Okuli:
Extending Mobile Interaction Through Near-Field Visible Light Sensing

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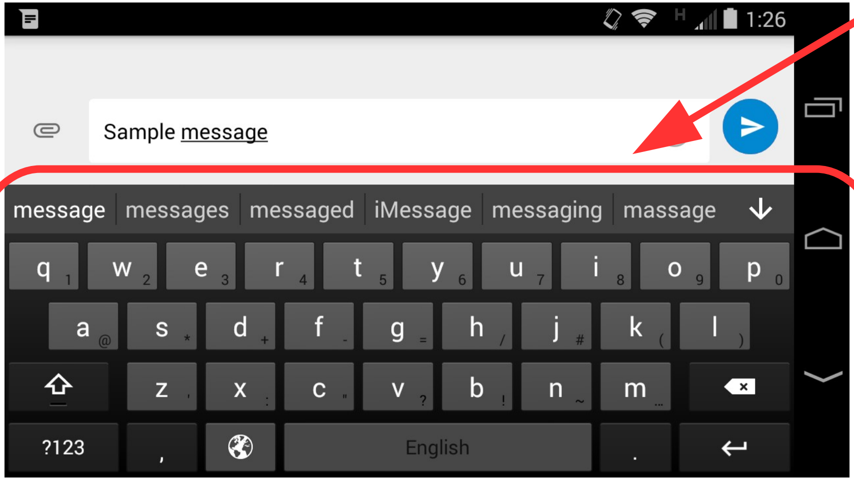
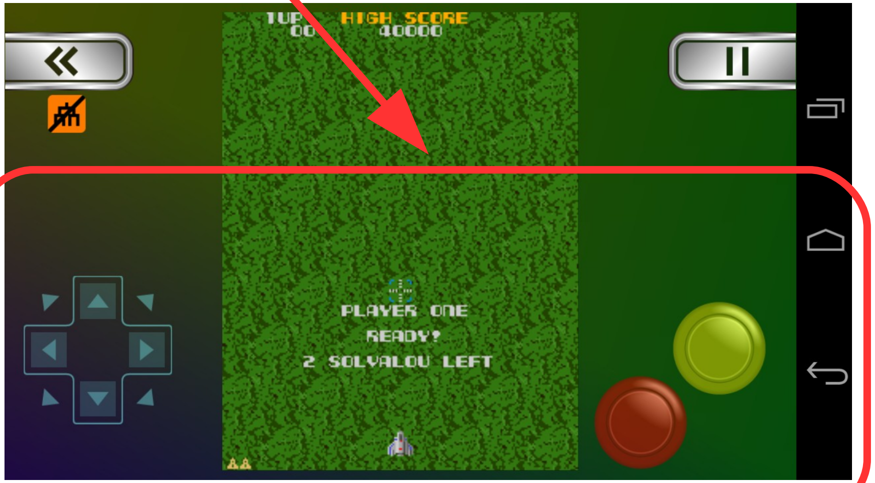
Touch is a dominant mode of mobile interaction

But on-screen touch input is not always effective!





Screen multiplexed between display and input

Wastes precious display area

On-screen keyboard hard to use

Input area depends on device size

Infeasible on wearable devices

Lack of physical interaction

No accurate feedback

Separate device means extra burden

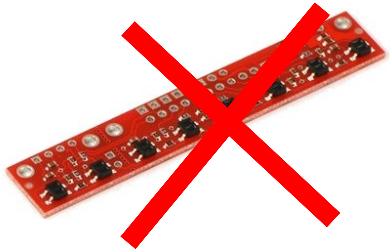
Can be solved by separating display and input

With passive wireless sensing

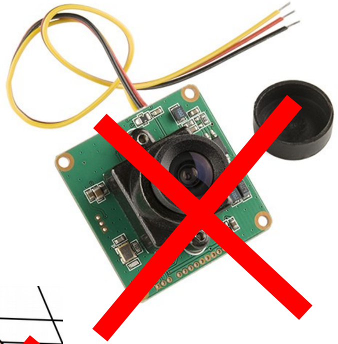
Bridging VLC and touch sensing

Previous solutions

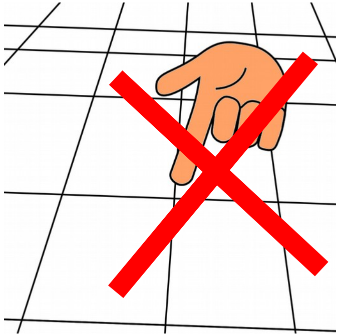
Array of LED/PD pairs: energy hungry, cumbersome



Computer vision: heavy computation, obtrusive camera



Machine-learning: excessive run-time training



Use PD/LED pairs in a different way

Visible light channel

- No phase information
- Amplitude is fine-grained and deterministic

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Requires a fine-grained model to achieve localization

Use PD/LED pairs in a different way

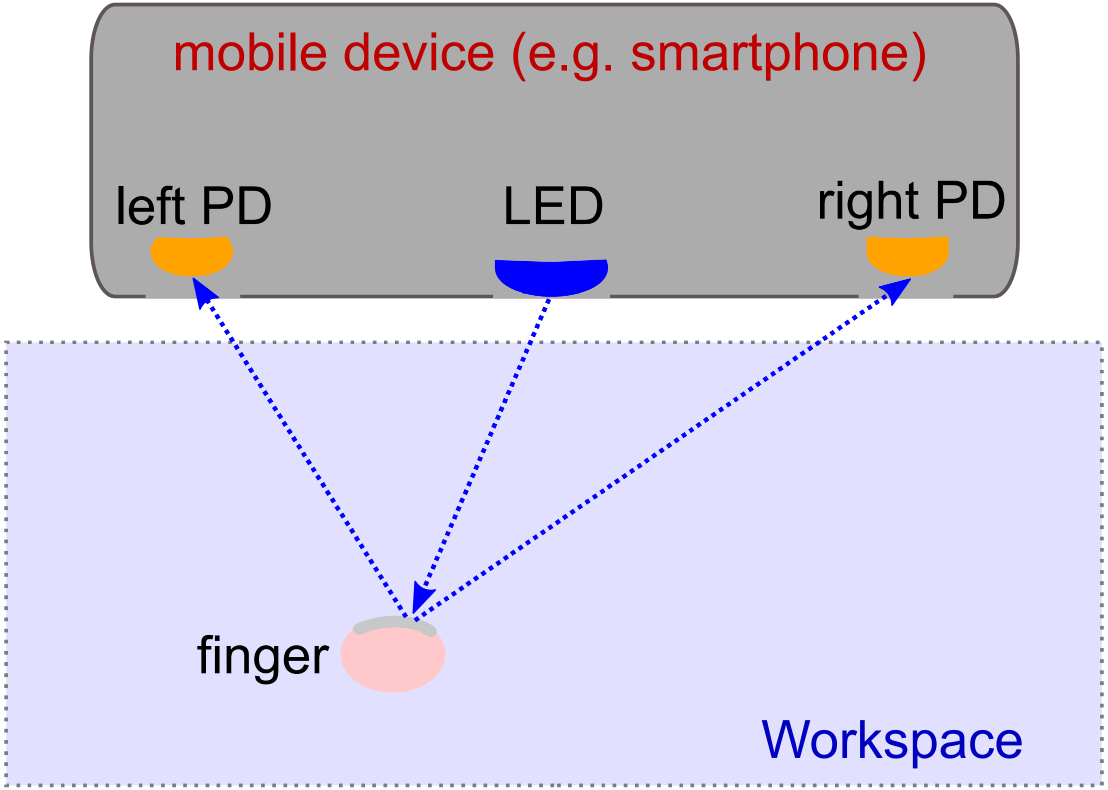
Unlike simple “finger blocking beam” model,

fine-grained propagation model can enable lightweight localization

With such model and 2 channels, we can locate user's finger

- This is how *Okuli* works

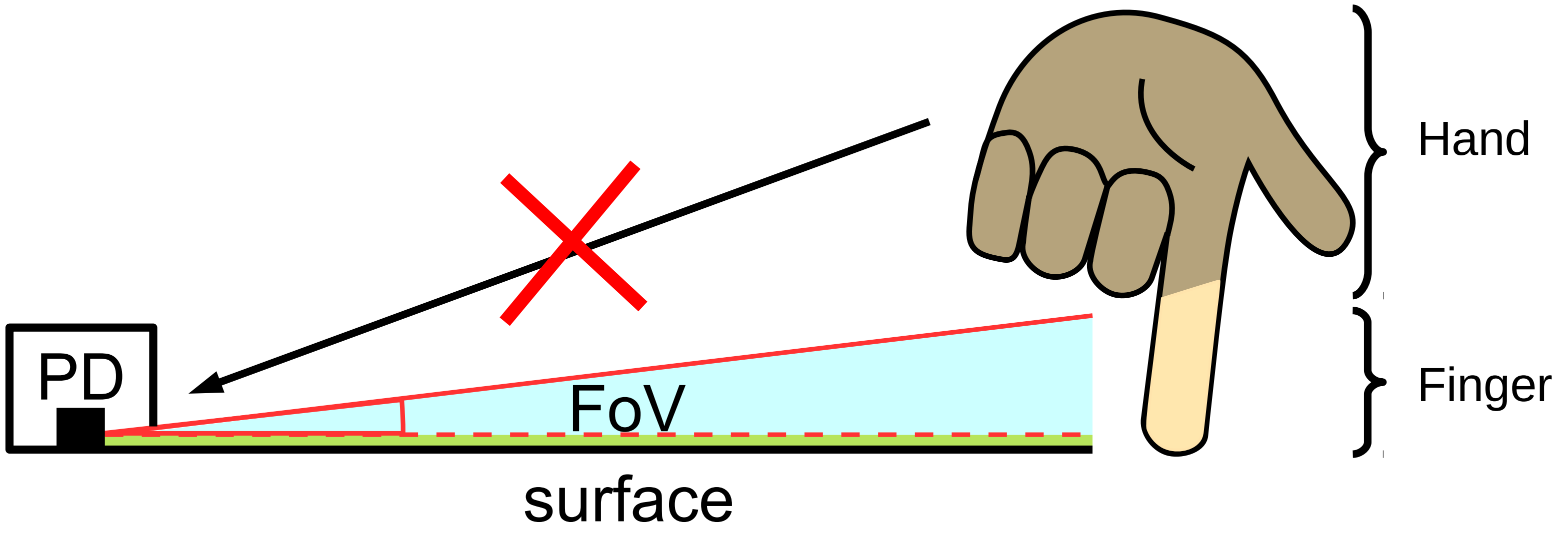
***Okuli*: overview**



Okuli: light grooming

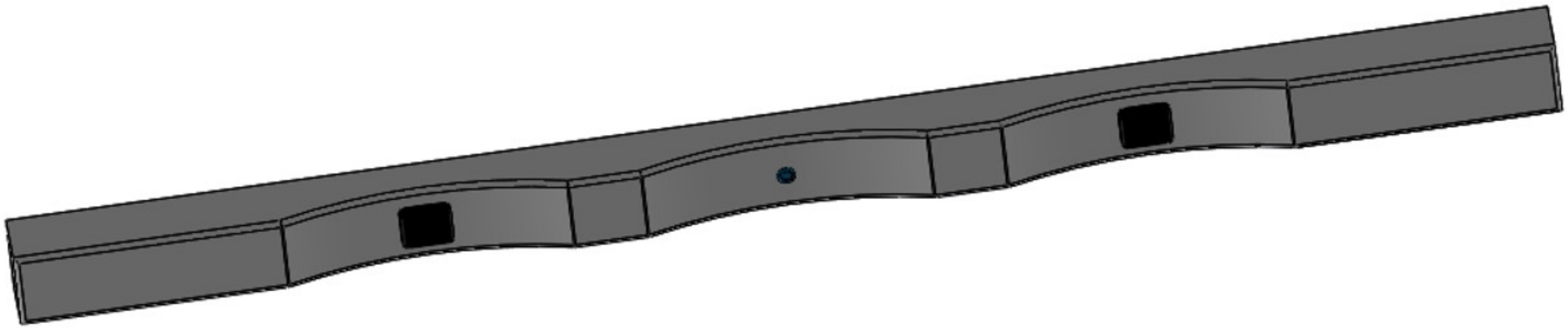
2D localization → want to limit to 2D surface → light grooming

- Eliminates interferences from outside the surface



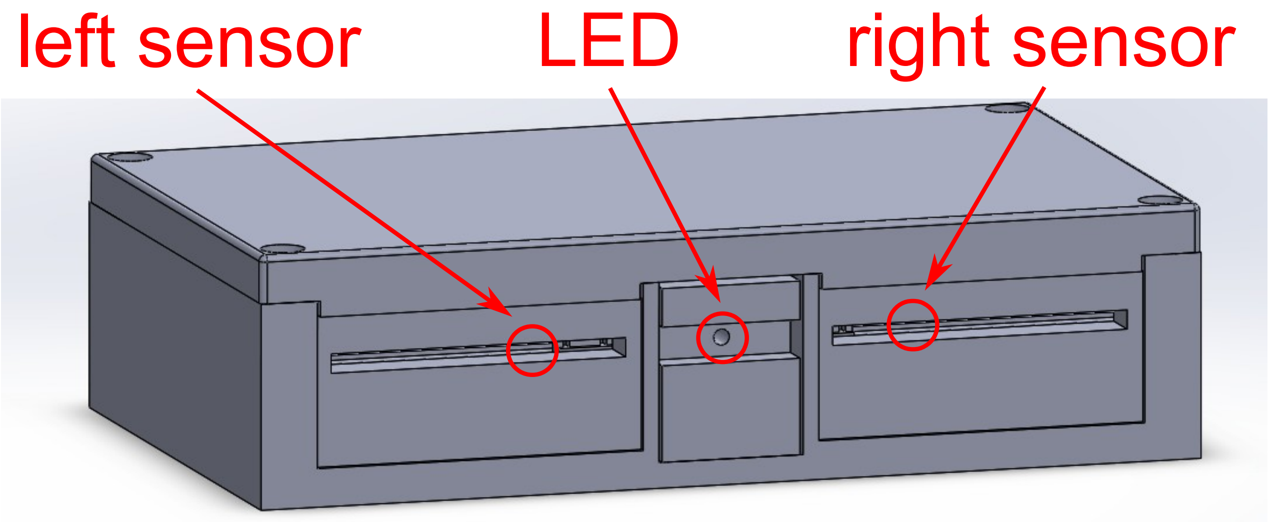
Okuli: light grooming

Can be done with tiny lenses attaches to PDs / LED

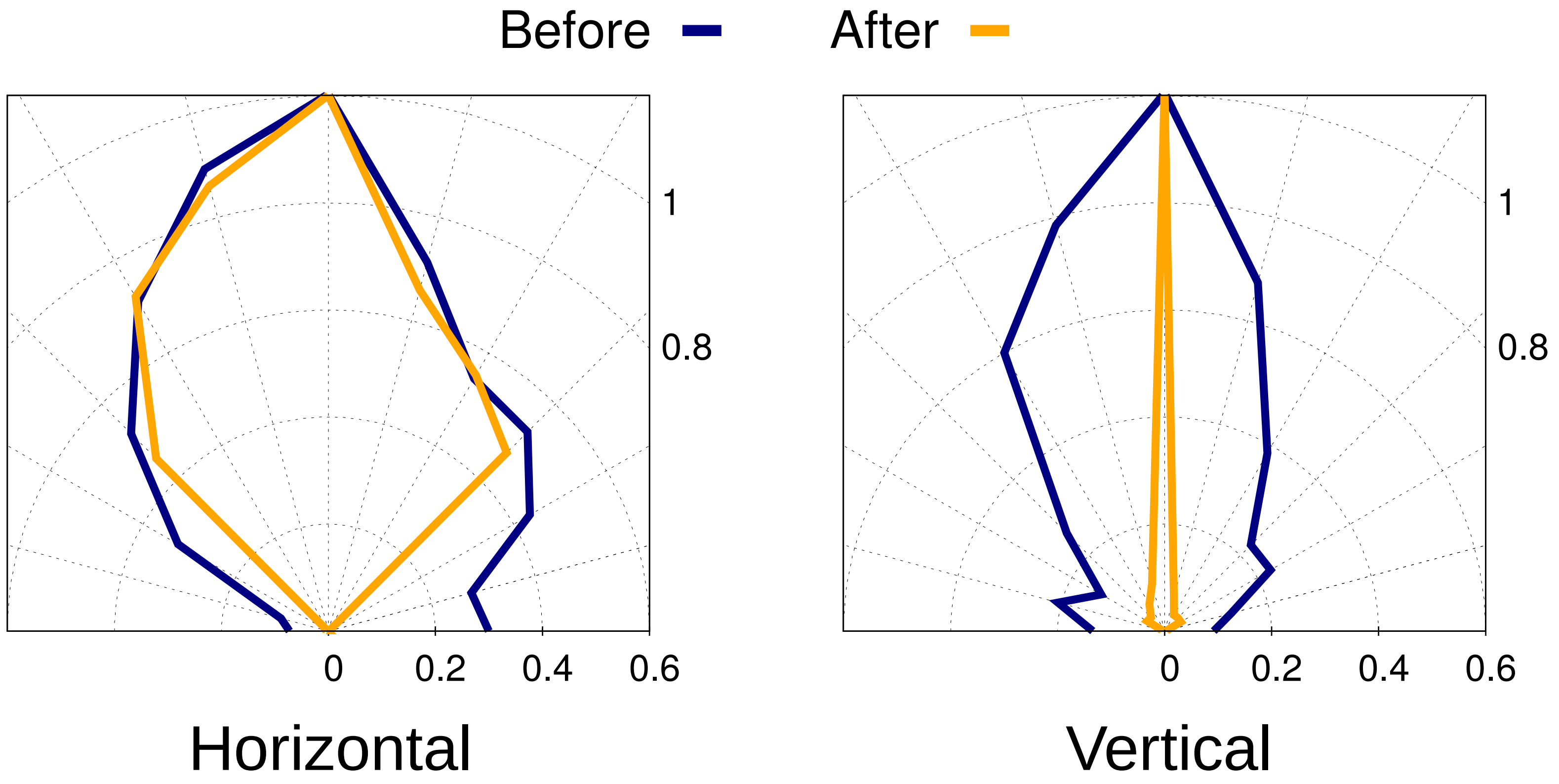


Okuli: light grooming

For prototyping we use a 3D-printed shroud



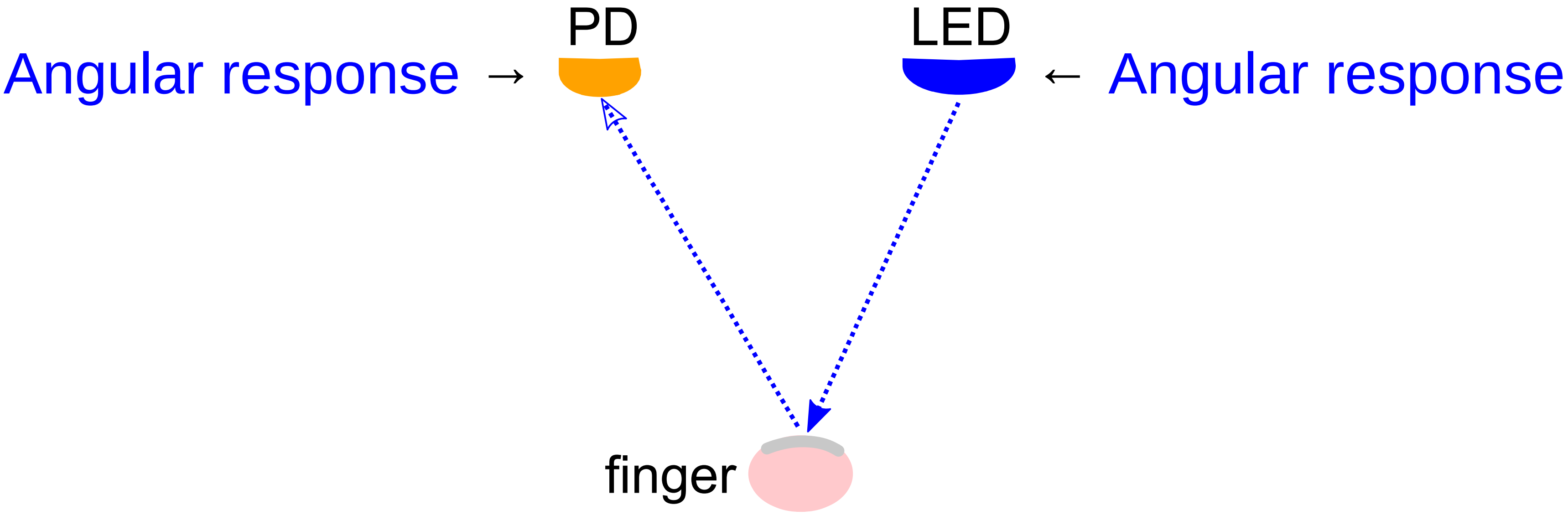
Okuli: light grooming



***Okuli*: channel model**

Received signal is affected by multiple factors

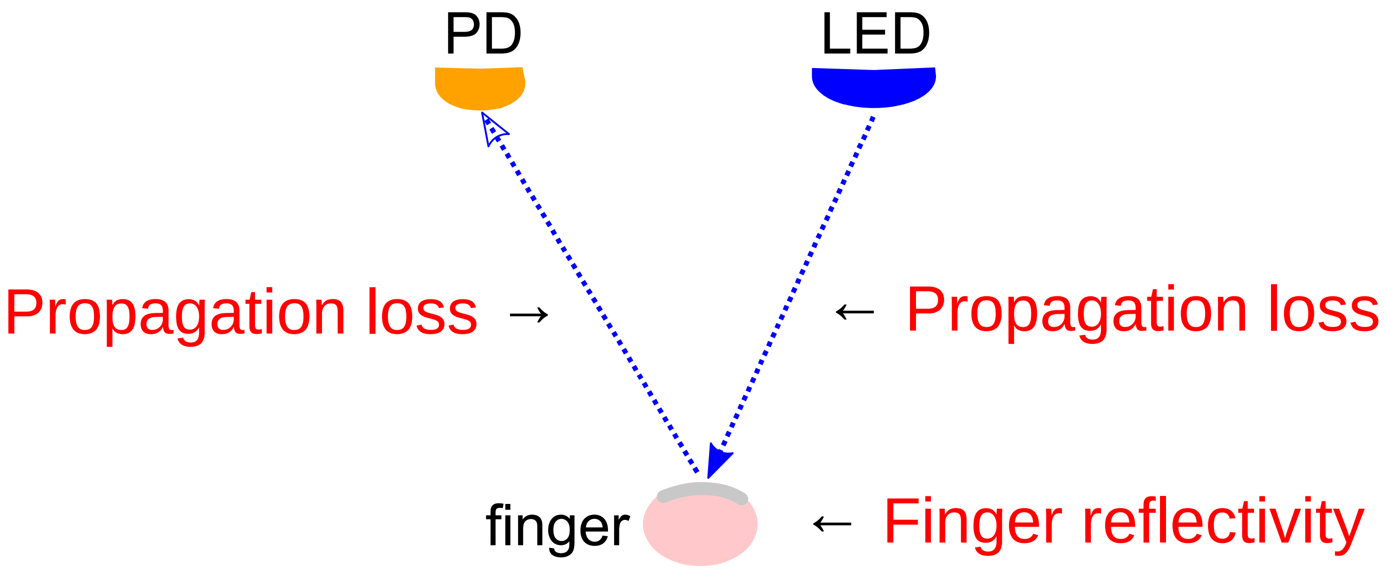
- Factory calibration measures invariant part



Okuli: channel model

Received signal is affected multiple factors

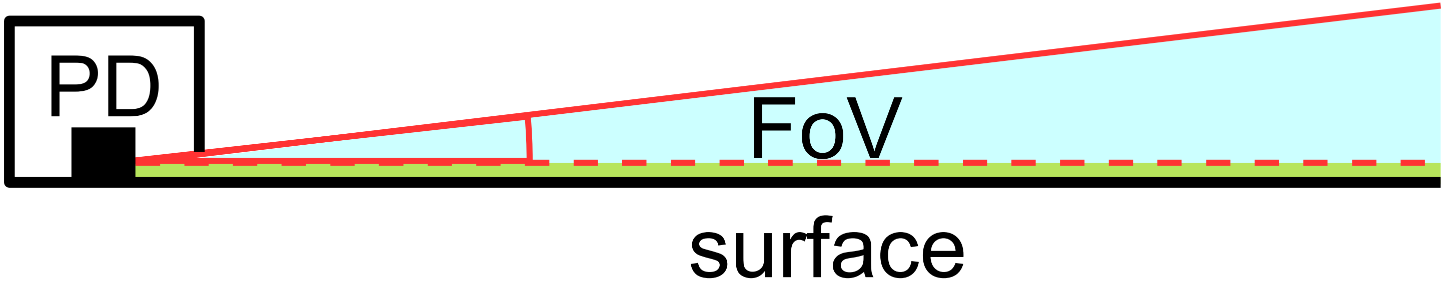
- Model calculates variant part



***Okuli*: channel model**

Path loss is not simple: it is not actually only 2D

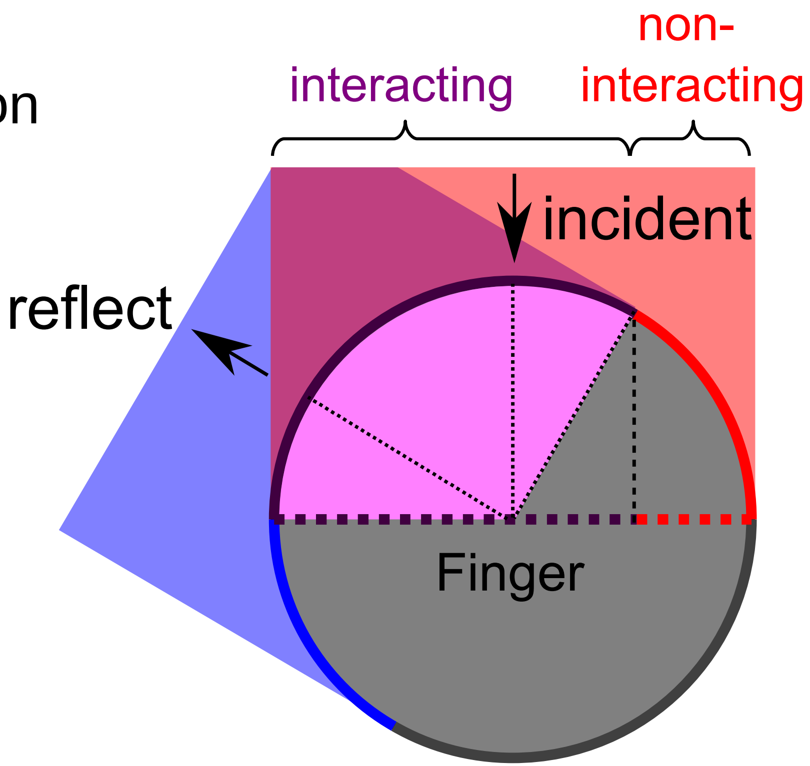
- Further away, more area visible
- Model needs to compensate



Okuli: channel model

Finger reflectivity can be hard to characterize

- Abstract by interacting ratio of the beam
- Overall reflectivity corrected by calibration



***Okuli*: interference canceling**

Surrounding light sources

- Can be much stronger than desired RSS
- Not “coherent” with our light emission

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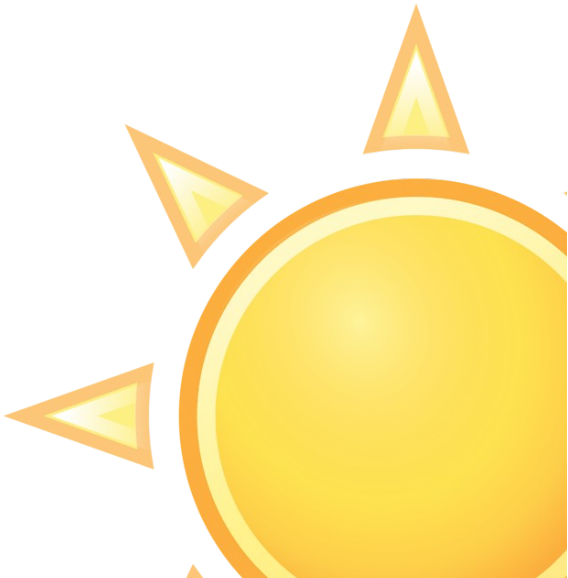
Modulate our own emission with OOK

- Also helps saving energy



Okuli: interference canceling

Background reflection

- Cannot be removed by modulation
- Usually slow-changing and not very strong

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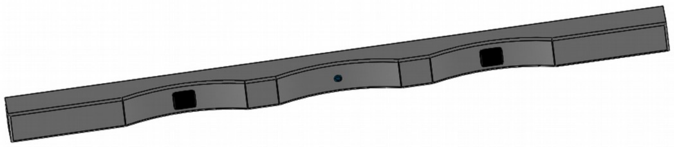
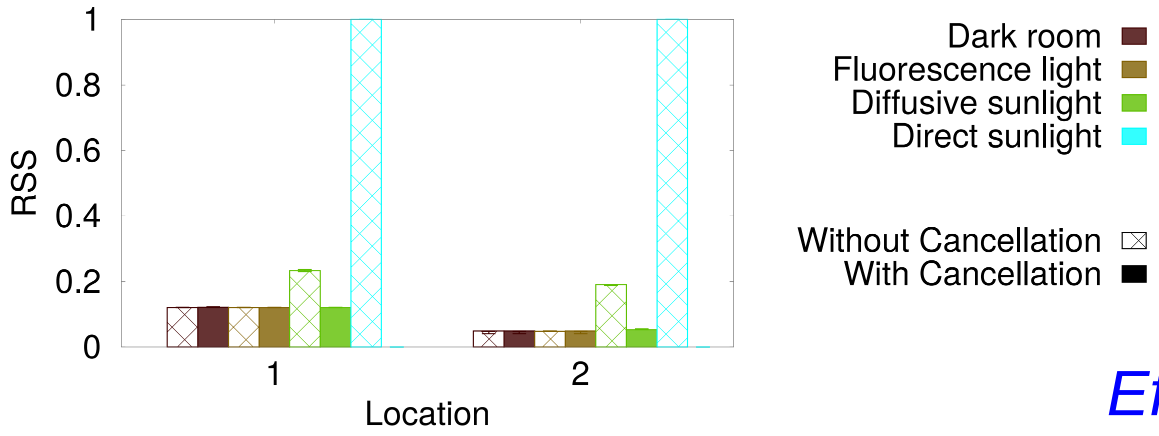


Spatial solution: narrow vertical FoV

Temporal solution: dynamic estimation & removal

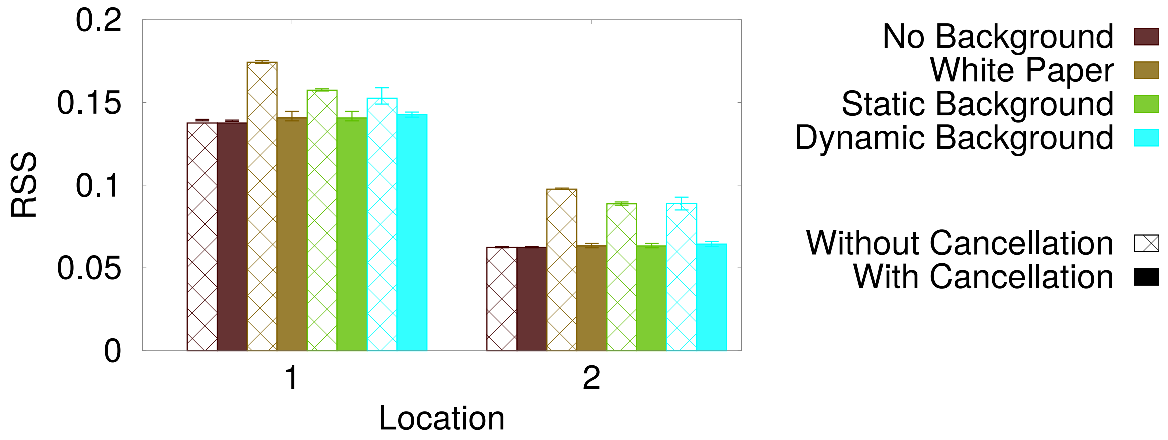
- Identifies and tracks background
- Also detects clicks

Okuli: interference canceling



Ambient light

Effective in most cases



Dynamic background

***Okuli*: localization**

For each point, model produces an expected RSS

Samples are compared with these RSS

Location that has minimum RSS error is selected

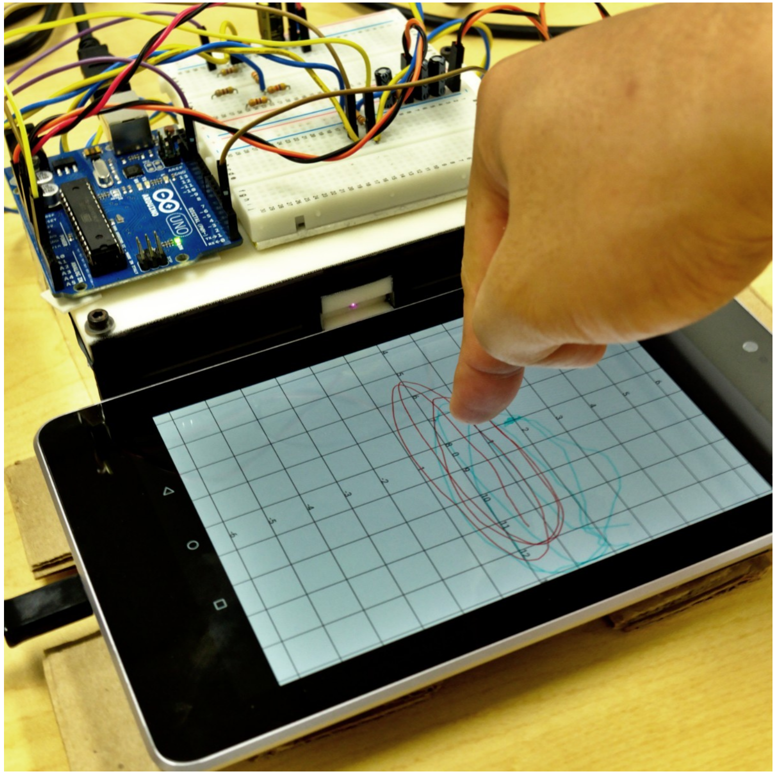
Prototyping ***Okuli***

3D-printed shroud controls FoV

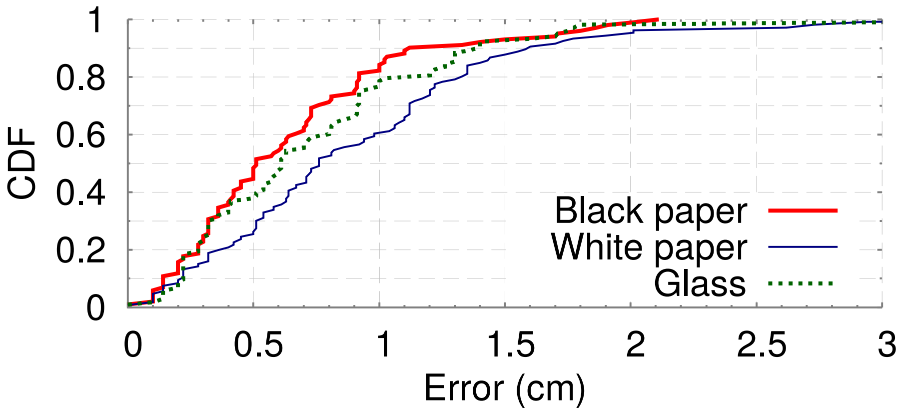
Arduino drives LED and samples PDs

Bluetooth connects *Okuli* to mobile devices

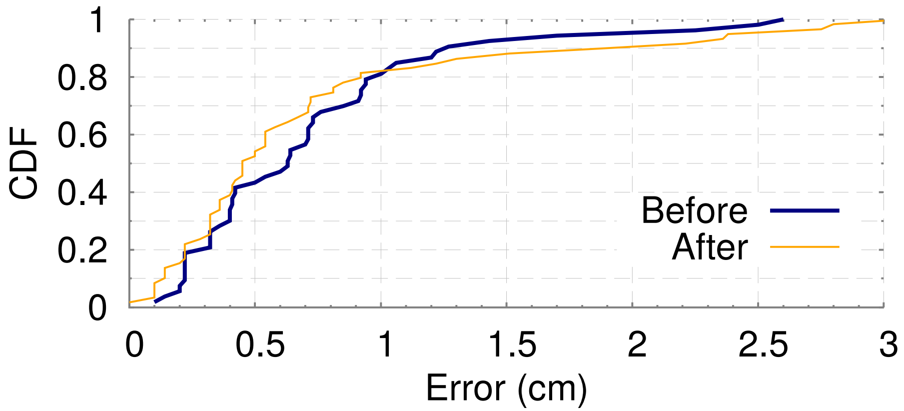
Mobile device runs the algorithm



Performance



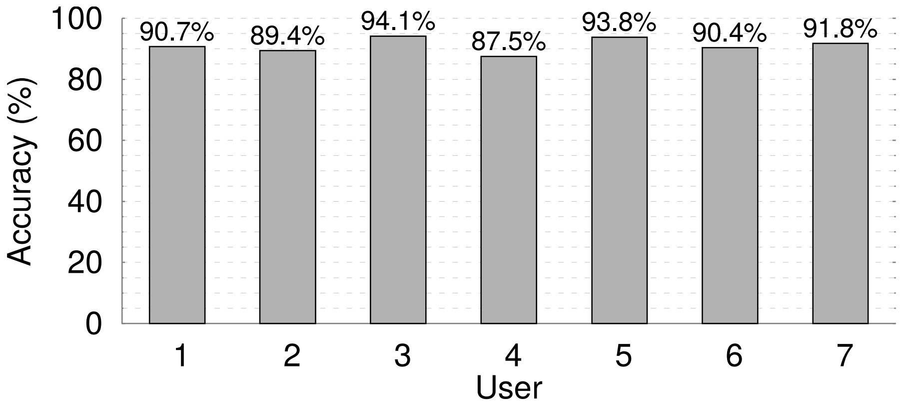
Accuracy across different surfaces



Accuracy across time (10 days)

Okuli is consistent across different surfaces and over time

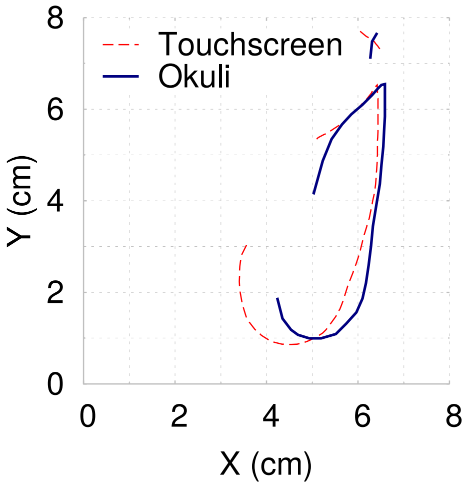
Performance



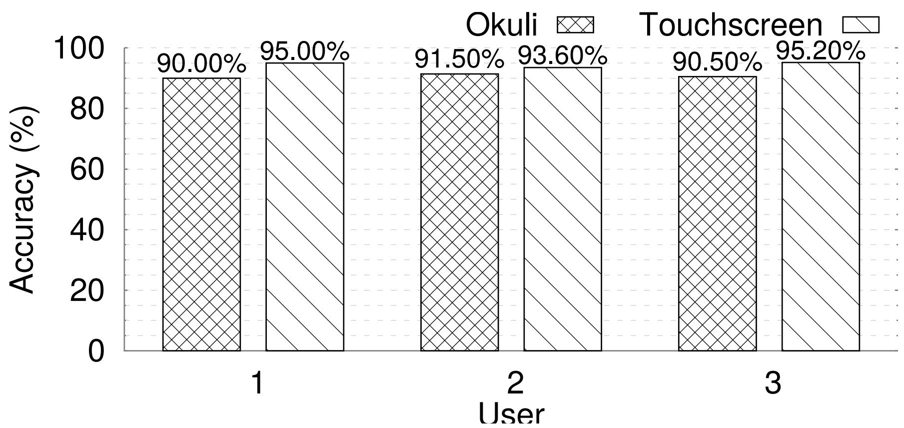
Keypad (20 keys)

Okuli is consistent across different users

Performance



Sample trackpad trace



Handwriting recognition

Okuli's performance is comparable with capacitive touch screens

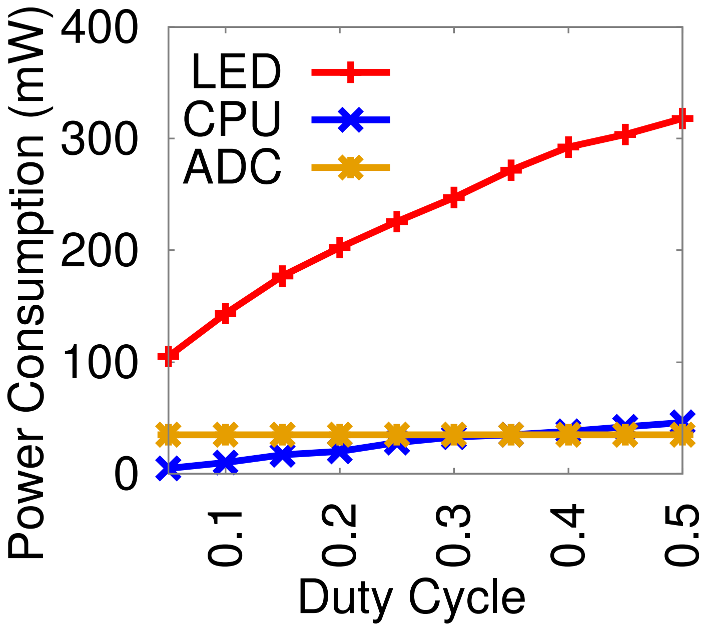
Performance

Most energy cost by light emission

- Can duty-cycle to reduce

Processing costs very little

- Smooth UI, good user experience



Conclusion

- Fine-grained light propagation model can enable accurate near-field visible light localization
- Multiple types of interferences exists in the visible light channel, and can be effectively canceled
- Visible light channel allows us to achieve centimeter grade passive localization with a compact system

Thank you!