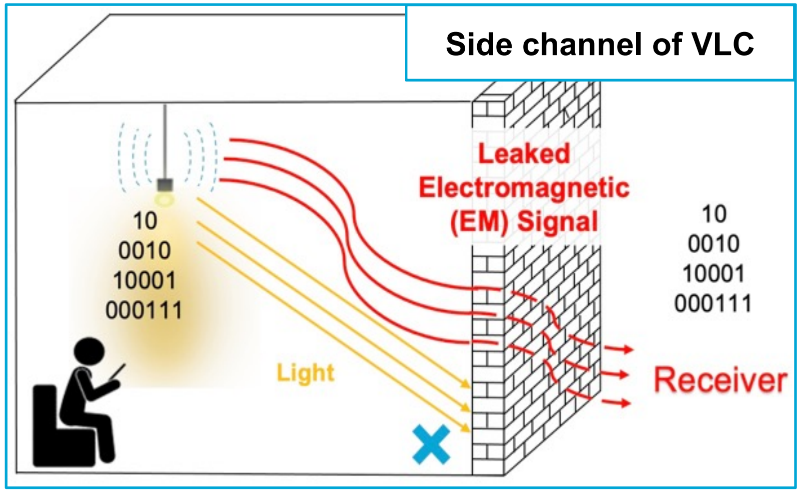
J. Beysens, Q. Wang, S. Pollin. Exploiting Blockage In VLC Networks Through User Rotations. *IEEE Open Journal of the Communications Society*, 2020.
J. Beysens, Q. Wang, S. Pollin. Improving Blockage Robustness in VLC Networks. *IEEE COMSNETS*, 2019. [Best Paper Award]

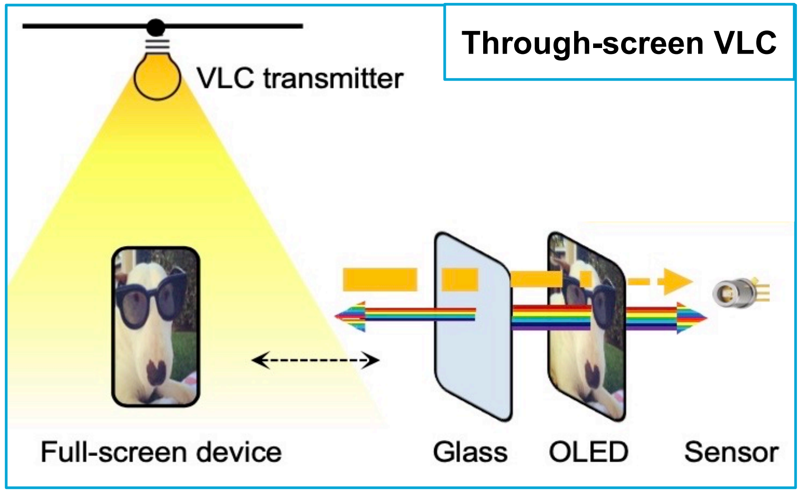
Outline of this talk



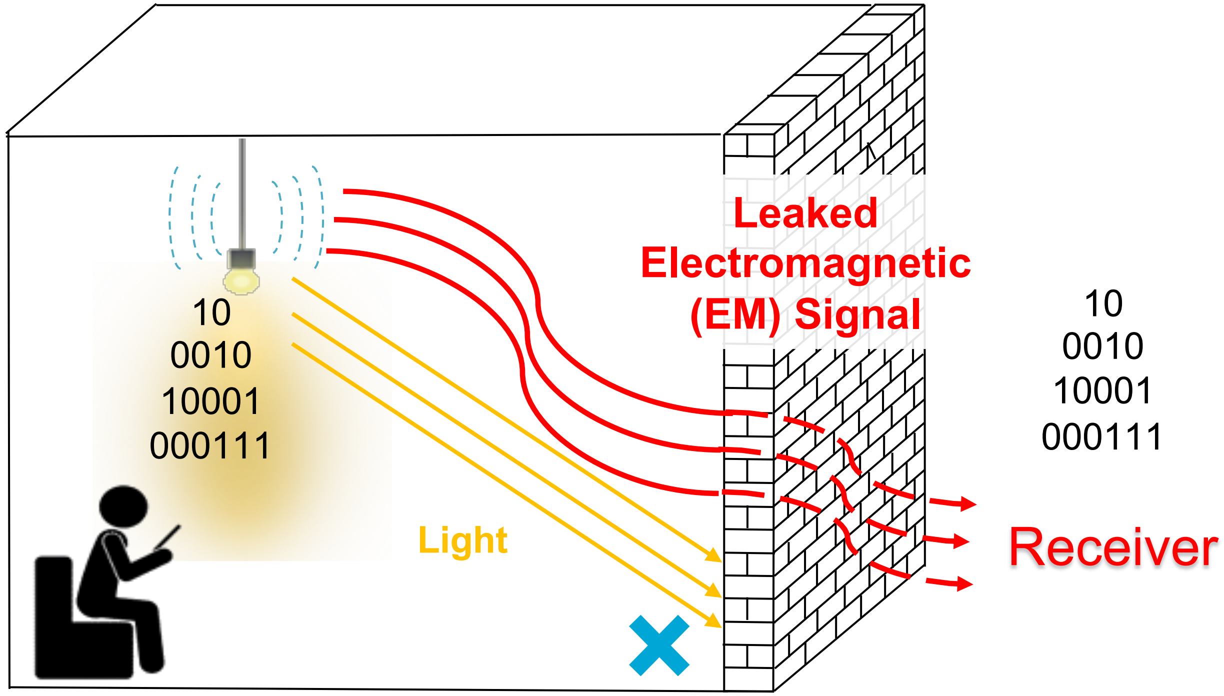


NEXT

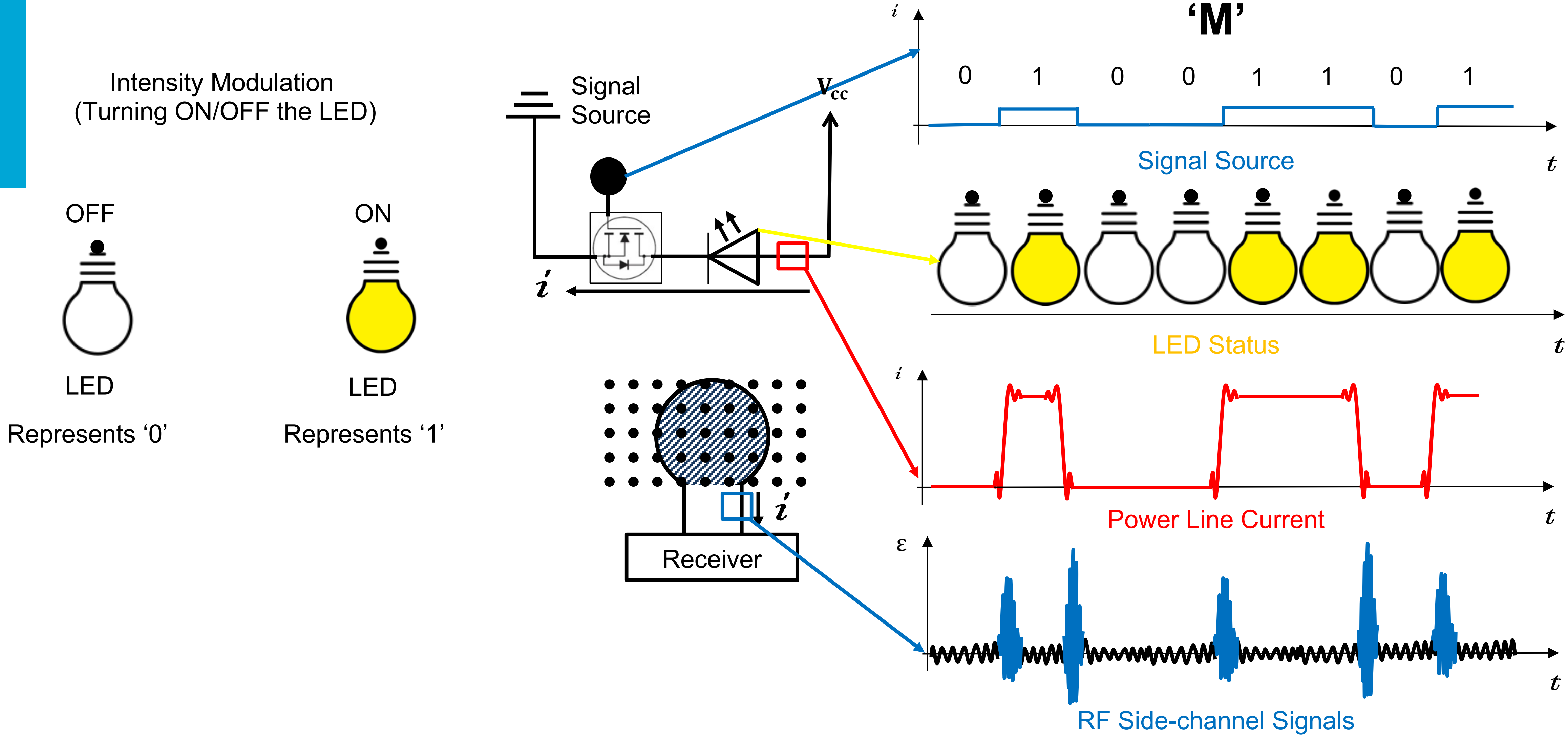




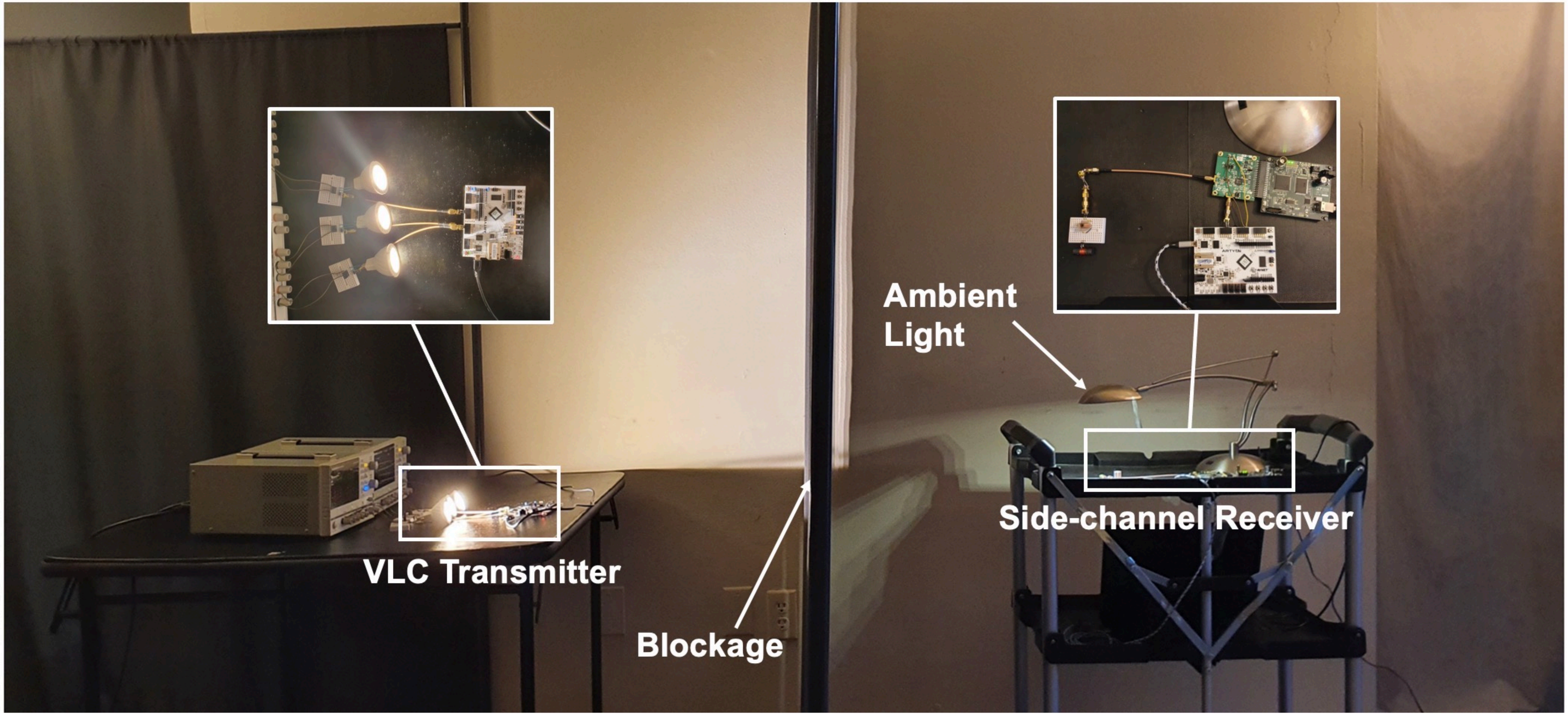
Solution 2: Exploiting the side channel of VLC



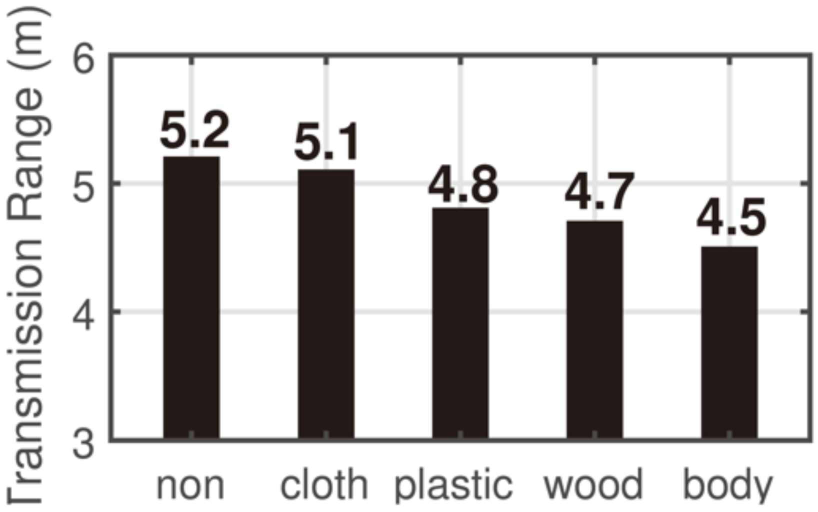
Why there is a side channel?
Changing current → changing magnetic field



Built system & experimental setup



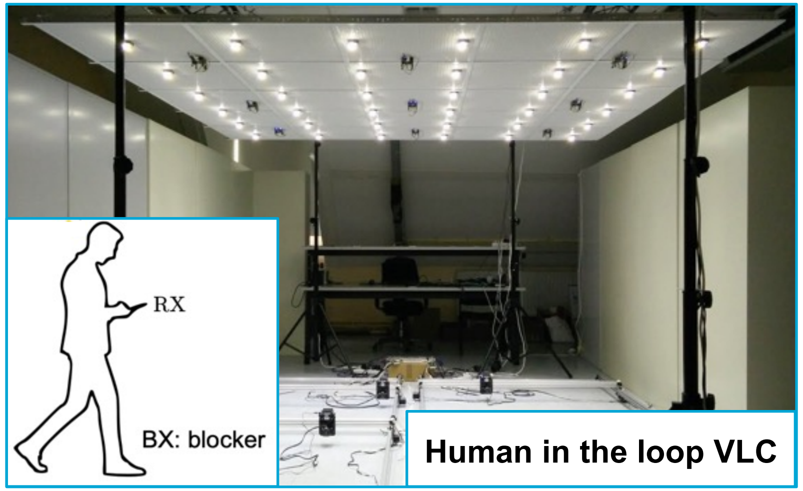
Experimental results



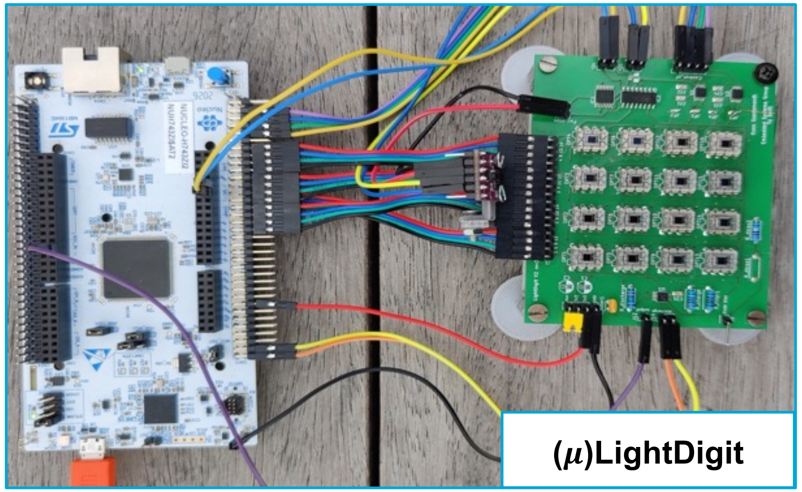
Transmission range: when bit error rate reaches 0.01

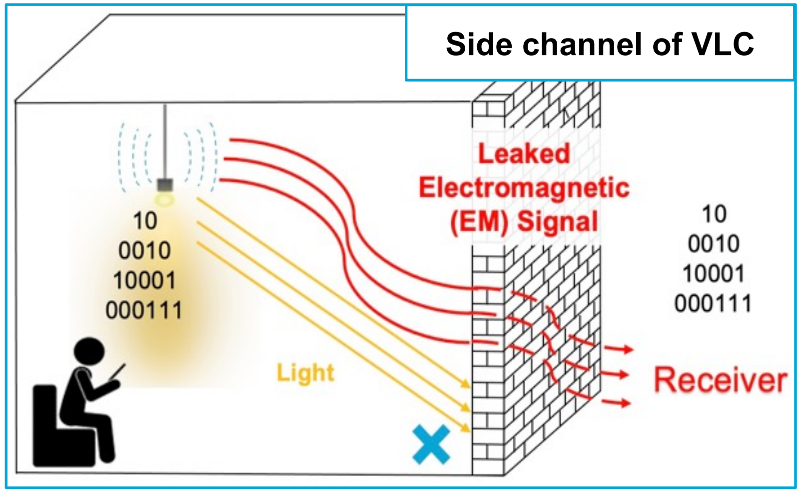
M. Cui, Q. Wang, J. Xiong. RadioInLight: Doubling the Data Rate of VLC Systems, *ACM MobiCom*, 2021.
M. Cui, Q. Wang, J. Xiong. Breaking the Limitations of VLC Through Its Side Channel, *ACM SenSys*, 2020.
M. Cui, Y. Feng, Q. Wang, J. Xiong. Sniffing visible light communication through walls, *ACM MobiCom*, 2020.

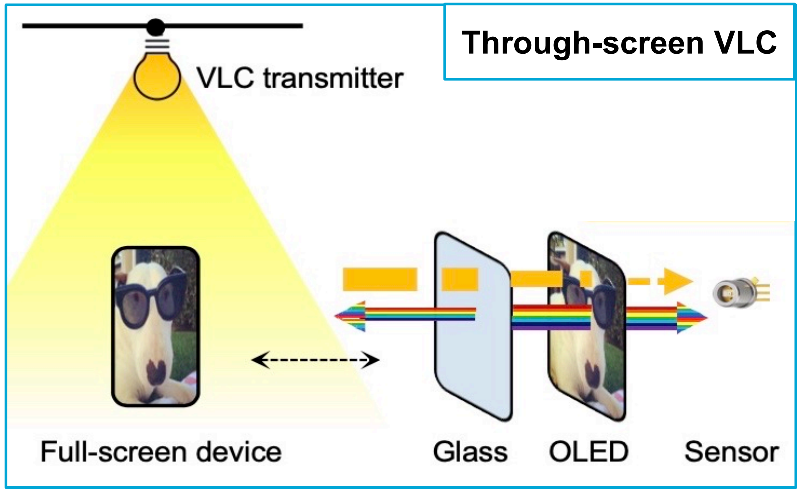
Outline of this talk



THIRD







Motivation: Protections against COVID-19

ATM

*Use **toothpicks** to press the buttons*

Tissues

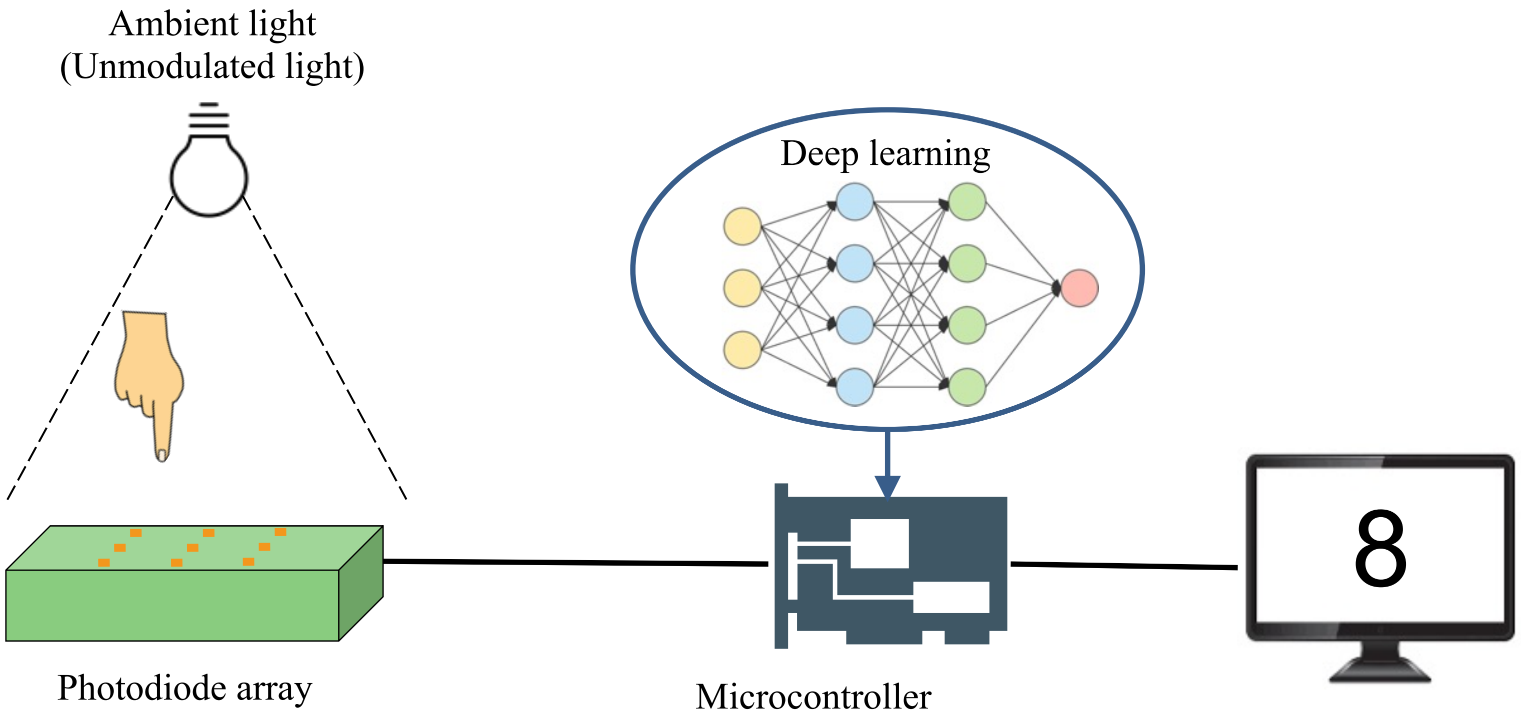
Sources: Economist, mashable.

Commercial solutions with a camera

Touch Free Sensing with Light and camera from **Ultraleap**

https://www.youtube.com/watch?v=tCLmmTk4S90

LightDigit: Embedded AI-empowered fingertip air-writing with ambient light and simple photodiodes



Objective

Design and implement an embedded system, allowing us to **write digits in-the-air with ambient light** and without any privacy issues (no camera)

→ **To enable touch-free and privacy-preserving interactions**

Key features of LightDigit

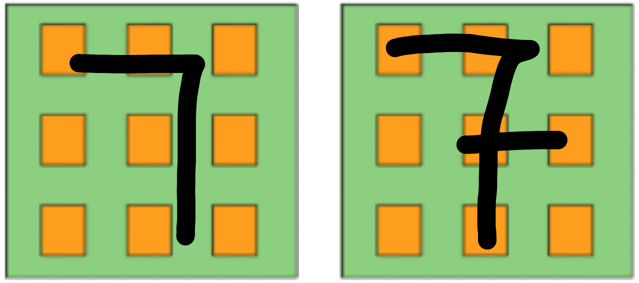
- Ambient light
- Simple photodiodes (no camera)
- Running in real-time on an embedded device
- Embedded AI algorithms

Research challenges

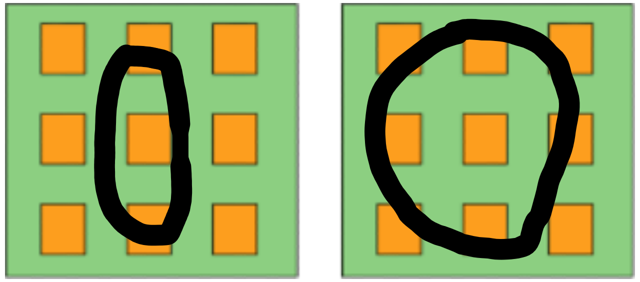
Different people, different writing styles

- Different shapes of handwritten digits, based on the region/person
- Different size of the written digits
- Different writing speed

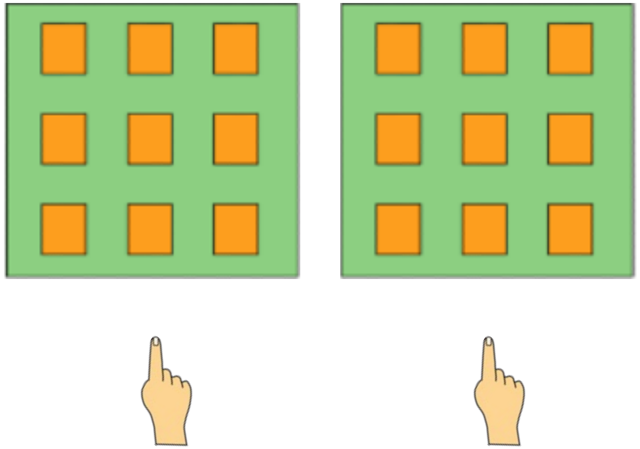
Different shape



Different size

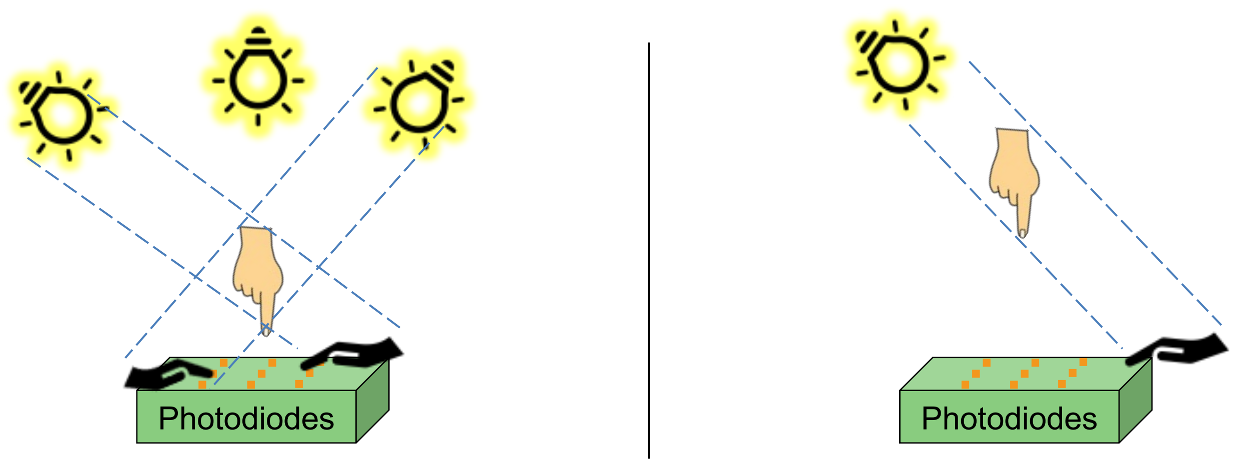


Different speed



Research challenges

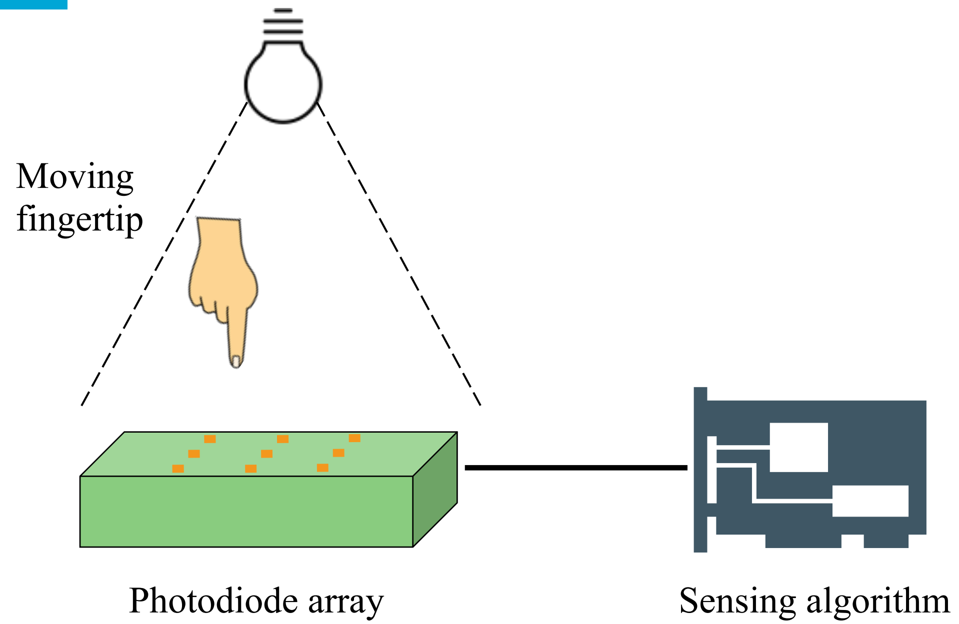
Different position of ambient light and height of fingertip, different shadow areas



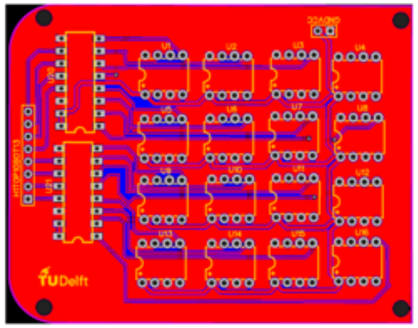
System Design

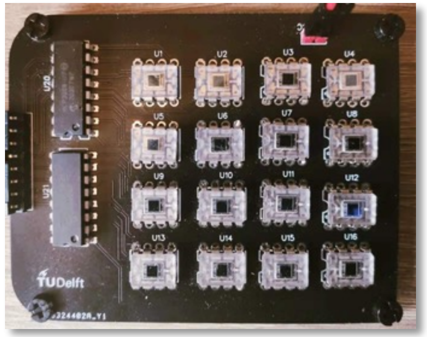
System architecture and prototype

Key components

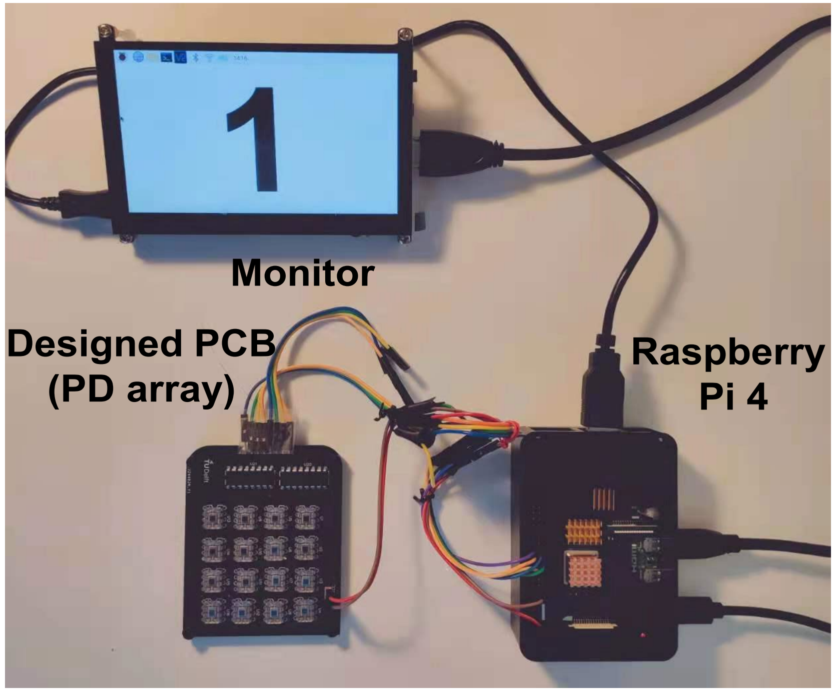


PCB design



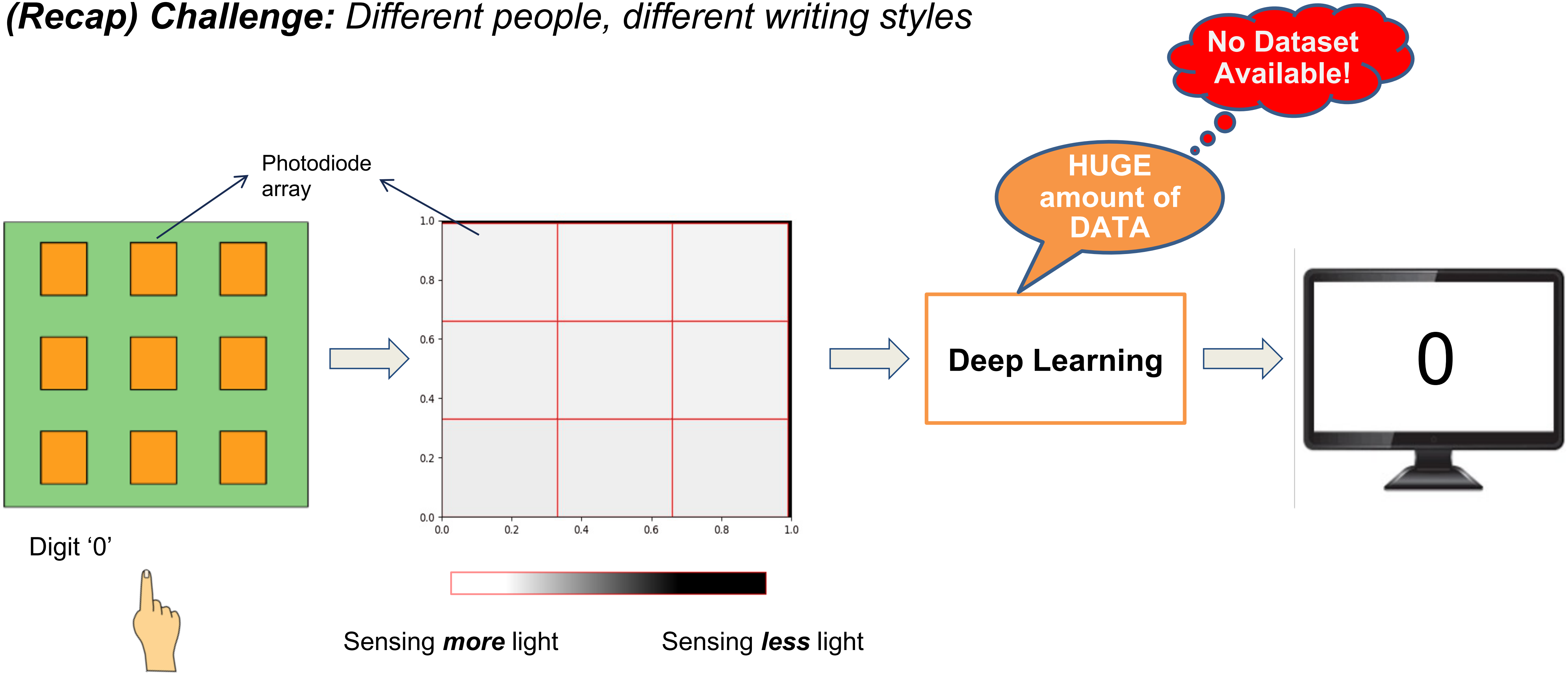


System prototype



Motivation for the LightDigit dataset

(Recap) Challenge: *Different people, different writing styles*



The popular MNIST dataset does not work here!

MNIST Dataset

- A large database of handwritten digits that is commonly used for training various image processing systems
- **2- Dimensional**

Our needs

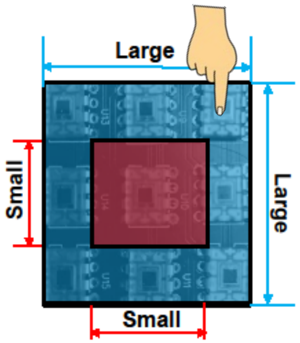
- **3-Dimensional** (including time domain)

A simple way to collect the data, *but…*

Building LightDigit dataset: Analysis of air-writing digits

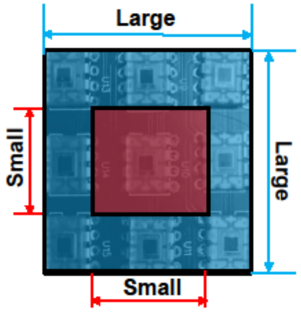
- **LightDigit Dataset:** Simulate 3-D datasets based on state-of-the-art 2-D datasets *(data collection can be done by only one person)*
  1) Define **five features** for each digit

Height × Width × Inclination × Shape
= 2 × 2 × 2 × 27
= 216

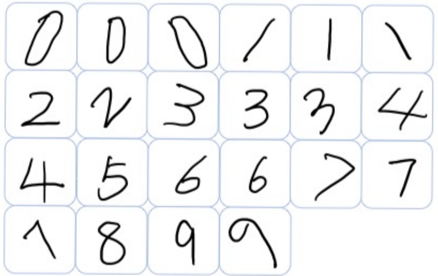


142

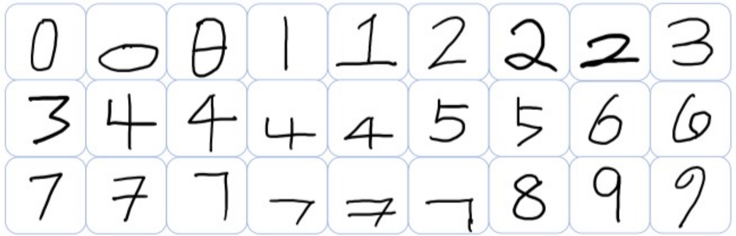
- Height
  - Small
  - Large
- Width
  - Small
  - Large



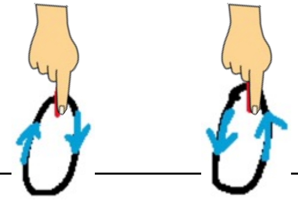
- Inclination
  - Vertical
  - Inclined



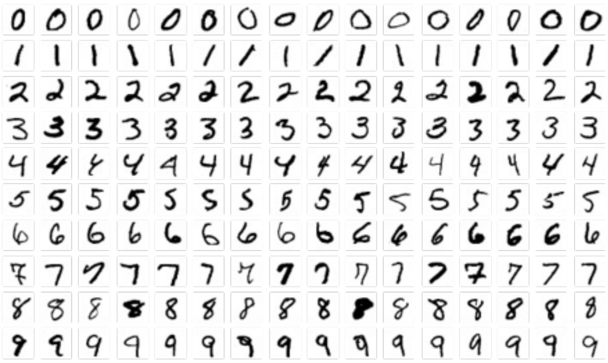
- Shape



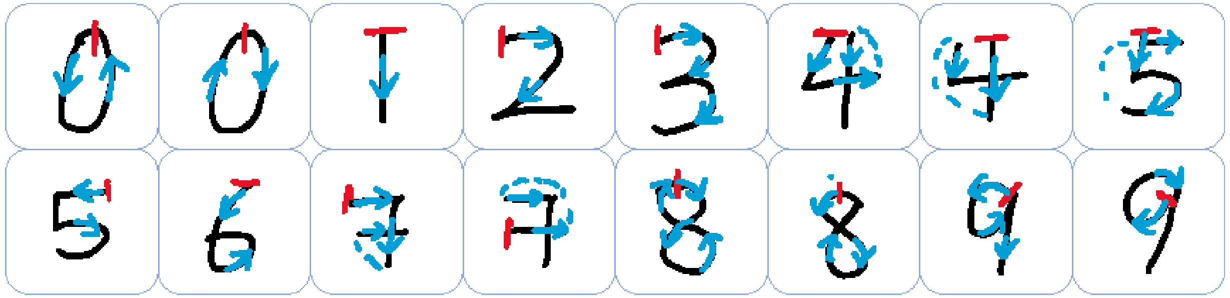
- Time Sequence



Effectiveness evaluation

2D-dataset	CASIA Dataset	EU (NL) Dataset	MNIST Dataset
Samples			
Size	10592	1999	70000
Coverage Rate	99.36%	99.30%	96.43%

Analysis of air-writing digits: Time sequence



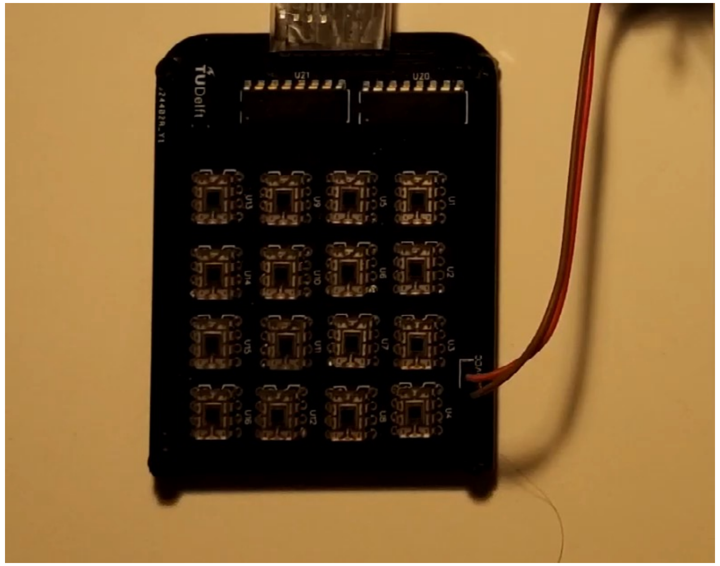
Height × Width × Inclination × Shape + Uncovered Shapes + Time Sequence

= 142 + 32

= 174 types of the ten digit 0--9

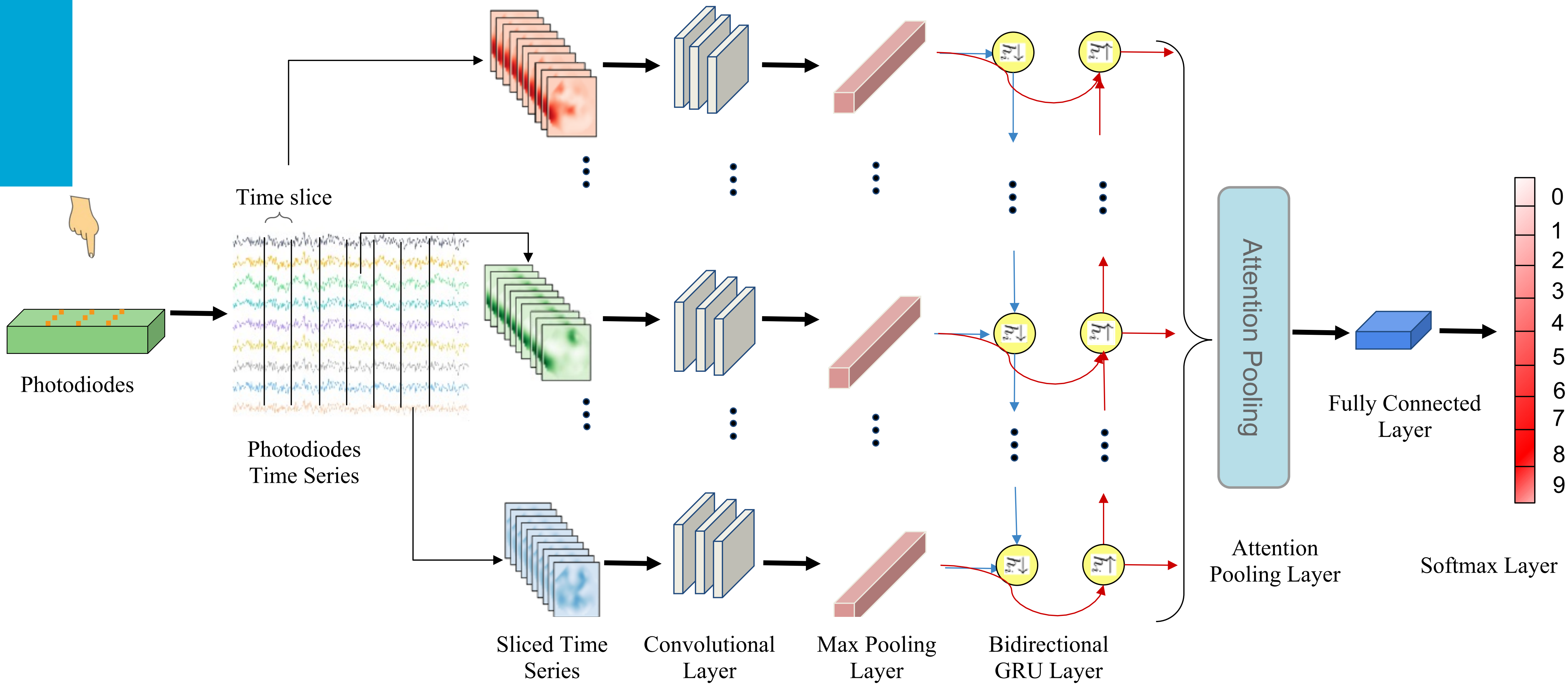
LightDigit dataset: Data collection

- **LightDigit Dataset:** Simulate 3-D datasets based on state-of-the-art 2-D datasets *(data collection can be done by only one person)*
  1) Define **five features** for each digit
  2) Effectiveness evaluation

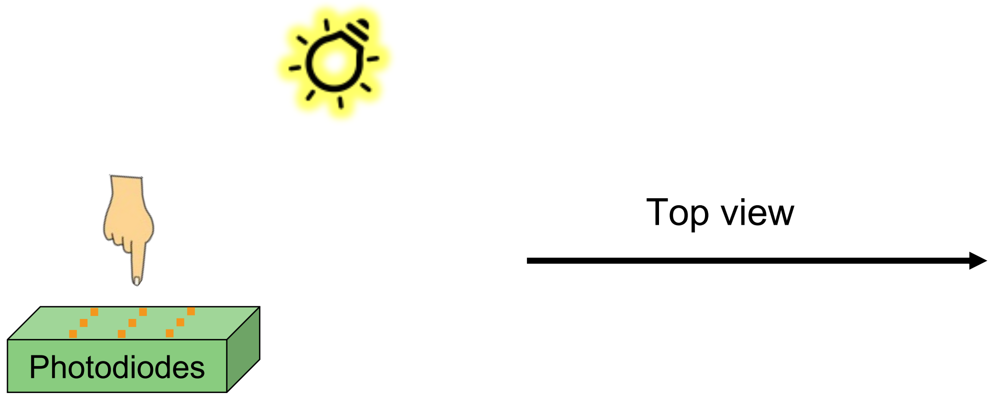


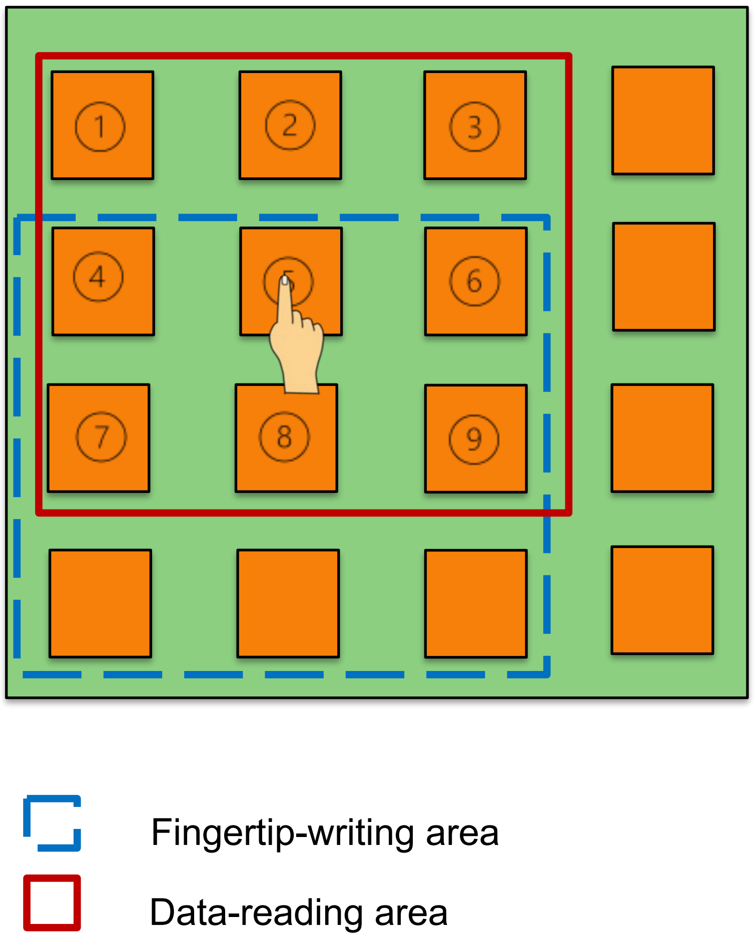
- **LightDigit Dataset**
  - Total **174** types of digit writing
  - Each type is repeated/collected for **120** times
  - One drawing/writing lasting for **5** seconds
  - Total **20880** drawings & took **~3 weeks**

Customized deep learning model: ConvRNN with attention



Calibration for different shadow areas / angles

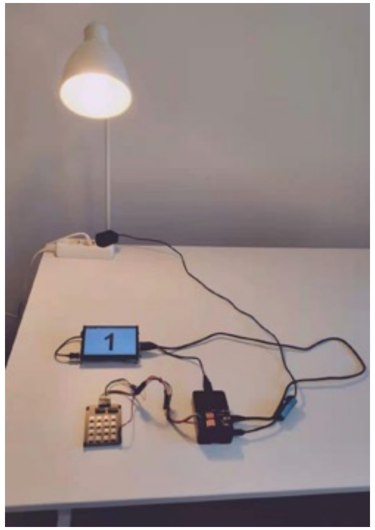




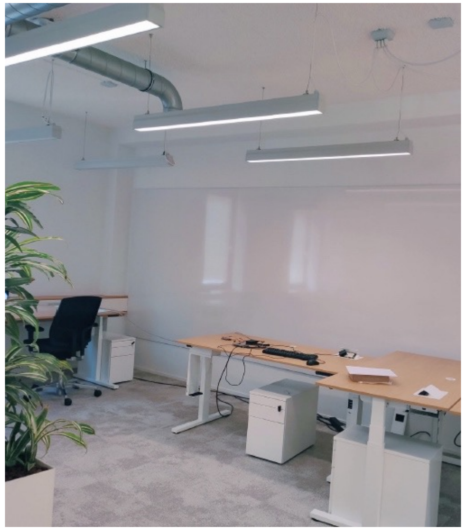
Evaluation

Experimental setup

- **Testing environments**



Home



Office

- **Real Dataset: collected from 24 participants**
  - Participants are from different countries: Mexico, Peru, Canada, Netherlands, Syria, and China
  - Each digit is repeated for 24 times
  - Each drawing/writing lasting for 5 seconds
  - Total 5561 drawings & took about 3 weeks

Samples *(here we use* ***2-D*** *for better visualization; note that the data we have collected are actually* ***3-D****)*

Experimental setup: Test scenarios

Scenario 1: Intra Subjects

- **Training: LightDigit** dataset **+** 80% of each participant in **Real** dataset

- **Testing:** 20% of each participant in **Real** dataset

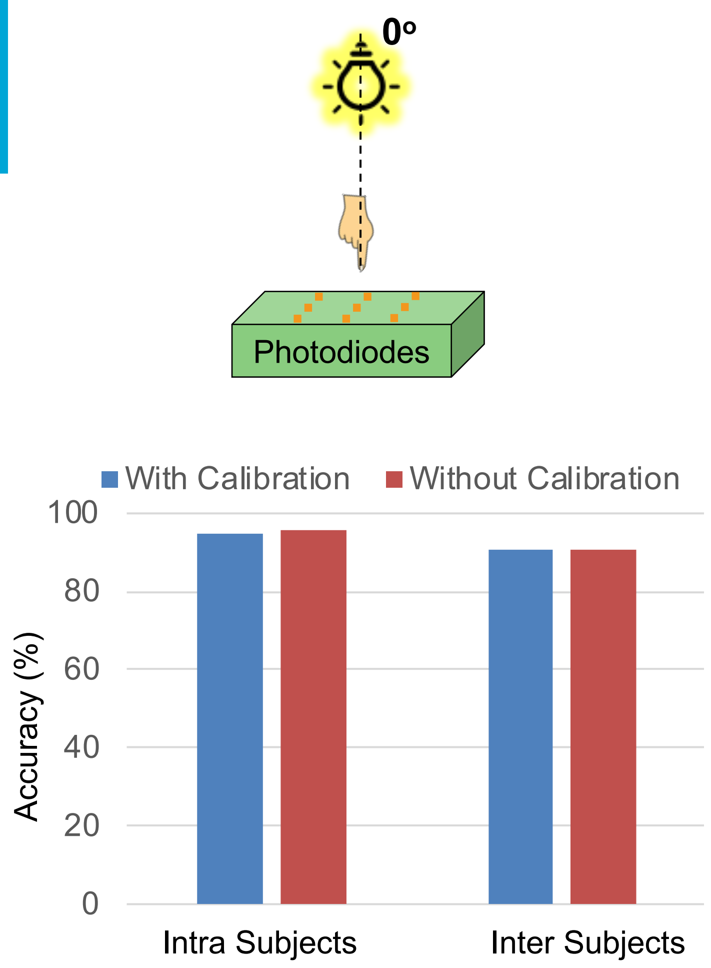
Scenario 2: Inter Subjects

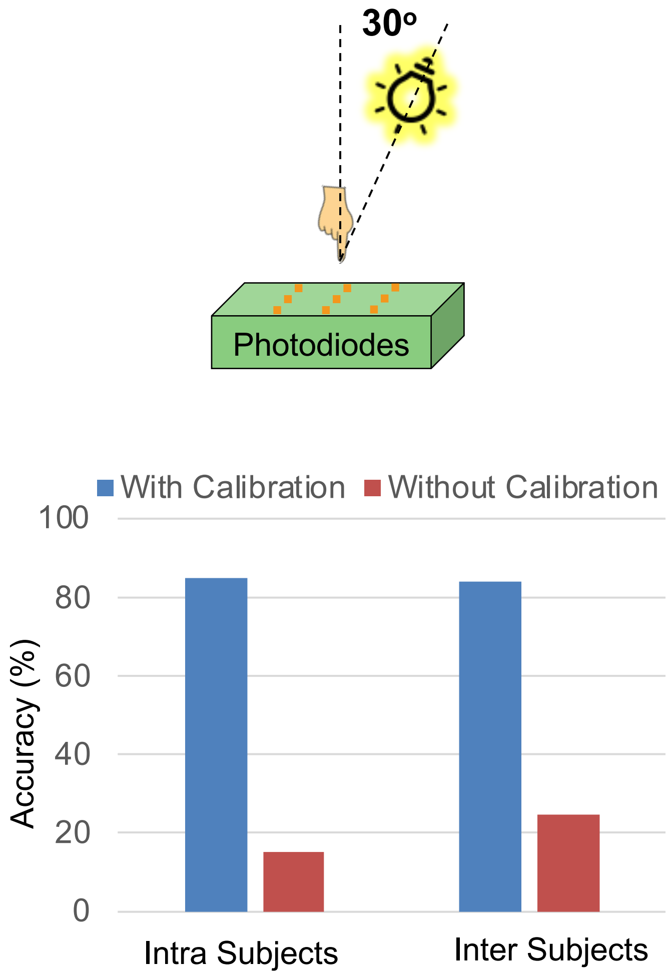
- **Training: LightDigit** dataset **+** 18 random participants in **Real** dataset

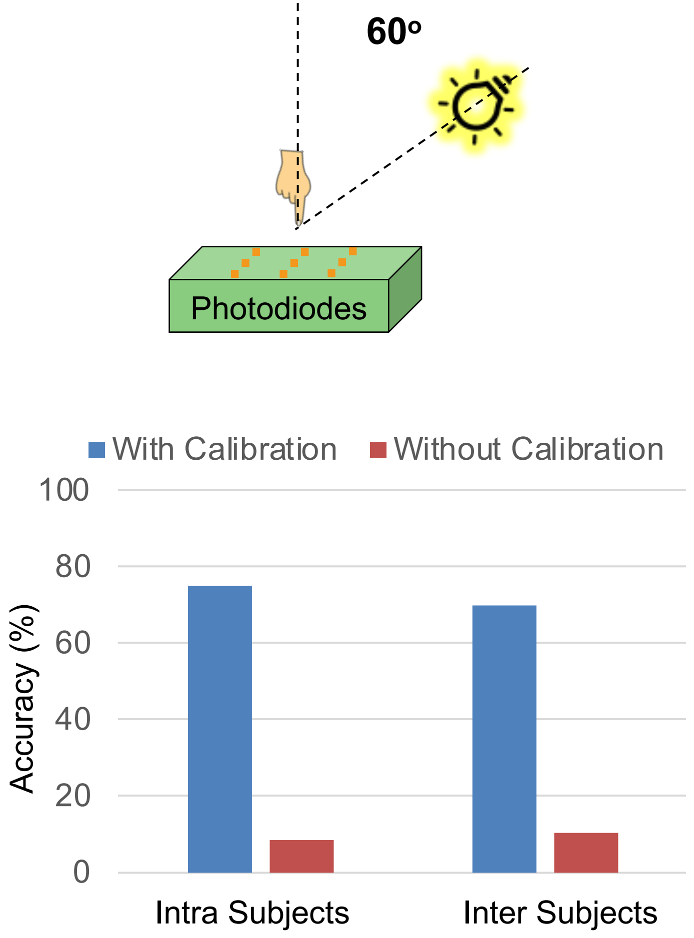
- **Testing:** the remaining 6 random participants in **Real** dataset

Performance of ConvRNN

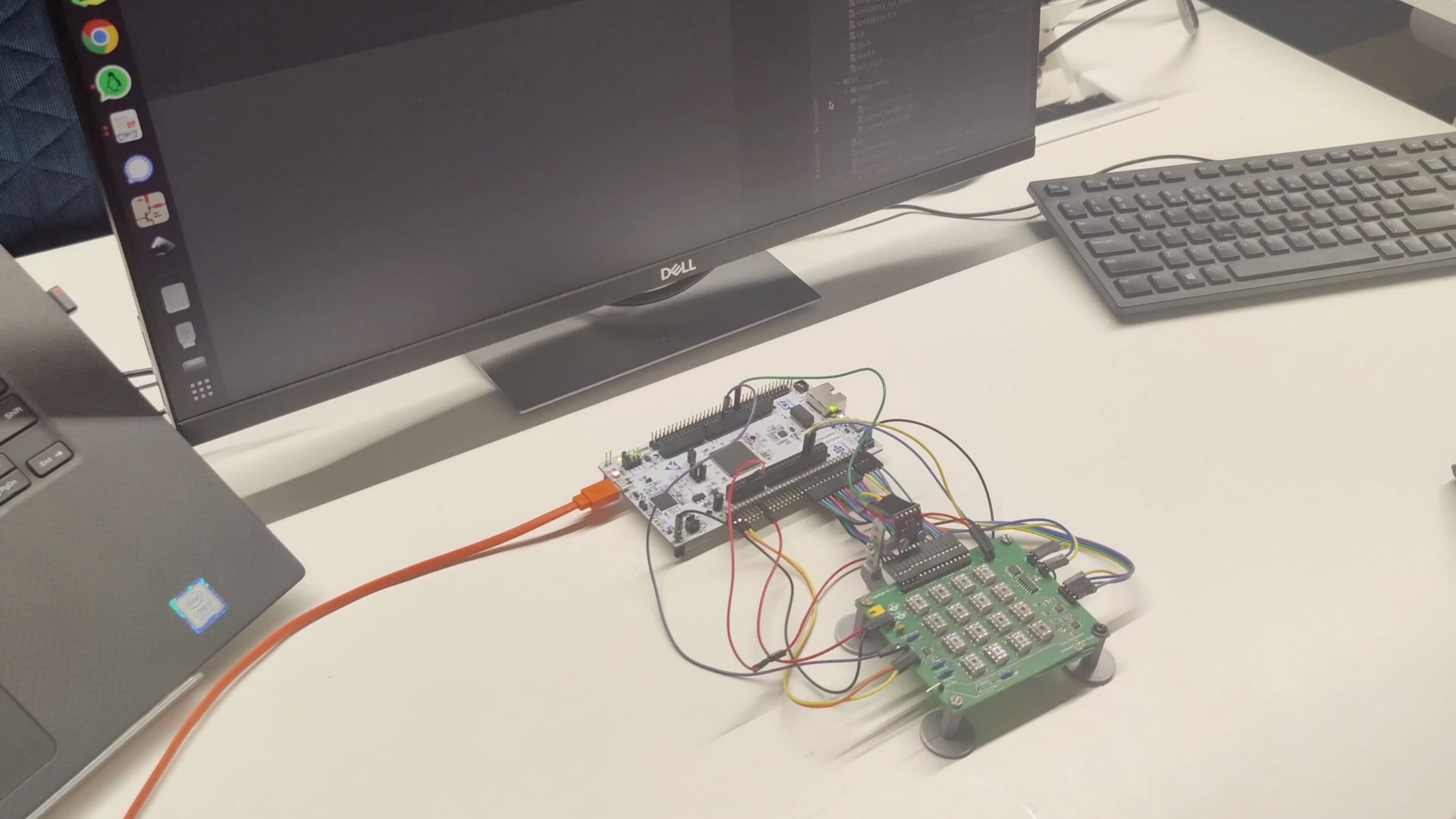
Results are averaged over 10 runs in each configuration.



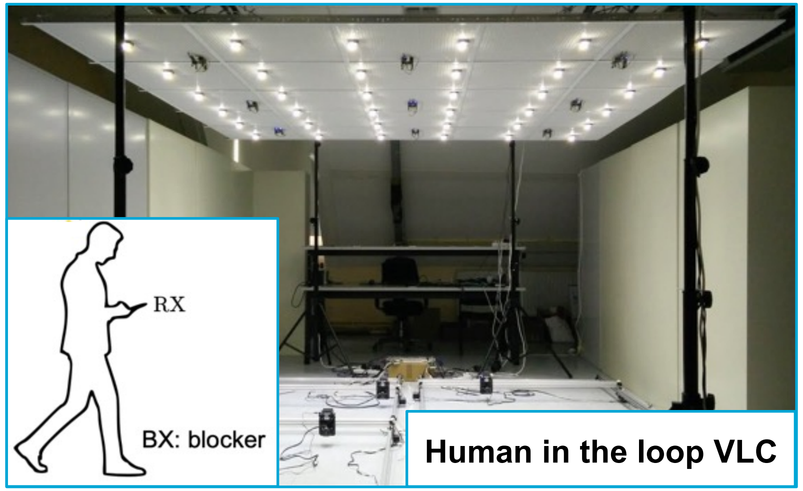




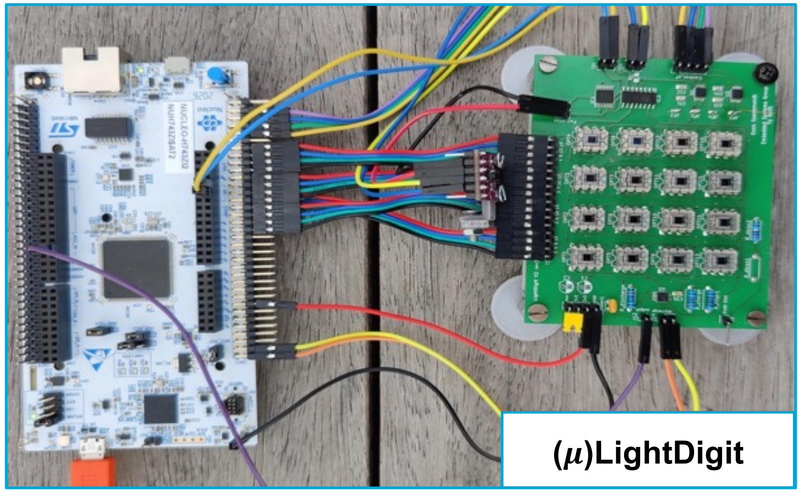
Demo


DELL
Shift
End

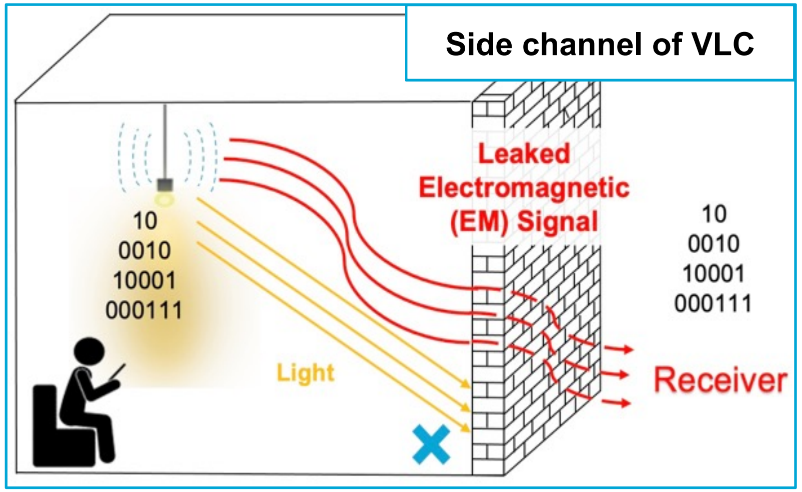
Outline of this talk



Human in the loop VLC

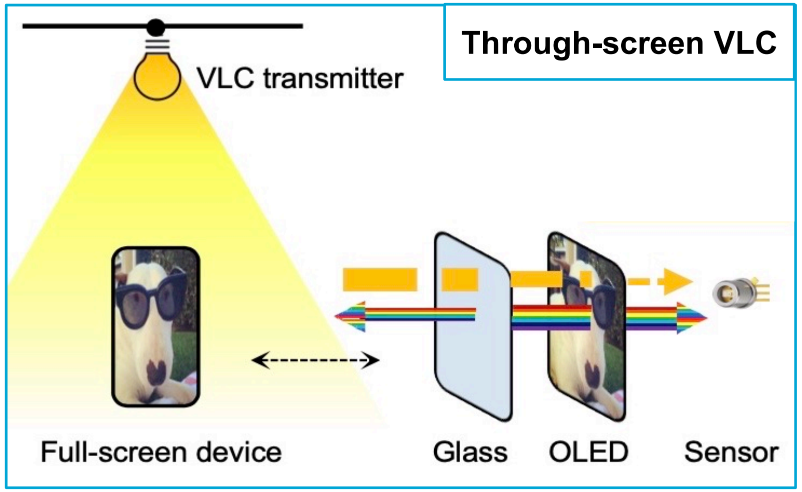


(μ)LightDigit



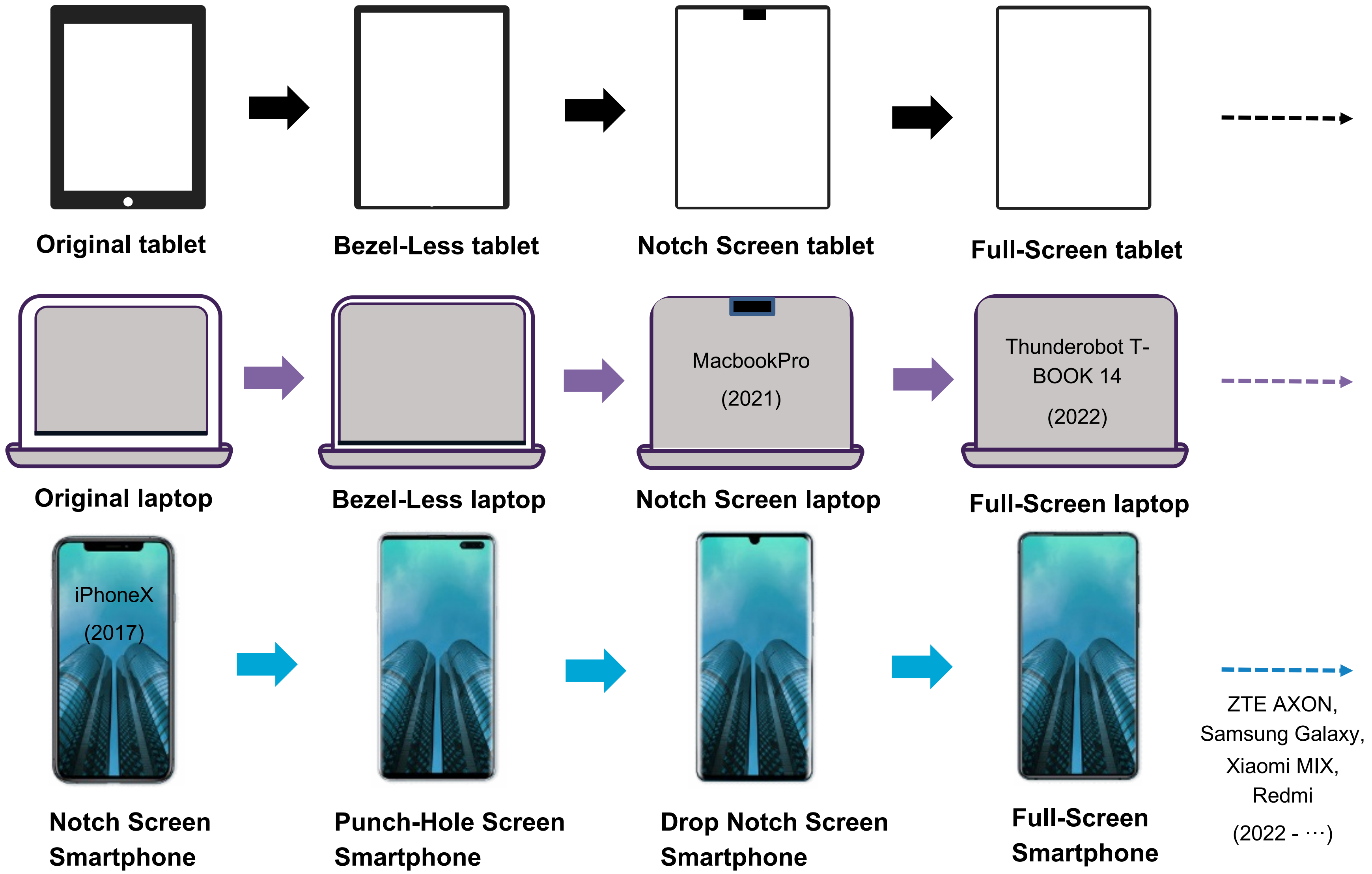
Side channel of VLC

LAST

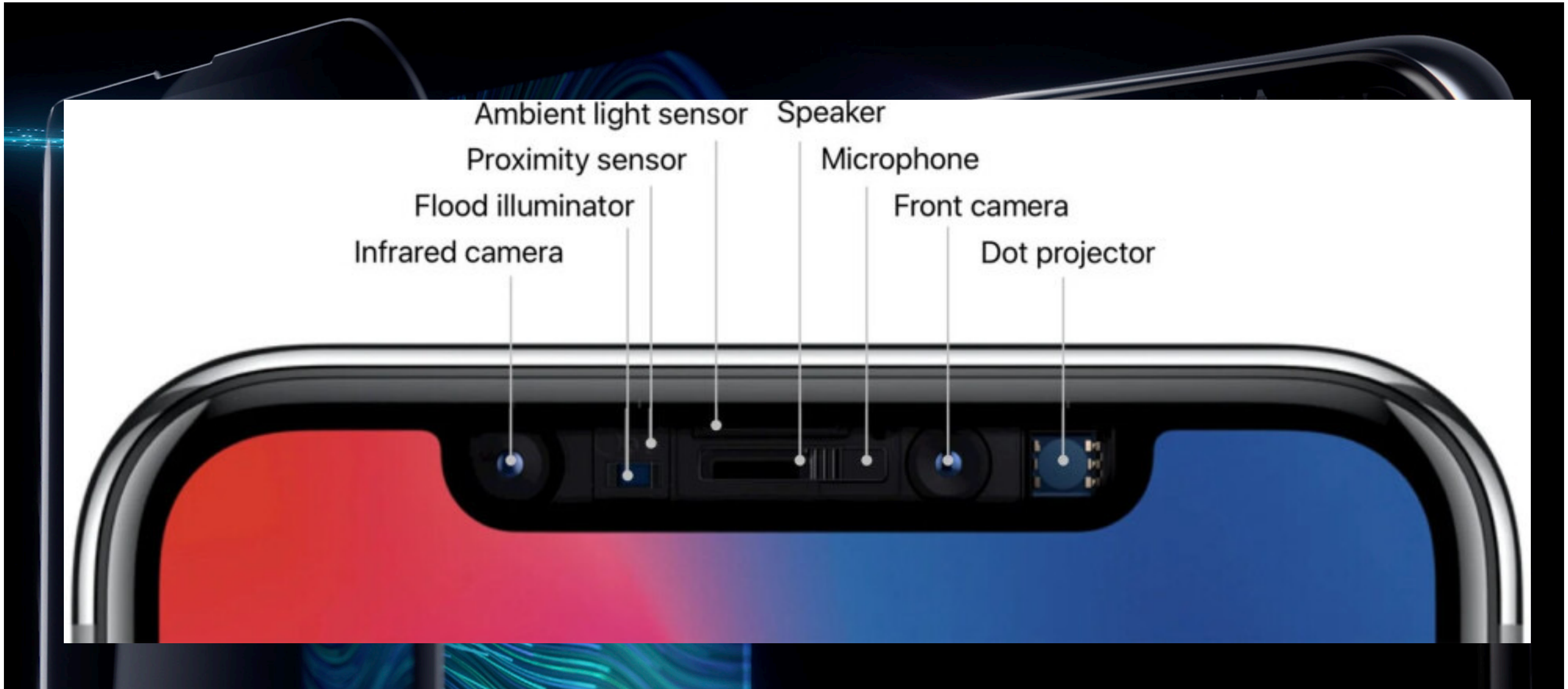


Through-screen VLC

Full-screen device evolution

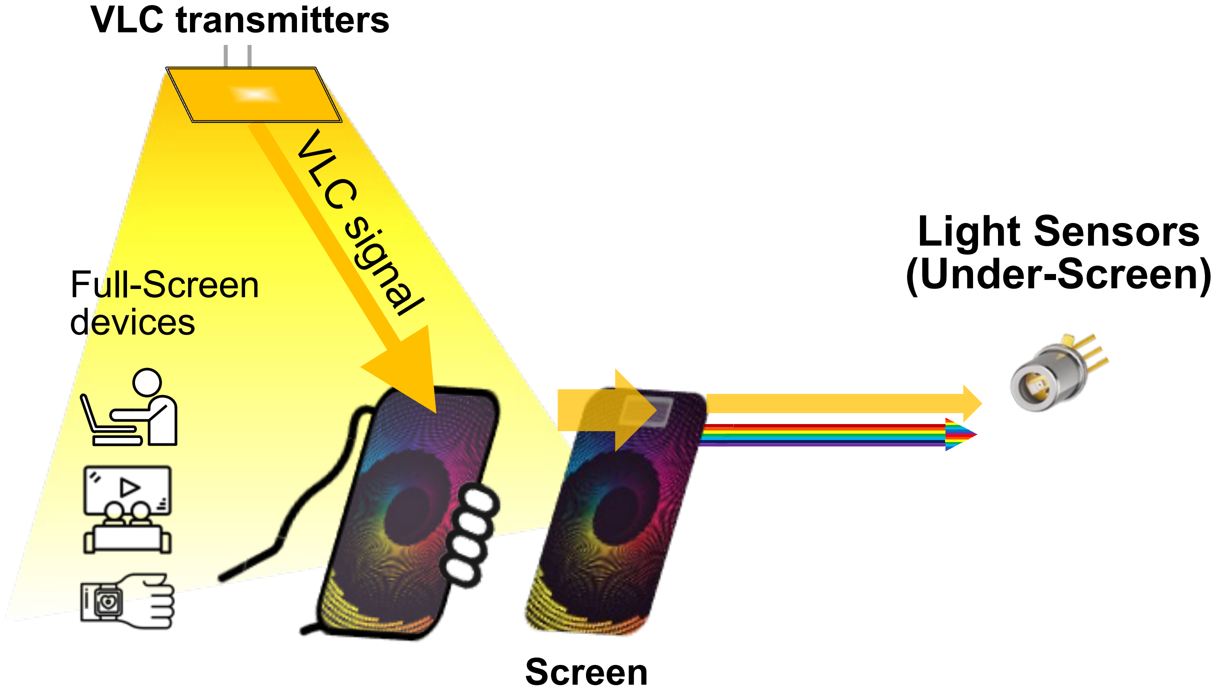


Full-screen & under-screen optical sensors

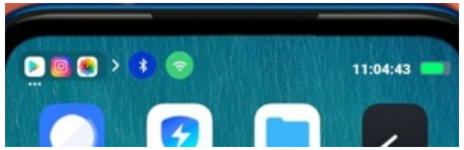


Notch Screen Smartphone

Through-screen VLC system



Static content



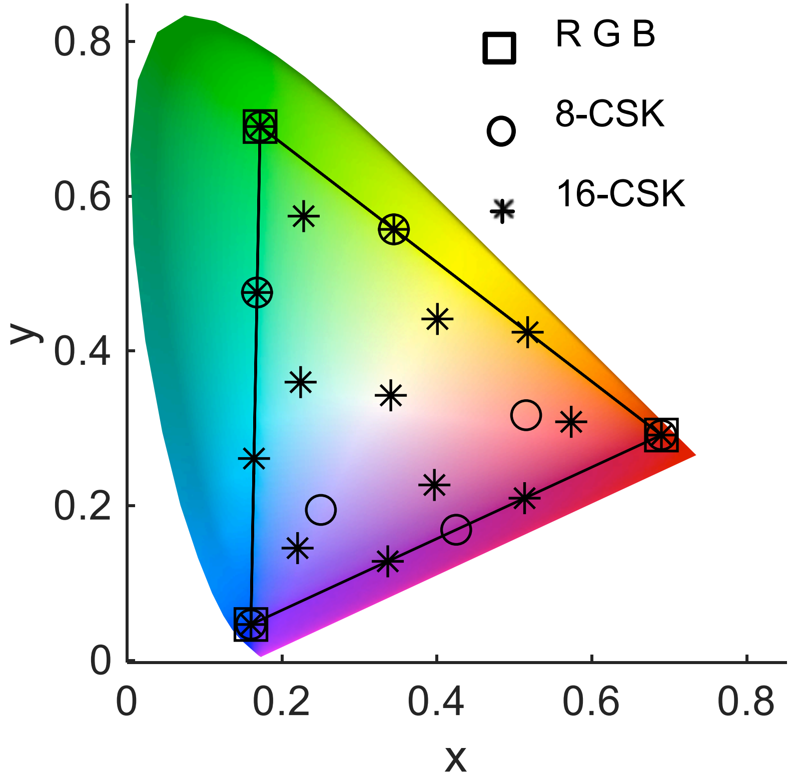
Dynamic content

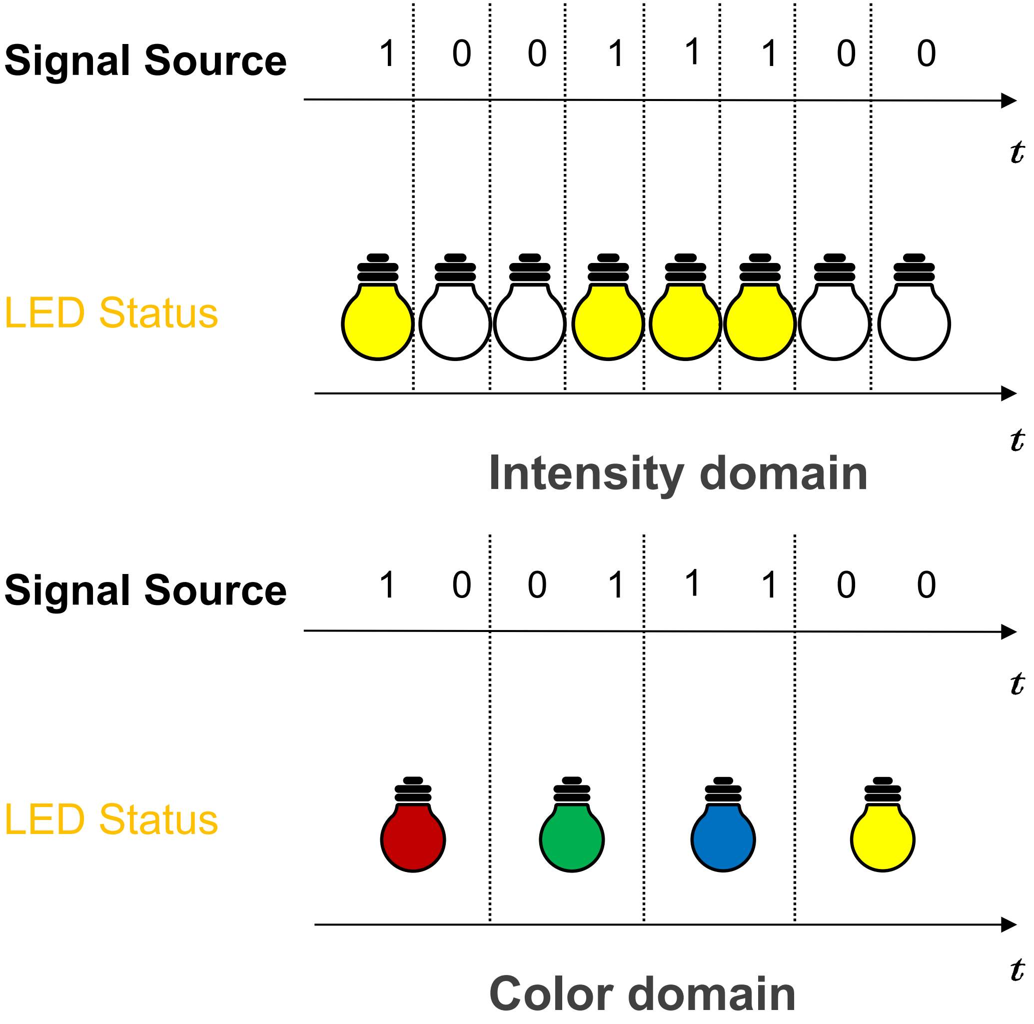
Screen's challenges:

Passive blocker: >90% light loss ('blocked')

Active interference: diffractive blur and color shift

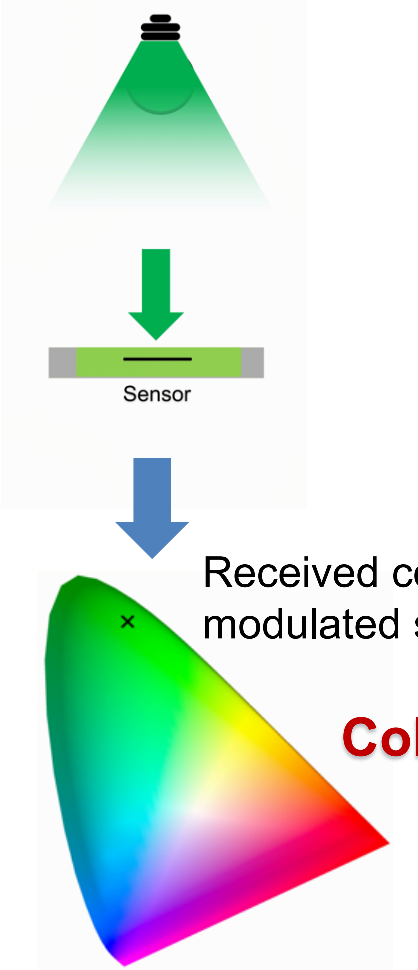
CSK: Color-shift keying modulation





Color-pulling effect & SWebCSK

Common CSK VLC



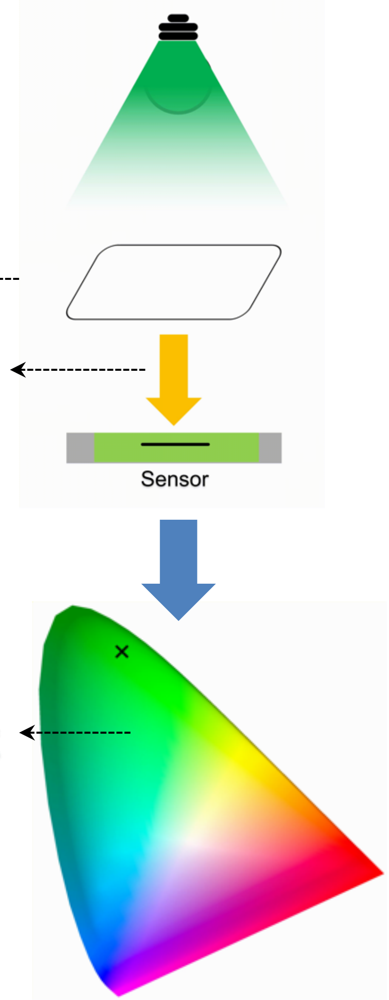
Received color-modulated symbol

Through-Screen CSK VLC

Screen

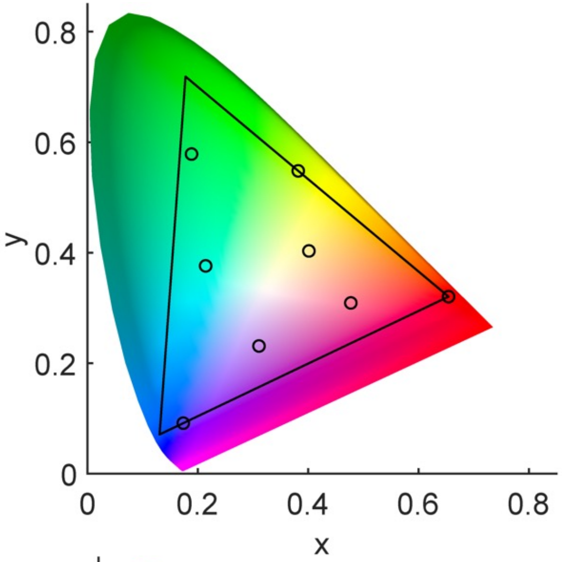
The superposition of modulated light and screen light

Color-Pulling effect

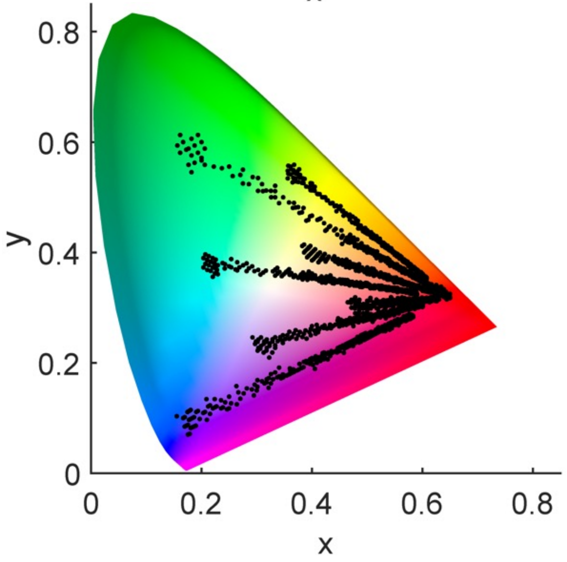


Proposed SWebCSK Solution:

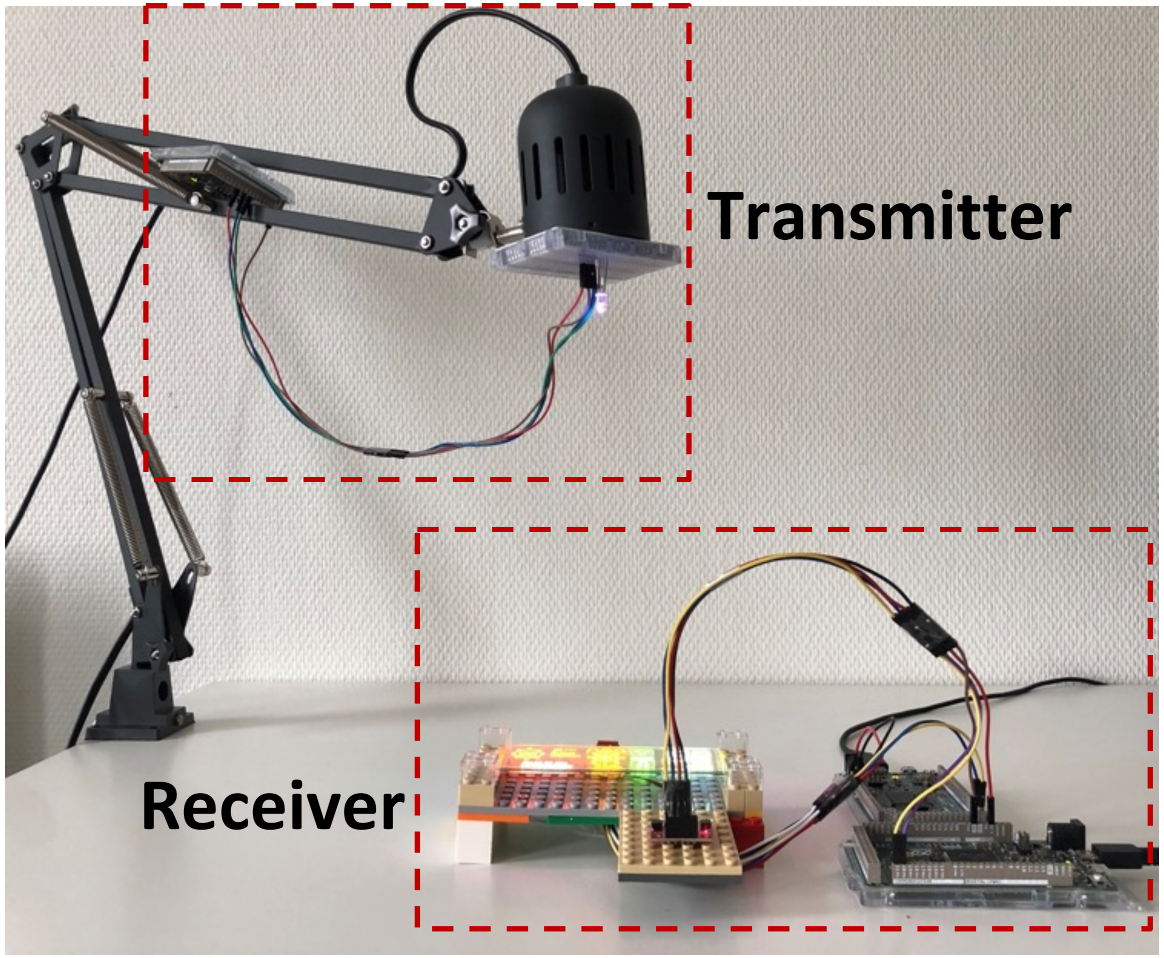
Transmitted SWebCSK Symbols

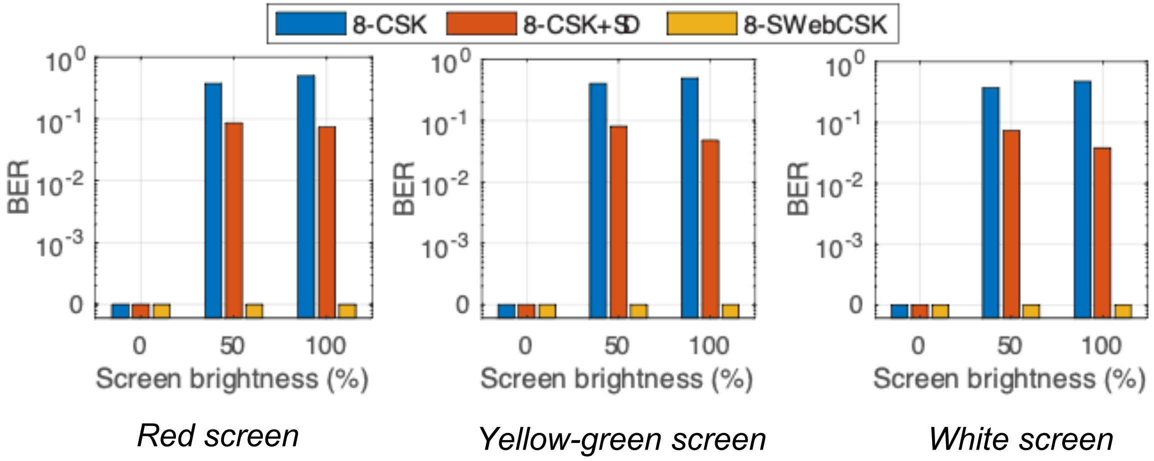


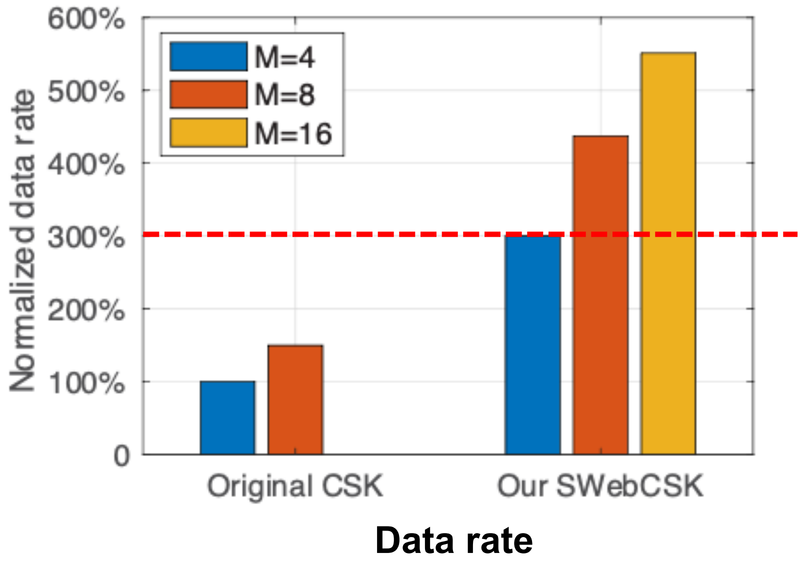
Received SWebCSK Sampling points



Built testbed & experimental results



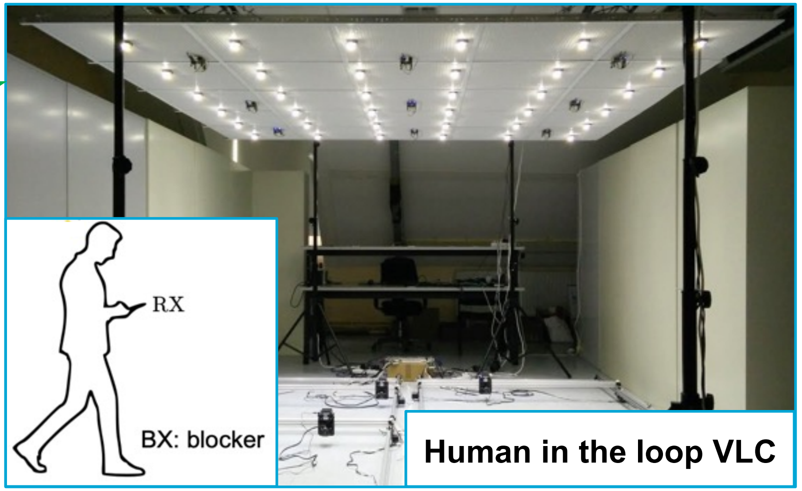




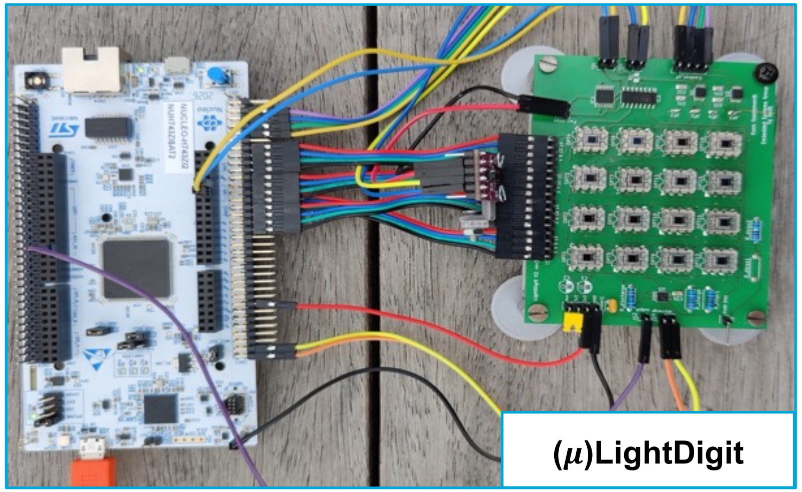
SpiderWeb: Enabling Through-Screen Visible Light Communication
***Hanting Ye**, Qing Wang. ACM SenSys, 2021.*

Conclusion

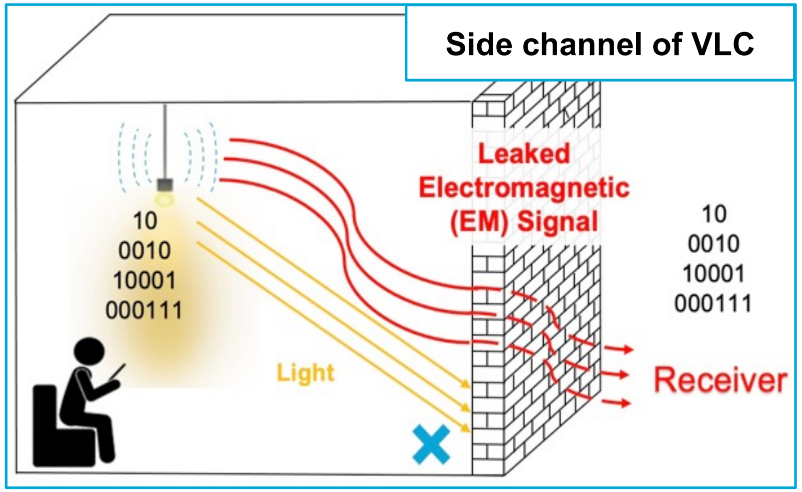
START HERE



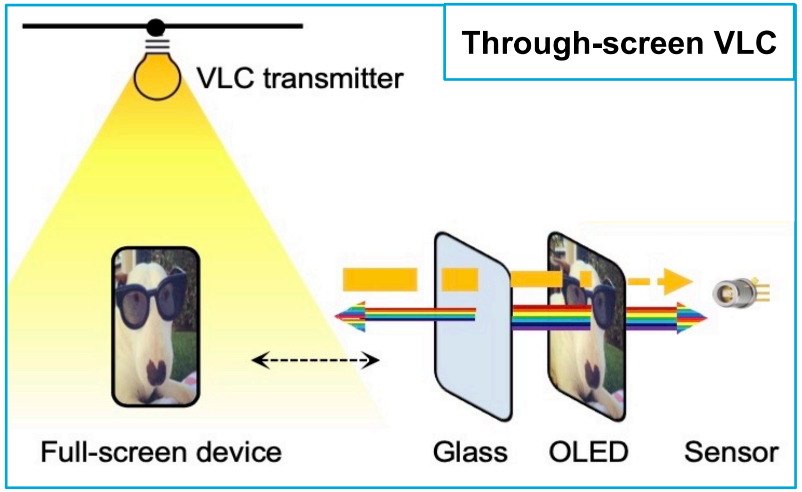
THIRD



THEN



LAST




Thank you!