Unleashing the power of LED-to-camera communications for IoT devices

Alexis DUQUE[1,2], Razvan STANICA[2], Hervé RIVANO[2], Adrien DESPORTES[1]

[1] *Rtone* - [2] *Univ Lyon, INSA Lyon, Inria, CITI*

Outline

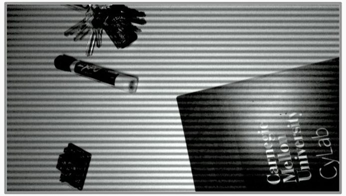
1. Motivations
2. Related Works
3. Platform description
4. Evaluation
5. Conclusion

Motivations

- Add connectivity to consumers electronics products at low cost
- When radio (BLE, NFC, WiFi) does not fit well
- Avoid hardware modifications
- User friendly and easy to use

SMARTPHONE CAMERA and SMALL LOW COST LEDs

Related Works



- LED to Camera communication has already been studied
- Rolling Shutter Effect based
  - [1] *Kuo, Y.-S., Pannuto, P. (2014).* ***Luxapose***. *MobiCom '14*
  - [2] *Lee, H., Lin, H. (2015).* ***RollingLight*** *: Enabling Line-of-Sight Light-to-Camera Communications. Mobisys '15*
  - [3] *Ferrandiz-Lahuerta, J., Camps-Mur, D. (2015).* ***A reliable asynchronous protocol for VLC communications based on the rolling shutter effect.*** *GLOBECOM '15*
  - [4] *Rajagopal, N., Lazik, P. (2014).* ***Visual light landmarks for mobile devices***. *Journal of Lightwave Technology.*
  - [5] *Hao, J., Yang, Y.* ***CeilingCast****: Energy Efficient and Location-Bound Broadcast Through LED-Camera Communication. INFOCOM '16*
- UFSOOK [6] *Roberts, R. D. (2013). Undersampled frequency shift ON-OFF keying (****UFSOOK****) for camera communications (CamCom). WOCC '13*

BUT THEY ALL TARGET LIGHTING PURPOSE LEDS

Related Works

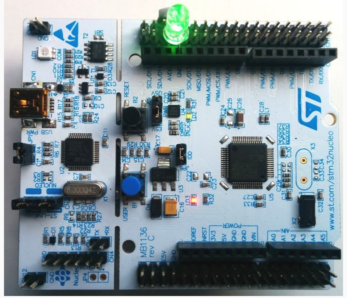
	Description	Computation Time	Modulation	Througput	Range
[2] RollingLight	LOS Ceiling/Spot LED	ROI Detection: ? **performed only once** Demodulation : 18.1ms	FSK	12 Bps	600 pixels
[3] Ferrandiz-Lahuerta	NON LOS Ceiling LED	ROI Detection: NA Demodulation : 18.1ms	OOK	700 bps	3m
[4] Visual Light Landmarks	NON LOS Ceiling LED	ROI Detection: NA Demod.: 18.1ms	FSK	1.25 Bps	3m
[5] Ceiling Cast	LOS LED strips	ROI Detection: ? **performed only once** Demod.: 9 ms	OOK	480 bps / LED	5m
[1] Luxapose	LOS Ceiling LED	Full algorithm : 300 ms **on a cloudlet**	OOK FSK	NA : **indoor loc.**	2.5m

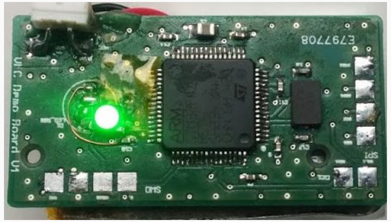
Motivations

- Can we apply previous works to small colour LED ?
- Adapt them to our context
- How much throughput ?
- Is our solution robust against ...
  - Indoor illumination ?
  - Sun ?
  - Motion ?
  - Distance ?

Platform description

Emitter : STM32 Cortex M0+



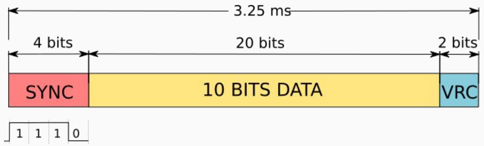


Receiver : LG Nexus 5

Platform description

Emitter : STM32 Cortex M0+

- 6 kHz On-Off-Keying modulation
- Manchester RLL code
- 10 bits payload + 2 parity bits

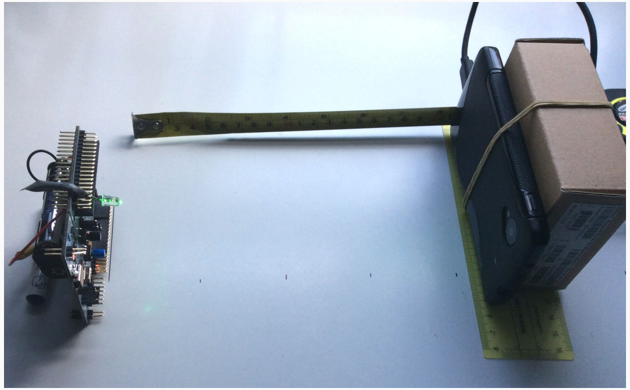


Receiver : LG Nexus 5

- Android Marshmallow 6.0 (API 23)
- 30 fps
- Sensor sensitivity : ISO 6400
- Exposure Time : 1/100000 s

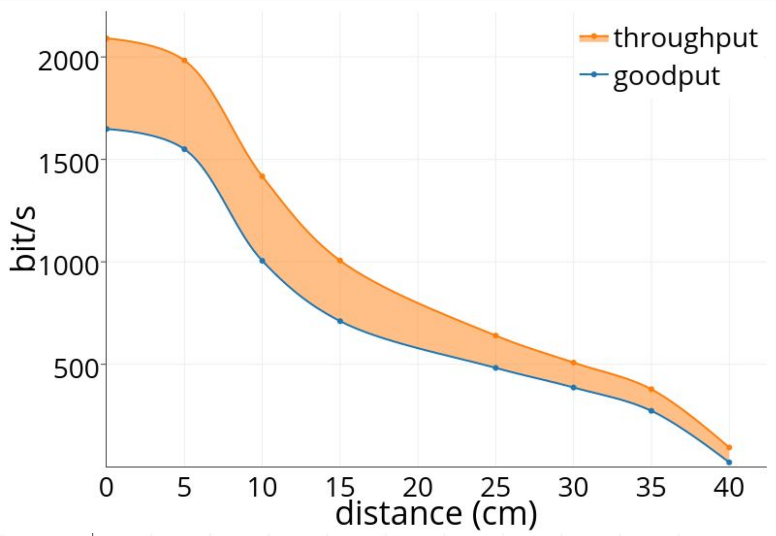
Evaluation

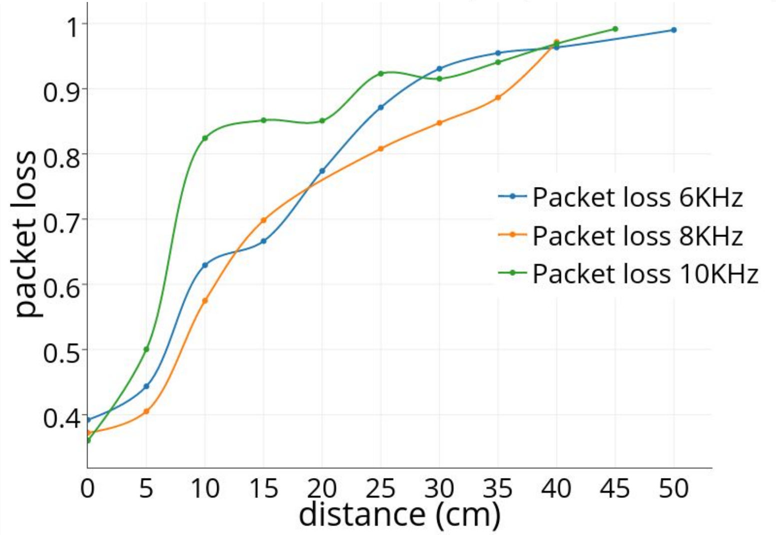
- Distance
- Illumination
- User impact
- Angle
- Algorithm performance



Evaluation
Distance

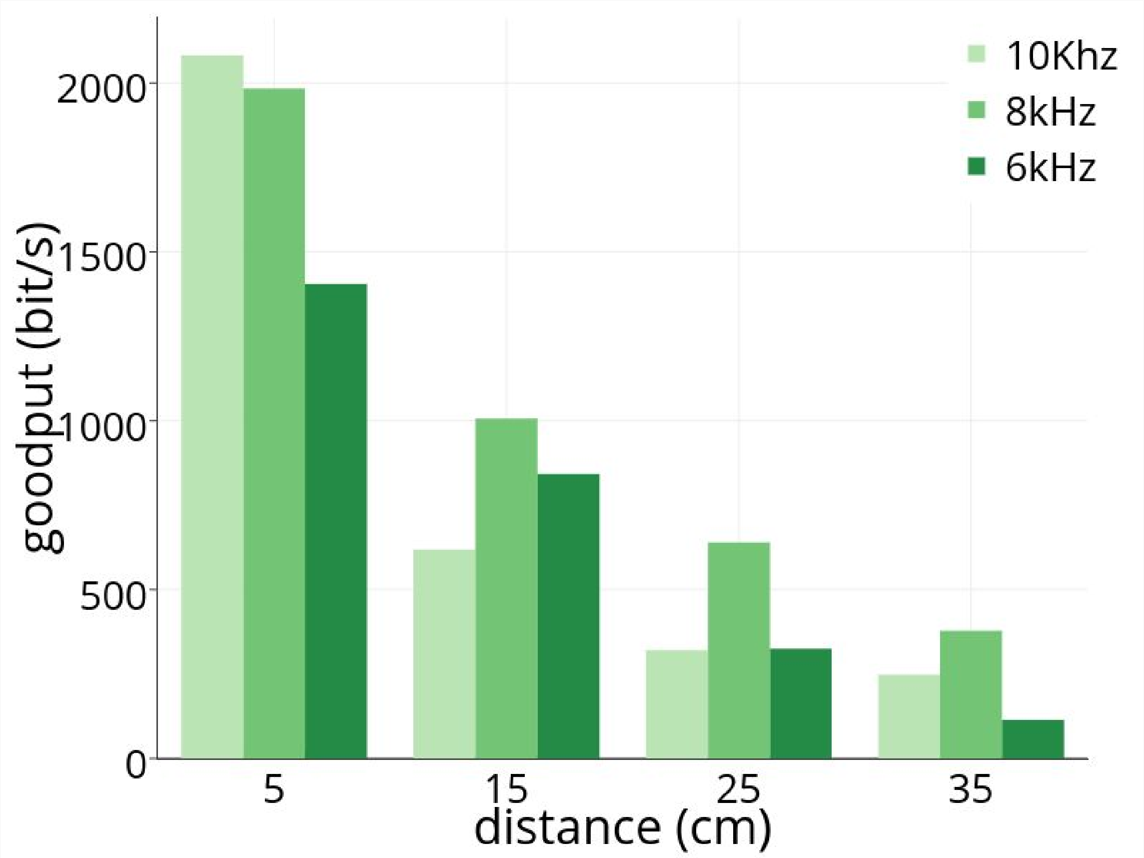
- ➔ 6 kHz Clock Rate
- ➔ 1600 bits/sec at 5cm
- ➔ / 2 at 15 cm
- ➔ Distance reduce the ROI on each frame





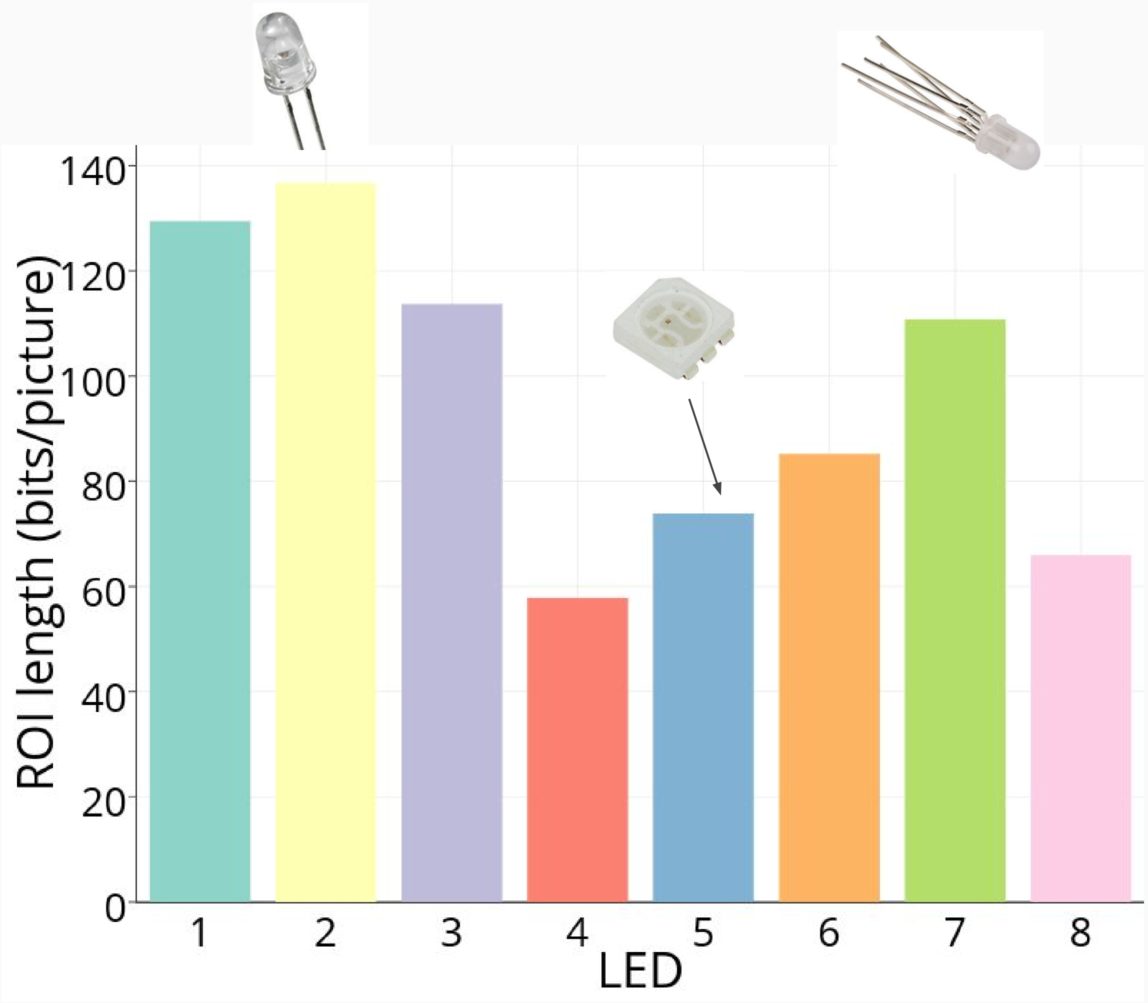
Evaluation
Frequency

- ➔ f > 8 kHz introduce decoding error
- ➔ Due to the camera row scan freq.
- ➔ High frequency -> smaller packets -> increase range



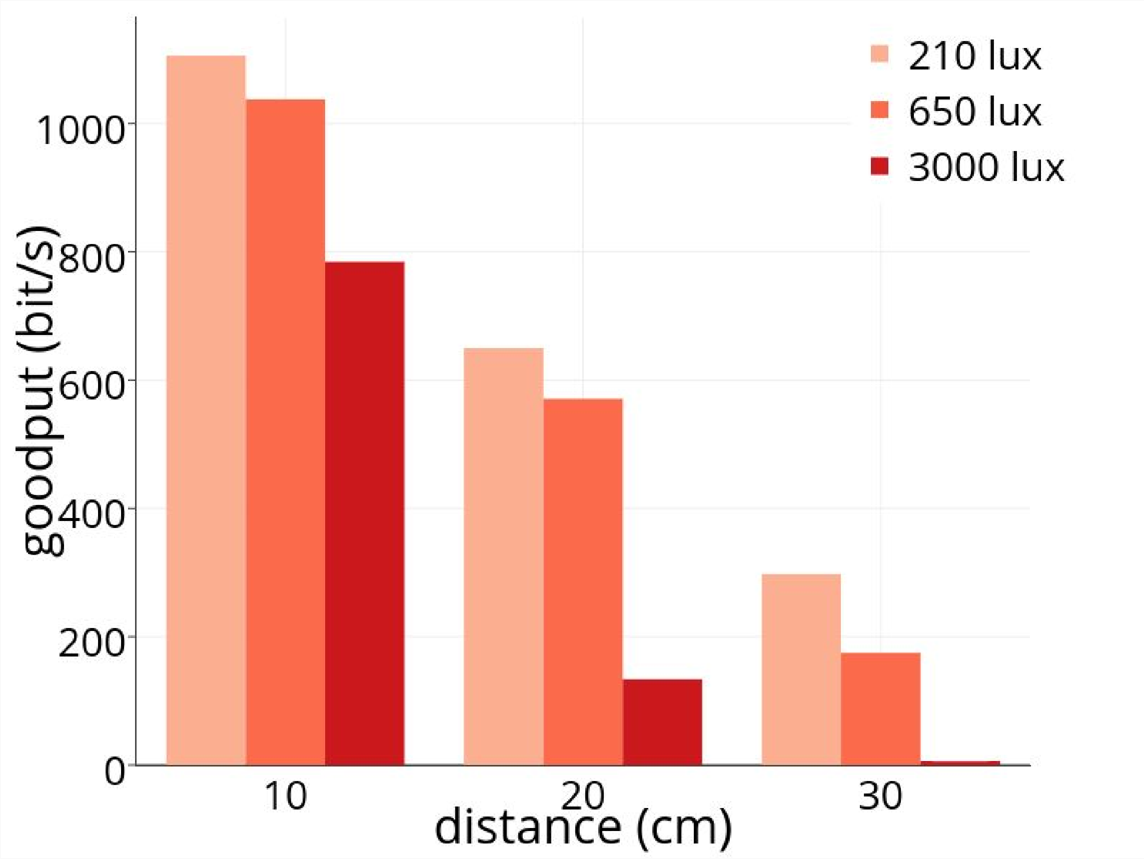
Evaluation
LEDs

- ➔ Green LED is better (2, 7, 5)
- ➔ Lens
- ➔ Different half power angle
- ➔ SMB LEDs (4, 5)



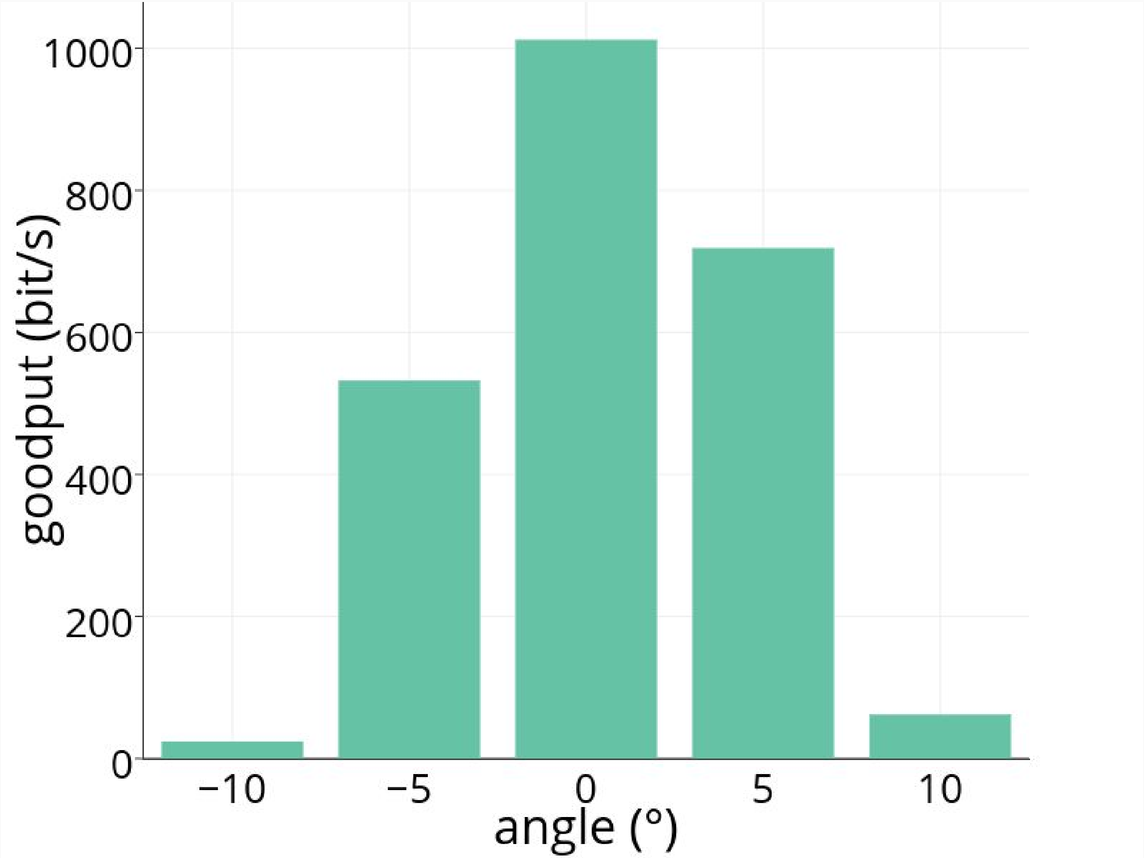
Evaluation
Illumination

- ➔ Robust in most indoor condition
- ➔ 650 lux ≈ standard indoor illumination for desk work
- ➔ Broken by sun due to CMOS sensor saturation



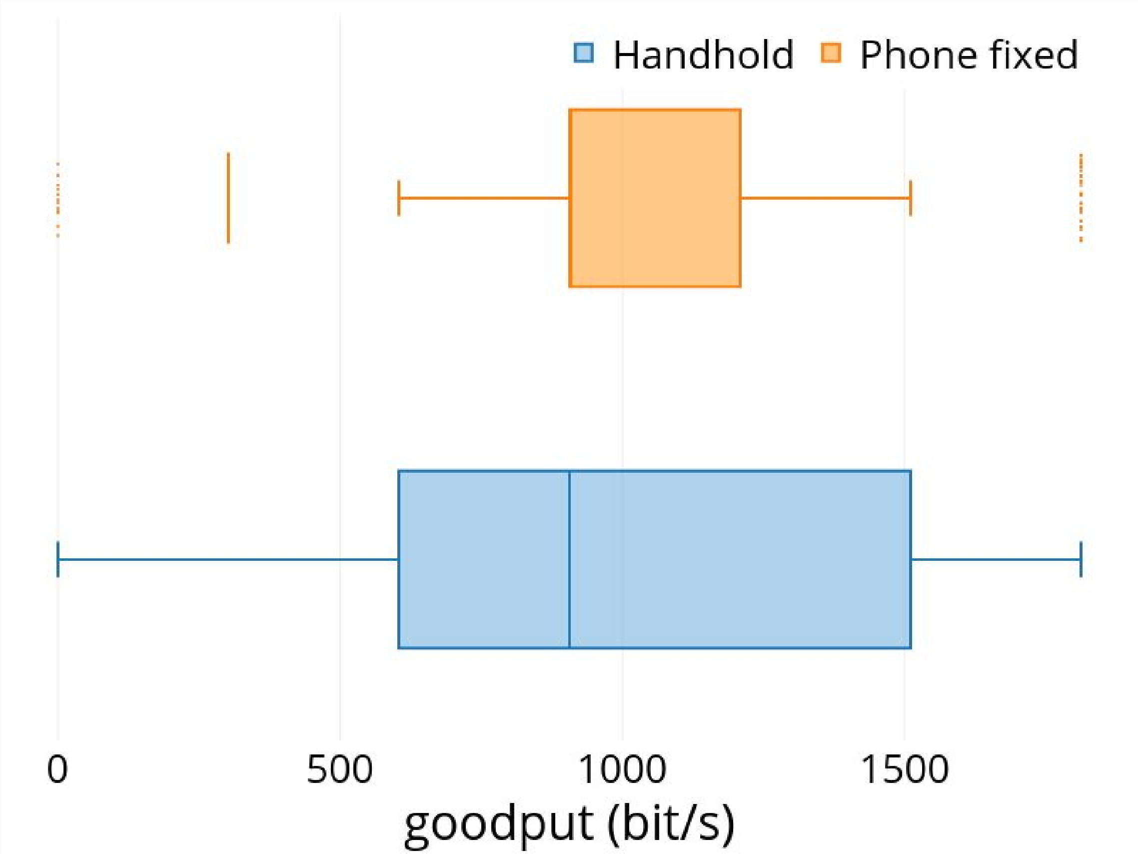
Evaluation
Angle

- At 10 cm
- Half-power angle LED (15 - 30°)
- Could be fixed using another kind of LED
- But max throughput will decrease



Evaluation
User impact

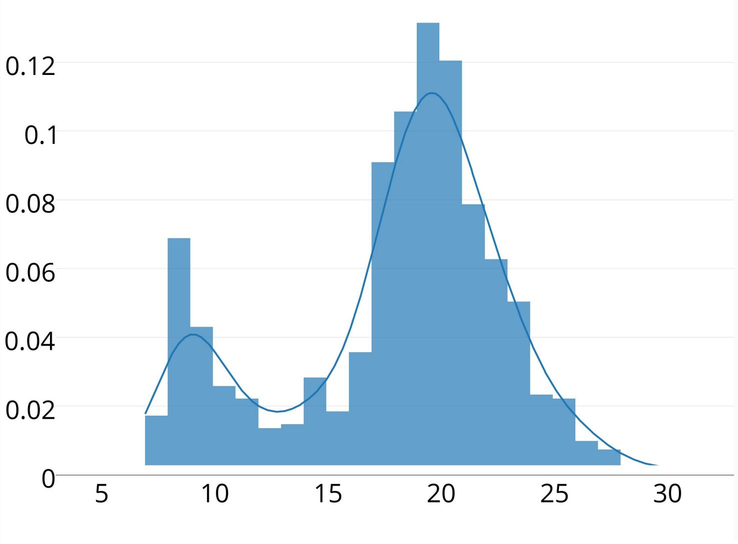
- ➔ Holding a smartphone, user introduce small angle changes
- ➔ High throughput change !

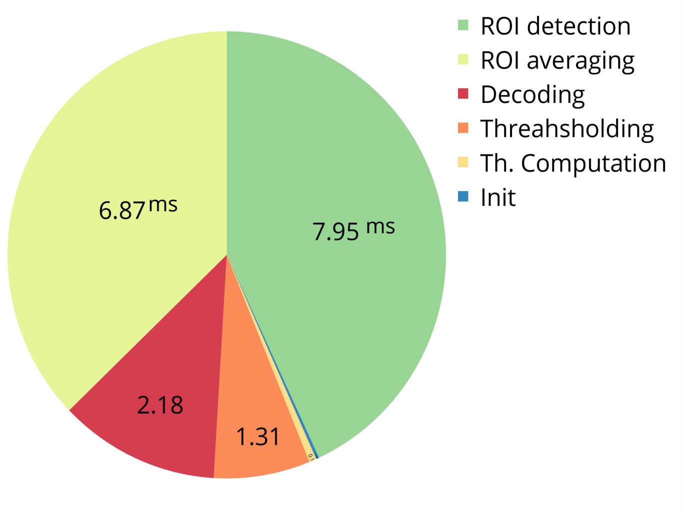


Evaluation

Algorithm performances

- ➔ Real time
- ➔ 18.4 ms on average
- ➔ LED position is computed on each frame (every 33 ms)



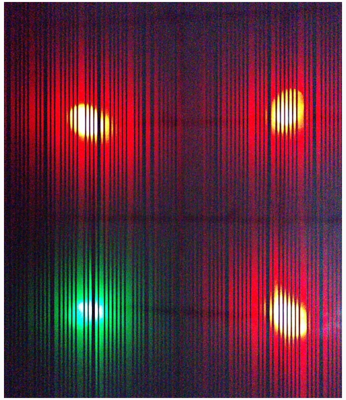


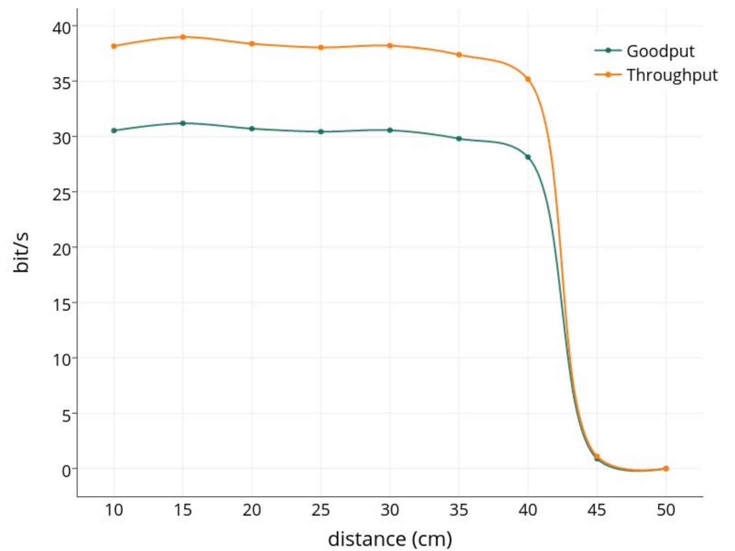
Conclusion

- Using **small color LEDs** is feasible
- Performance and impact of environment factors has been evaluated
- **1,6 kbit/sec** in **short range conditions** (5cm)
- **Real time** computation
- Robust against motion

Further work

- Study smartphone to LED using flashlight
- Multiple LEDs communications





Thank you for listening ! Questions time

RTONE

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Rolling Shutter Effect