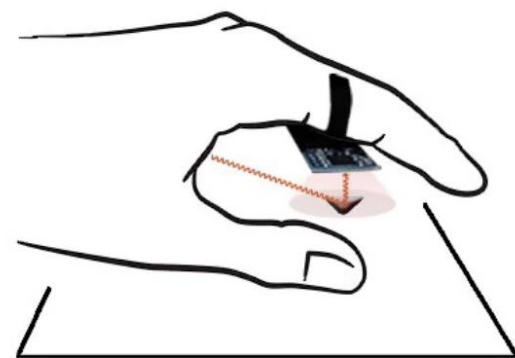
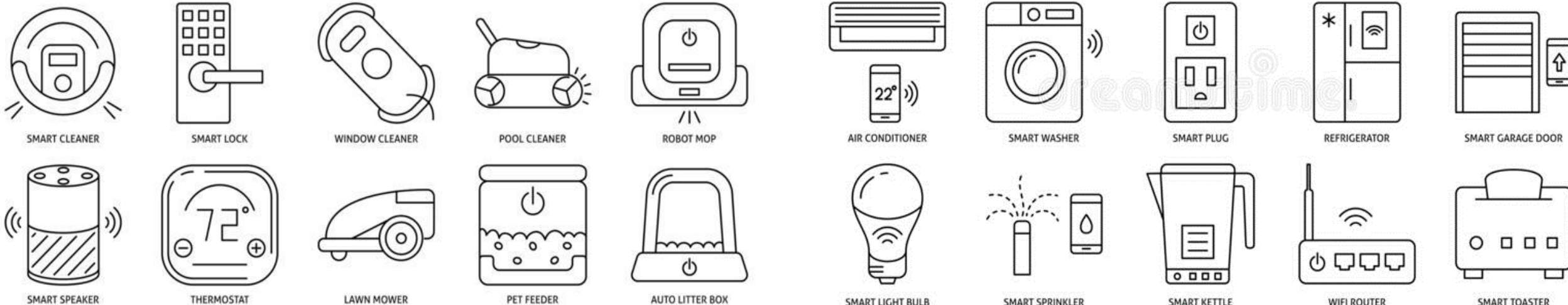


ThermalRing

Gesture and Tag Inputs Enabled
by a Thermal Imaging Smart Ring

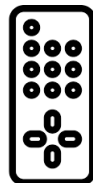


Tengxiang Zhang (ztxseuthu@gmail.com), Xin Zeng, Yinshuai Zhang, Ke Sun, Yuntao Wang, Yiqiang Chen

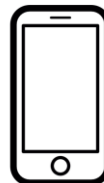


A Plethora of Smart Devices

Designated Controller



Universal Controller

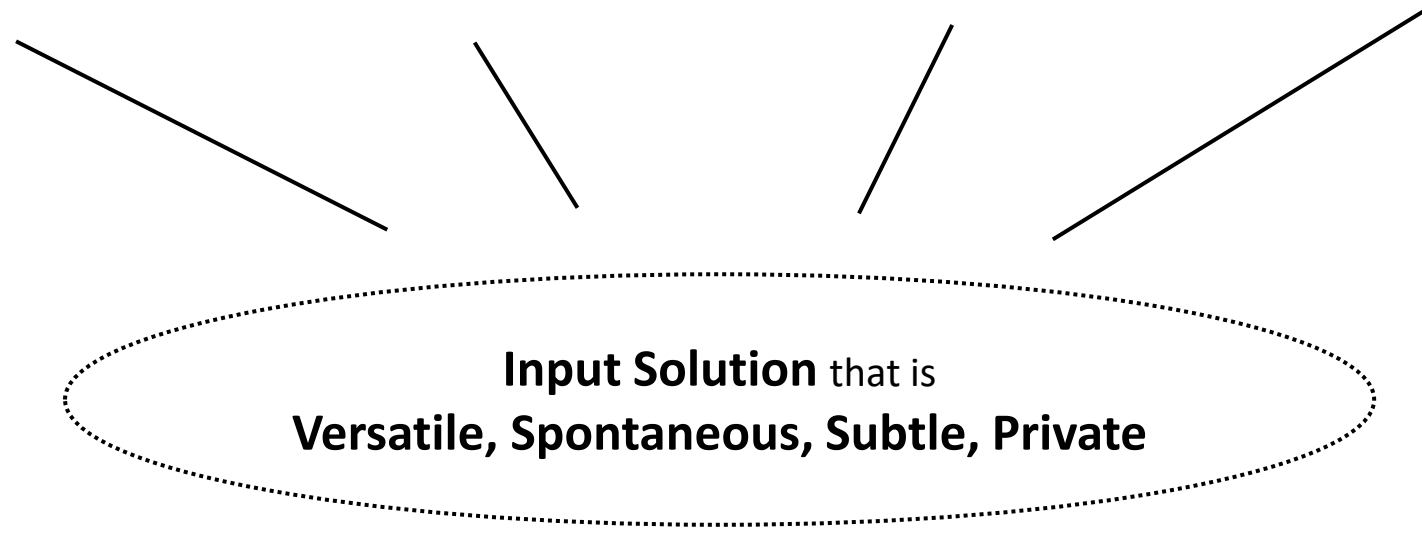
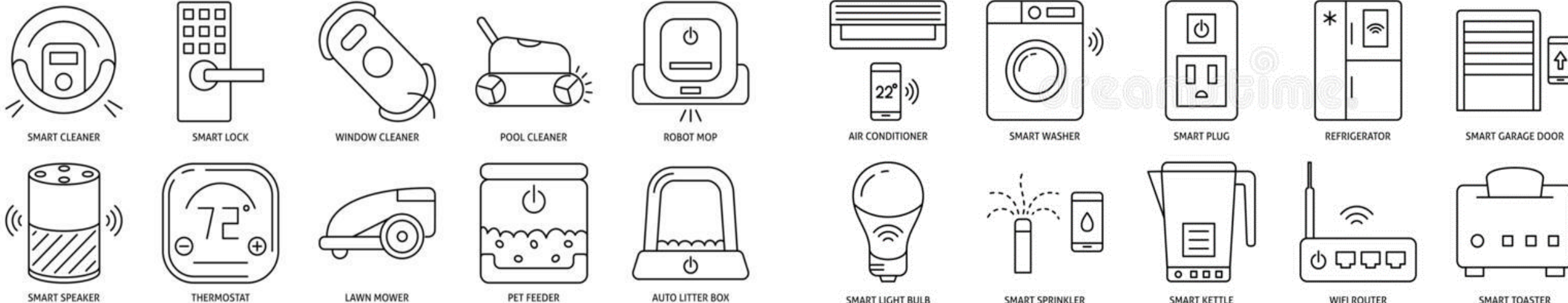


Vocal Commands



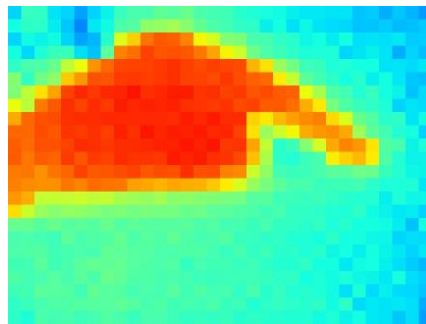
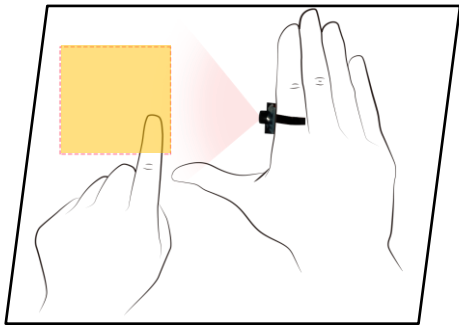
In-air Gesture



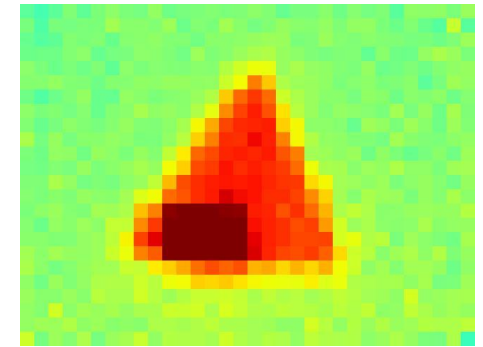
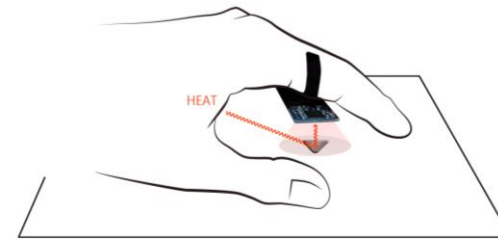


ThermalRing

Drawing Gesture Recognition



Thermal Tag Identification



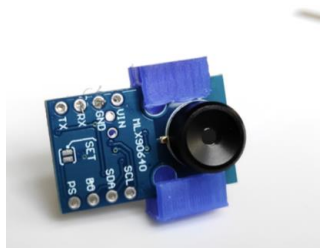
**Identity-anonymous, illumination-invariant, power-efficient
Finger-worn Vision-based Input Technique**



Versatile, Spontaneous, Subtle, Private

ThermalRing

Hardware Implementation

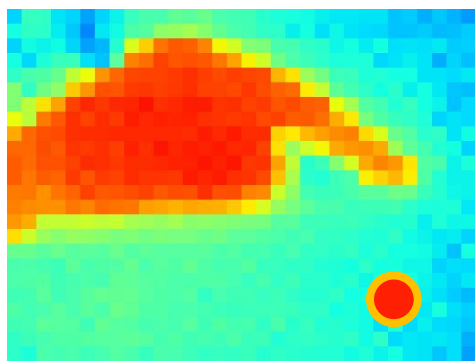


MLX90640 FoV: $110^\circ \times 75^\circ$ Res: 32x24 Size: $\Phi 8\text{mm}$, H6mm;
Cost: ~40 USD Power: 20mA@3V

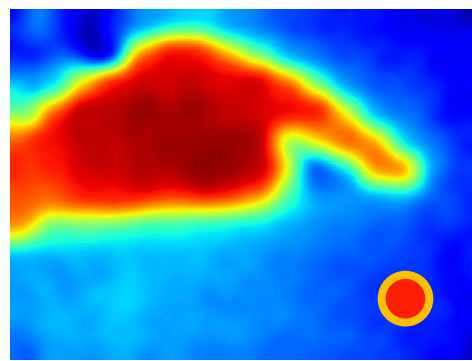
Communicate with PC via cabled serial port

*Bluetooth version firmware open sourced at <https://github.com/saintnever/thermalring>

Thermal Image Preprocessing Flow



Raw Temperature Data



Scale and Filter



Otsu Thresholding



Contour Filter



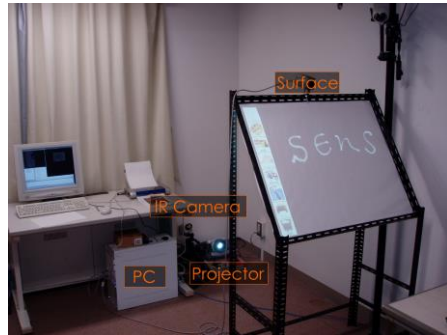
Related Work

- RGB Camera vs Near Infrared (NIR) Camera vs Long-wavelength Infrared (LWIR) Camera

	Wave Length	Imaging signal	Illumination Robustness	Privacy Preserving	Transmitter	Power Consumption
RGB	400nm-700nm	Reflection	Low	Low	No	Medium
NIR	750nm-1.4um	Reflection	Medium	High	Yes	High
LWIR	8um-15um	Emission	High	High	No	Low

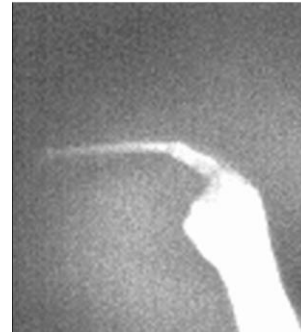
Related Work

- Thermal Imaging for Interaction



ThermoTablet'05 ^[1]

Imaging Canvas



HeatWave'11 ^[2]

Imaging Tabletop



Thermal Reflection'14 ^[3]

Imaging Surrounding Reflective Surfaces

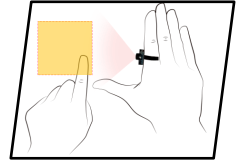
- ThermalRing
 - ✓ Directly imaging the hand itself
 - ✓ Leverage the dexterity of fingers

[1] Daisuke Iwai and Kosuke Sato. 2005. Heat sensation in image creation with thermal vision. In *Proceedings of the 2005 ACM SIGCHI International Conference on Advances in computer entertainment technology - ACE '05*, 213–216.

[2] Eric Larson, Gabe Cohn, Sidhant Gupta, Xiaofeng Ren, Beverly Harrison, Dieter Fox, and Shwetak Patel. 2011. HeatWave: thermal imaging for surface user interaction. In *Proceedings of the 2011 annual conference on Human factors in computing systems - CHI '11*, 2565.

[3] Alireza Sahami Shirazi, Yomna Abdelrahman, Niels Henze, Stefan Schneegass, Mohammadreza Khalilbeigi, and Albrecht Schmidt. 2014. Exploiting thermal reflection for interactive systems. In *Proceedings of the 32nd annual ACM conference on Human factors in computing systems - CHI '14*, 3483–3492.

Example Domain 1: Drawing Gesture Sensing



- Asymmetrical Bimanual Interaction: Natural, Easy, Affordant
- 6 step sensing flow

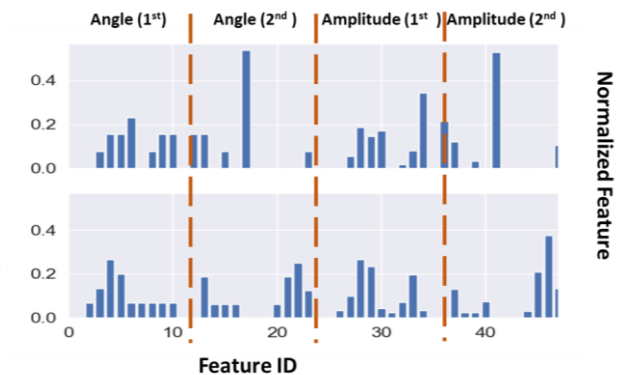
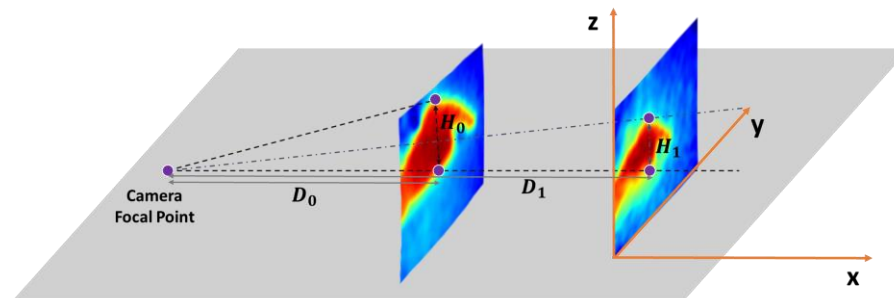
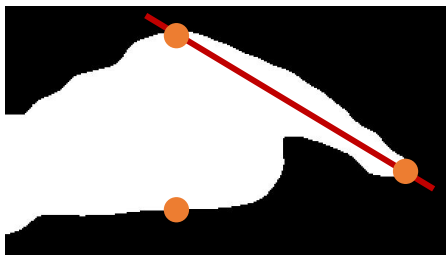
1. Fingertip Extraction
2. Finger Lift Detection



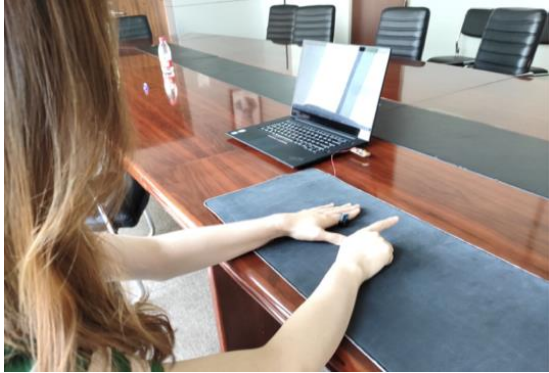
3. X/Y Coordinates Estimation
4. Kalman Filtering



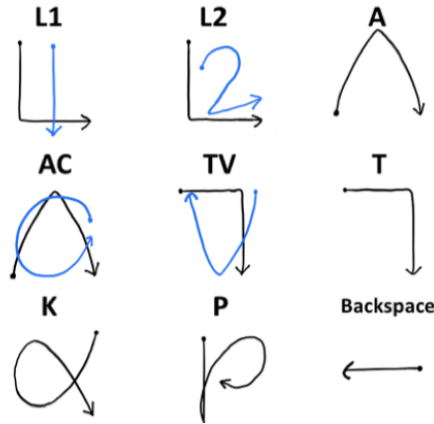
5. Bag of Words Feature Extraction
6. SVM Prediction



Example Domain 1: User Study



Experiment Setup



Graffiti Gesture Set

Task: Smart Device Pairing

Demographic: 6 participants (4 males) with ages 23-30

Procedure: 3 sessions (**ring taken down** during rest)
20 trials of each gesture per session

Data: 3240 trials, 360 for each gesture

Accuracy: Average **Within-user 89.2%** (SD=0.04)

Average **Between-user 85.7%** (SD=0.06)

Subjective: 5-point Likert Scale (the higher the better)

Comfort MEDIAN=4, MODE=4

Convenience MEDIAN=4.5, MODE=4

Ring Rotation MEDIAN=5, MODE=5

Input Speed MEDIAN=3, MODE=3

AC	94.8	0.0	0.0	4.2	0.0	0.0	1.0	0.0	0.0
TV	2.0	89.2	2.8	2.1	0.0	1.3	0.0	2.6	0.0
L1	4.6	2.6	81.9	6.5	0.0	3.1	0.7	0.7	0.0
L2	5.3	0.6	5.6	85.1	2.0	0.7	0.0	0.6	0.0
K	0.7	0.0	0.0	0.7	91.2	0.7	5.3	0.7	0.7
P	2.6	1.5	2.6	0.7	1.5	91.1	0.0	0.0	0.0
A	6.8	1.1	0.0	1.1	6.8	0.6	80.7	2.3	0.6
T	0.0	0.0	2.3	0.0	0.8	0.8	0.8	95.4	0.0
←	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	99.3
	AC	TV	L1	L2	K	P	A	T	←

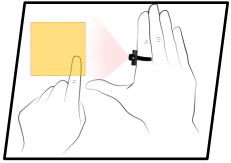
Within-user Confusion Matrix

AC	84.6	1.9	2.1	3.8	2.5	2.5	2.5	0.2	0.0
TV	1.0	86.2	2.3	0.8	1.0	4.6	1.2	1.9	0.8
L1	1.7	3.8	79.6	6.9	0.0	5.8	0.0	1.7	0.6
L2	5.2	1.0	7.5	72.3	5.0	6.5	0.8	1.5	0.2
K	1.5	0.0	0.0	2.7	89.8	1.0	3.3	1.2	0.4
P	3.1	4.6	3.1	2.9	1.7	82.9	0.6	0.4	0.6
A	2.7	0.8	0.0	0.2	4.8	0.4	87.9	2.9	0.2
T	0.8	0.0	1.0	1.5	0.8	0.2	6.2	89.4	0.0
←	0.0	0.6	0.0	0.0	0.2	0.2	0.0	0.0	99.0
	AC	TV	L1	L2	K	P	A	T	←

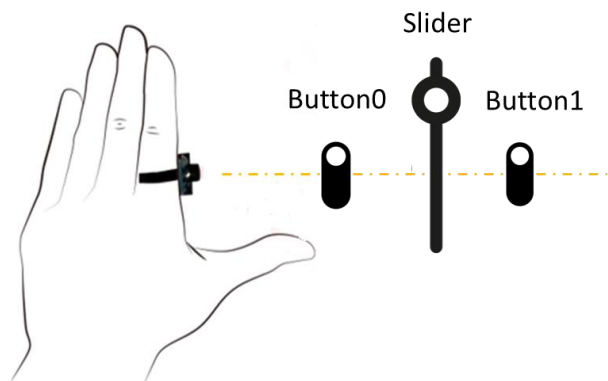
Between-user Confusion Matrix

Camera with a higher frame rate for faster drawing

Example Domain 2: Click and Slide Gesture Sensing



Experiment Setup



2 virtual buttons and 1 virtual slider

Task: Smart Device Click and Slide (5 scales) **Control**

Demographic: 8 participants (4 males) with ages 23-30

Procedure: 3 sessions (ring taken down during rest)
16 clicks and 8 slides per session

Data: 768 click gestures, 192 slide gesture

Result: Overall Accuracy **94.9%** (SD=0.02)
191 of 192 slides successfully completed

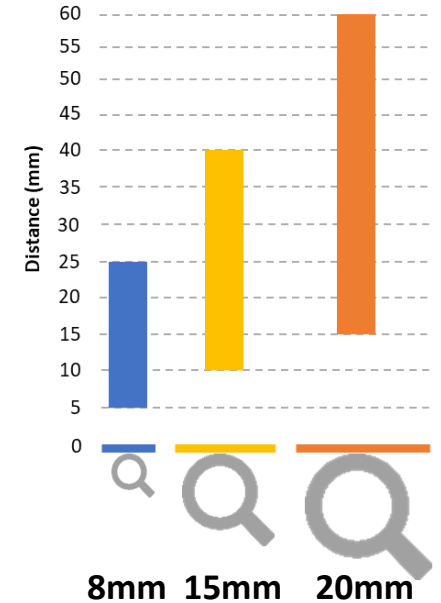
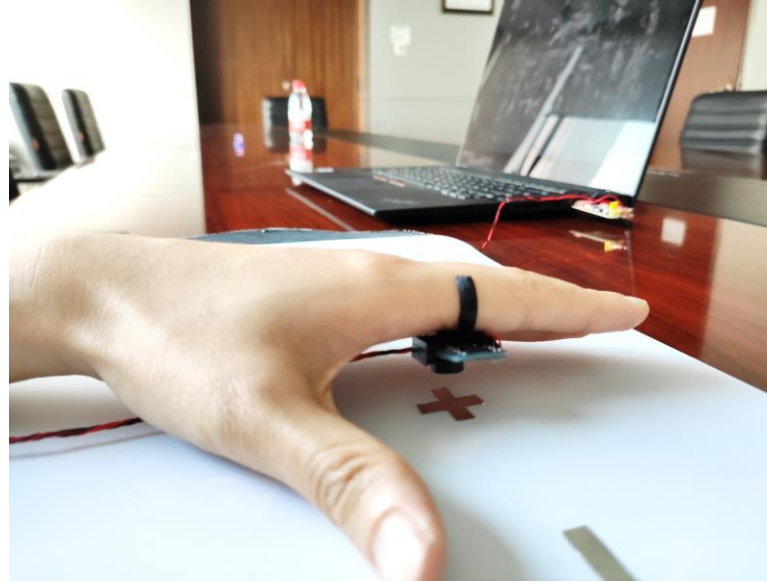
Subjective: 1. Users feel they can locate **4 buttons** (SD=1) and **2 sliders** (SD=0.71) referring to the auxiliary hand
2. 5-point Likert Scale (the higher the better)

UI Locating MEDIAN=4, MODE=4

Precision MEDIAN=5, MODE=5

Fatigue MEDIAN=5, MODE=5

Example Domain 3: ThermalTag Identification



- ThermalTag: **Thin** and **Passive** Tags made of **high heat reflection** materials in **DIY** manner
- Imaging Principle: ThermalTag **reflects** heat from the **hand**
- Interaction: **Touch-Lift-Hold**
- Tag size: **20mm** Square

Example Domain 3: User Study



Task: Scanning 6 different ThermalTags

Demographic: 8 participants (4 males) with ages 23-30

Procedure: 2 sessions (**ring taken down** during rest)
6 blocks per session and 20 trials per block

Data: 1920 scans, 320 for each tag

Result: Average **Within-user 95%** (SD=0.04)

Average **Between-user 90.1%** (SD=0.08)

Average scan complete time **3.5 seconds**

Subjective: 5-point Likert Scale (the higher the better)

Physical efforts MEDIAN=4, MODE=4

Mental efforts MEDIAN=4, MODE=4

Scan speed MEDIAN=4, MODE=4

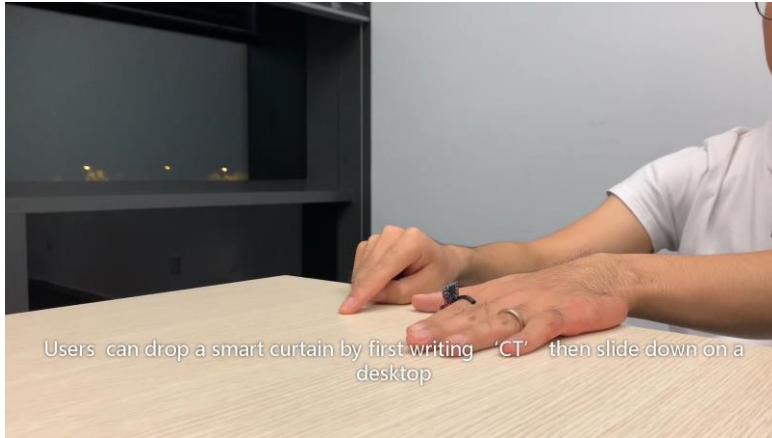
Up	93.1	0.0	1.6	3.8	0.8	0.7
Down	0.0	95.5	4.5	0.0	0.0	0.0
Play	1.2	0.0	97.9	0.8	0.0	0.0
Stop	0.0	0.0	0.0	100.0	0.0	0.0
Search	0.0	0.0	0.0	0.0	98.2	1.8
Help	0.8	0.0	0.0	0.0	4.7	94.5
	Up	Down	Play	Stop	Search	Help

Within-user Confusion Matrix

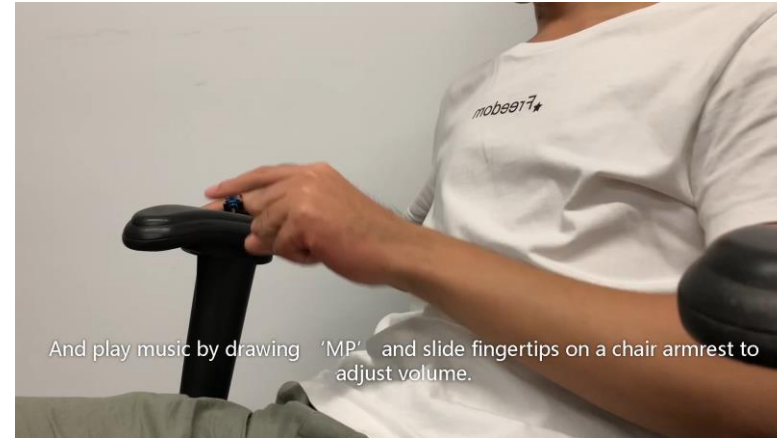
Up	93.2	0.0	0.3	0.9	1.5	4.1
Down	0.9	95.0	3.1	0.3	0.3	0.3
Play	2.2	0.0	96.6	0.9	0.3	0.0
Stop	4.7	5.0	1.2	89.1	0.0	0.0
Search	1.2	0.0	0.9	0.6	87.3	9.9
Help	2.8	1.6	0.6	0.0	15.4	79.6
	Up	Down	Play	Stop	Search	Help

Between-user Confusion Matrix

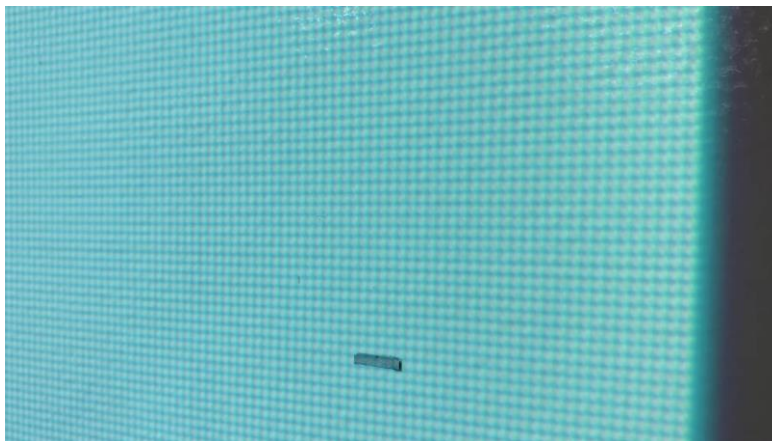
Application Scenarios



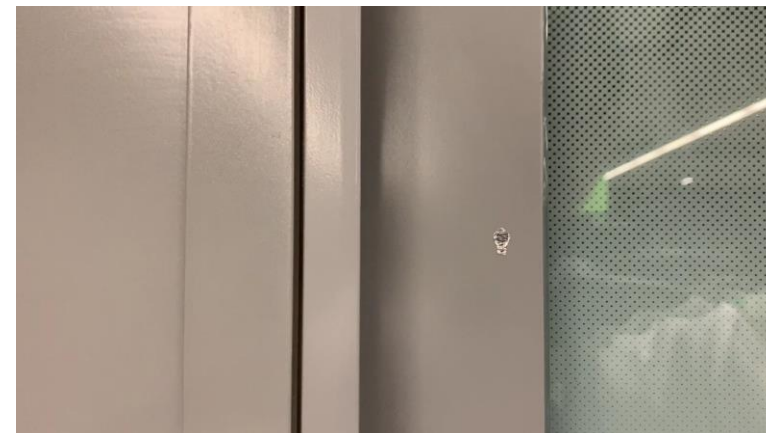
Smart Curtain Control on a Table



Smart Speaker Control on a Chair



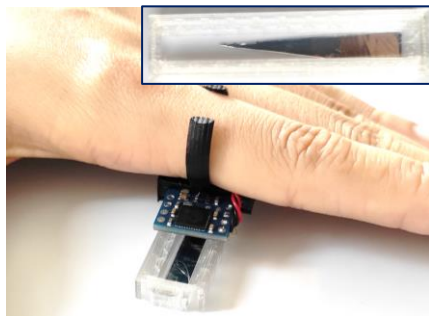
Slides Navigation on Whiteboard



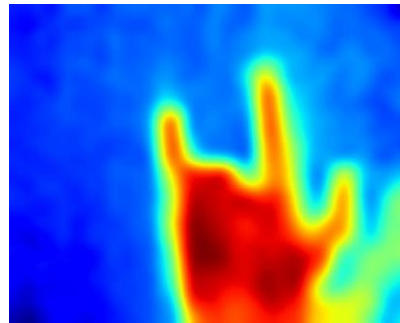
Smart Light Control on a Door

Discussion

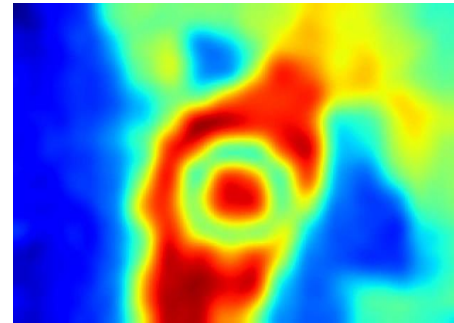
- Limitation
 - Robustness
 - Mode Switch and Feedback
 - Discreet and One-handed Interaction
- Future work



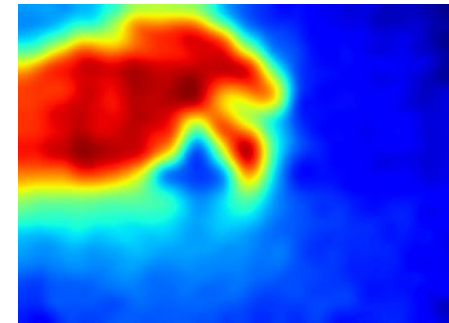
Thermal UI



In-air Gesture



Object Recognition



Context Recognition



Thank You !

Tengxiang Zhang, ztxseuthu@gmail.com