MotionCompass: Pinpointing Wireless Camera Via Motion-activated Traffic

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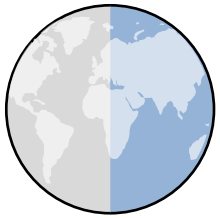
An outlook to security camera market



64.8 million

Global shipment volume of cameras in 2019

$33.89 Billion

Expected global security camera market in 2020

Annual growth rate from 2017 to 2023

Global wireless camera market

Wireless cameras can be everywhere (1)

- Outdoor environment

Wireless cameras can be everywhere (2)

- Indoor environment

Wireless cameras can be hidden

→ A visible camera can be a deterrence, but may

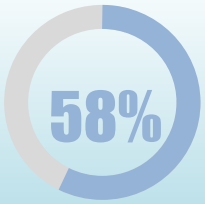
- Be more susceptible to damage or theft
- Attract more interest of burglars
- Be avoided by leveraging blind spots

People may thus install wireless cameras inconspicuously

ON THE OTHER HAND

→ Bring privacy concerns

- Targets are unaware of their existence
- A survey of 2,023 guests



Concerned about hidden cameras

Discovered a hidden camera

Traditional ways to detect a wireless camera

→ Lens detection

→ Physical search

→ RF (Radio Frequency) scanning

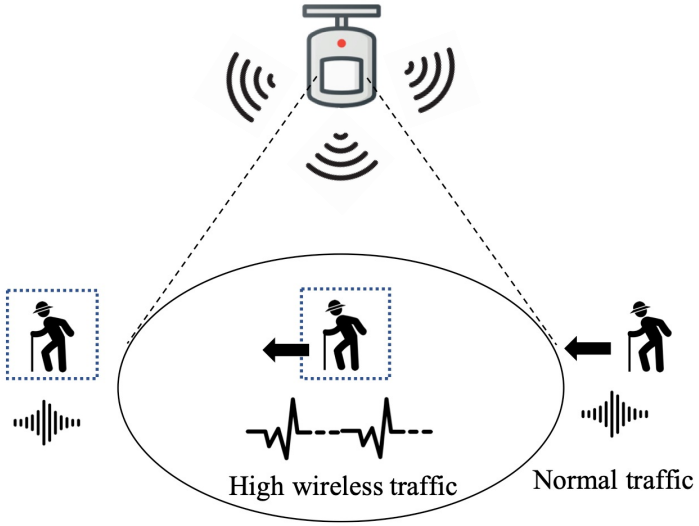
- Work when the camera is transmitting
- Detect the existence but cannot tell exact locations

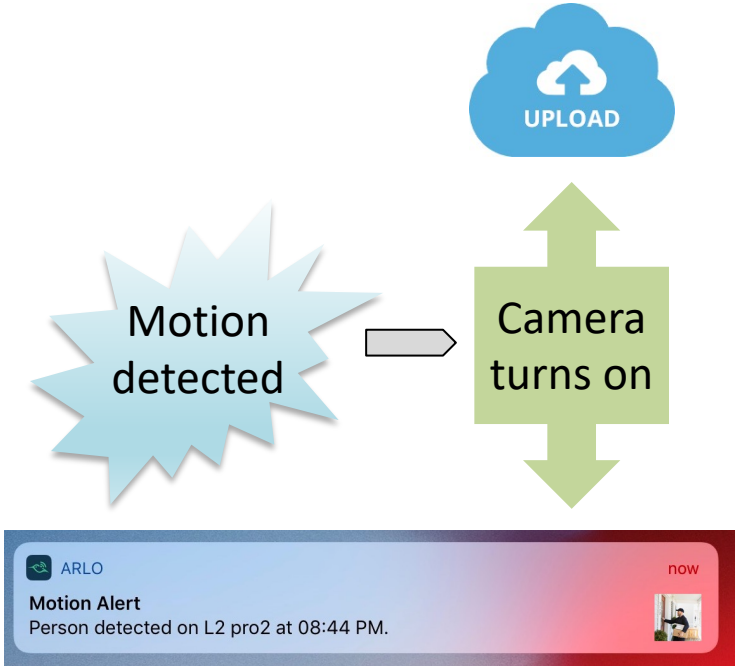
✓ **Wireless camera localization** is important.

- For example, a victim can obtain evidence by finding the hidden camera

Motion activation

- Battery-powered wireless cameras usually incorporate **motion sensors (**small size, low cost, and power efficient**)**
  - We cannot keep our eyes glued to our security cameras
  - Sit in standby mode to conserve battery





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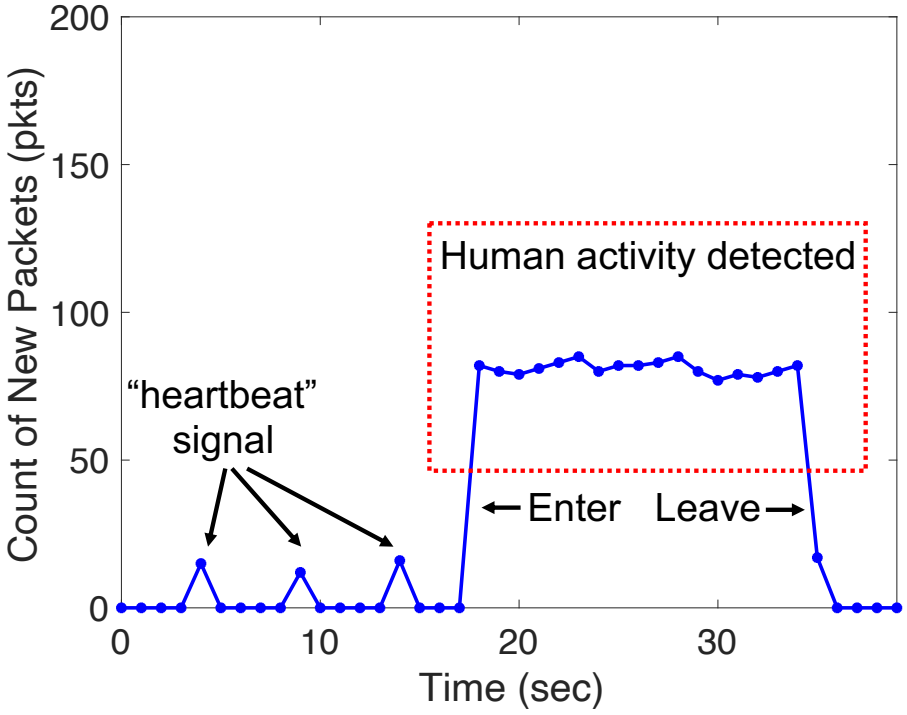
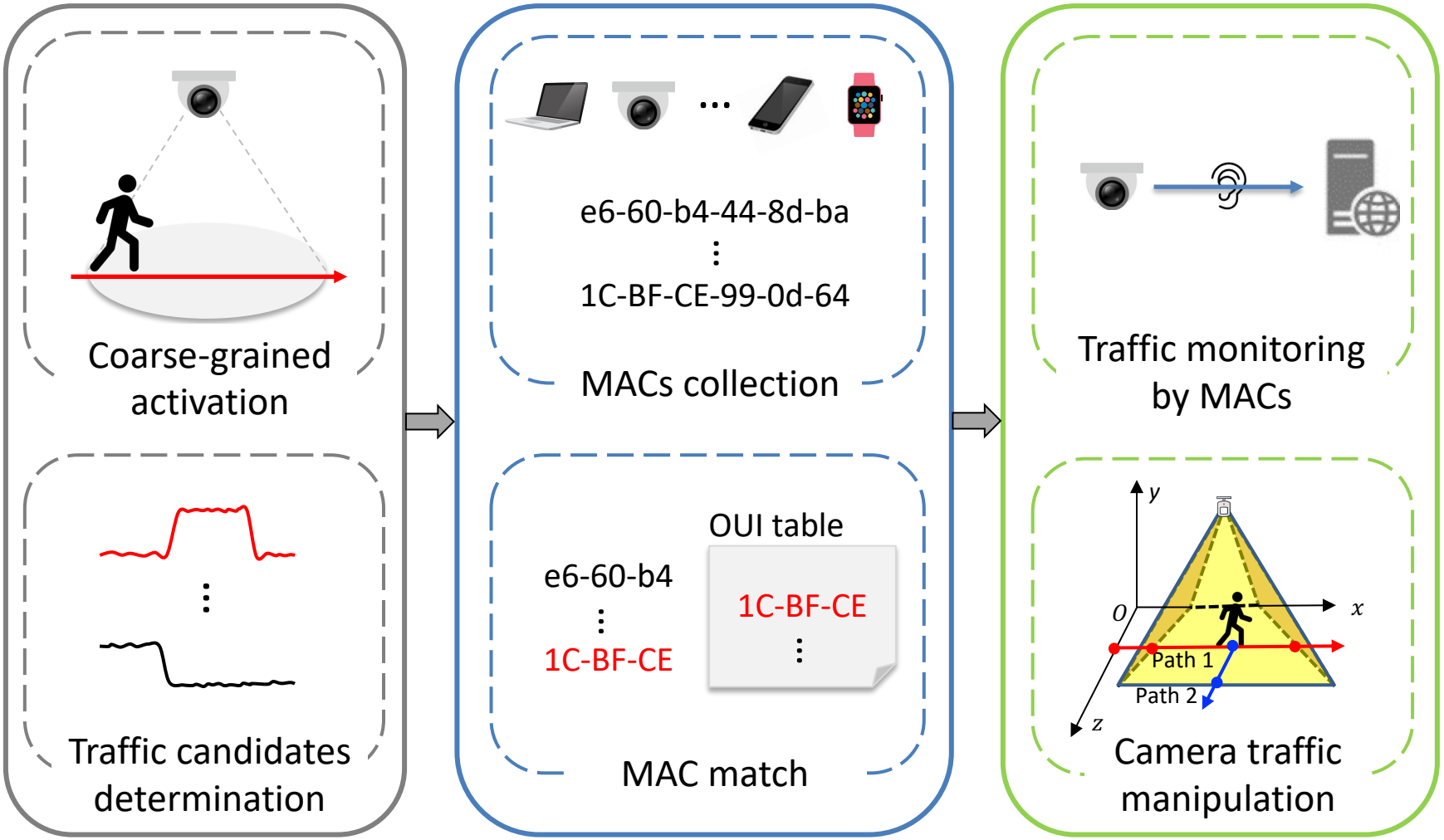


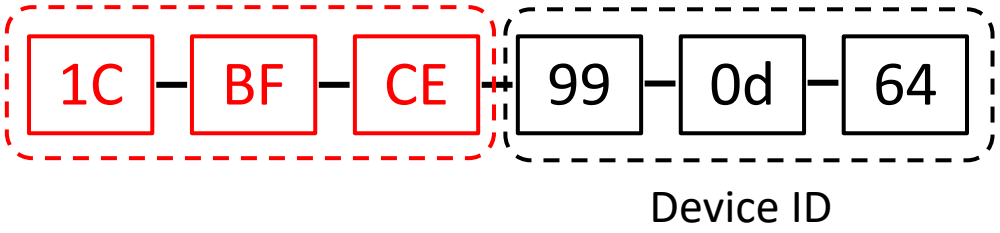
Overview of *MotionCompass*



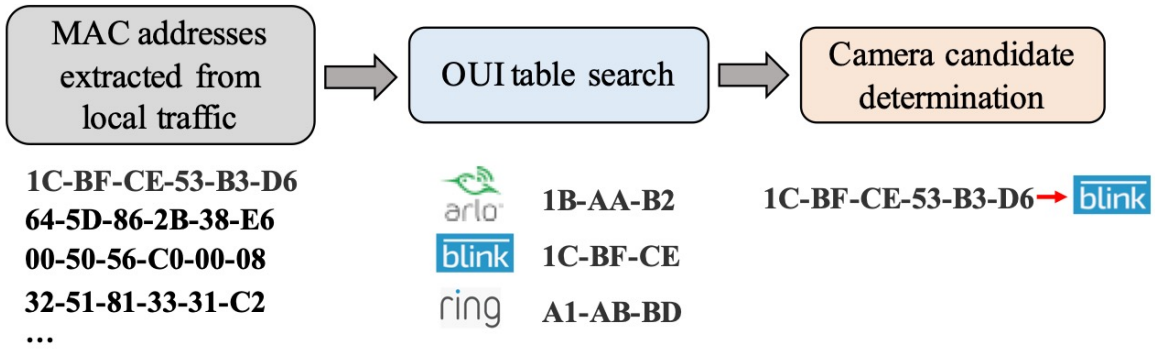
Phase II: Camera MAC extraction

- MAC address is determined by corresponding SoC manufacturer and has the following format:

OUI → device manufacturer and device type
(Organizationally Unique Identifier)

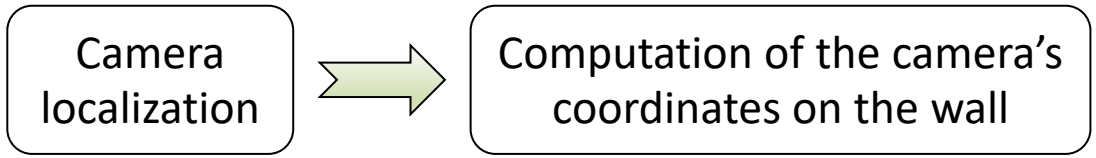


- Camera-labeled OUI table: contain OUIs of all cameras on the market



Phase III: Camera traffic manipulation

- Consider a camera deployed on a vertical wall

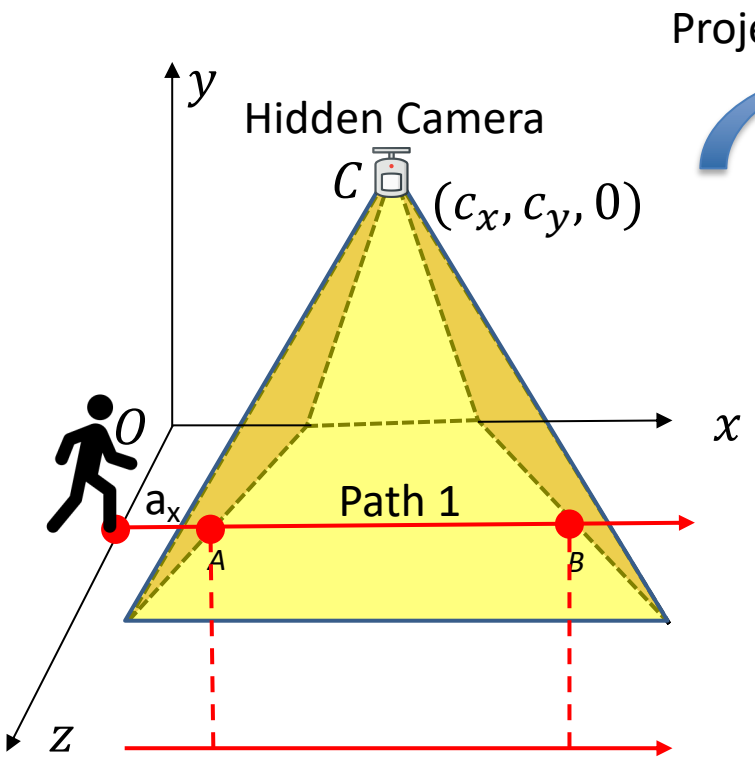


- Special case: to maximize horizontal breadth, the camera body is often mounted perpendicular to the wall
  - Just move up and down

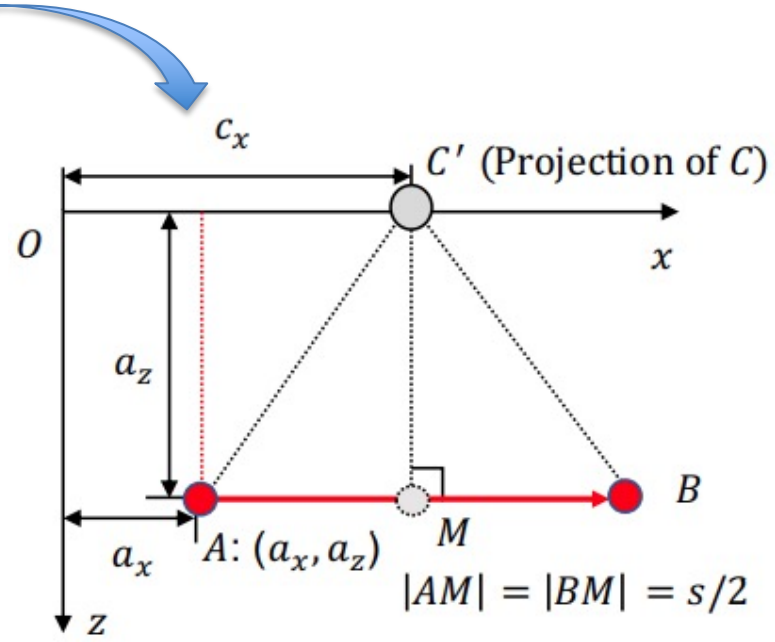
- General case: the camera can be mounted at any angle to the wall as long as its view is not obstructed by the wall
  - Can be swiveled in any direction (up/down/left/right)

Special case: two-step procedure (1)

- Move parallel to the wall from left to right



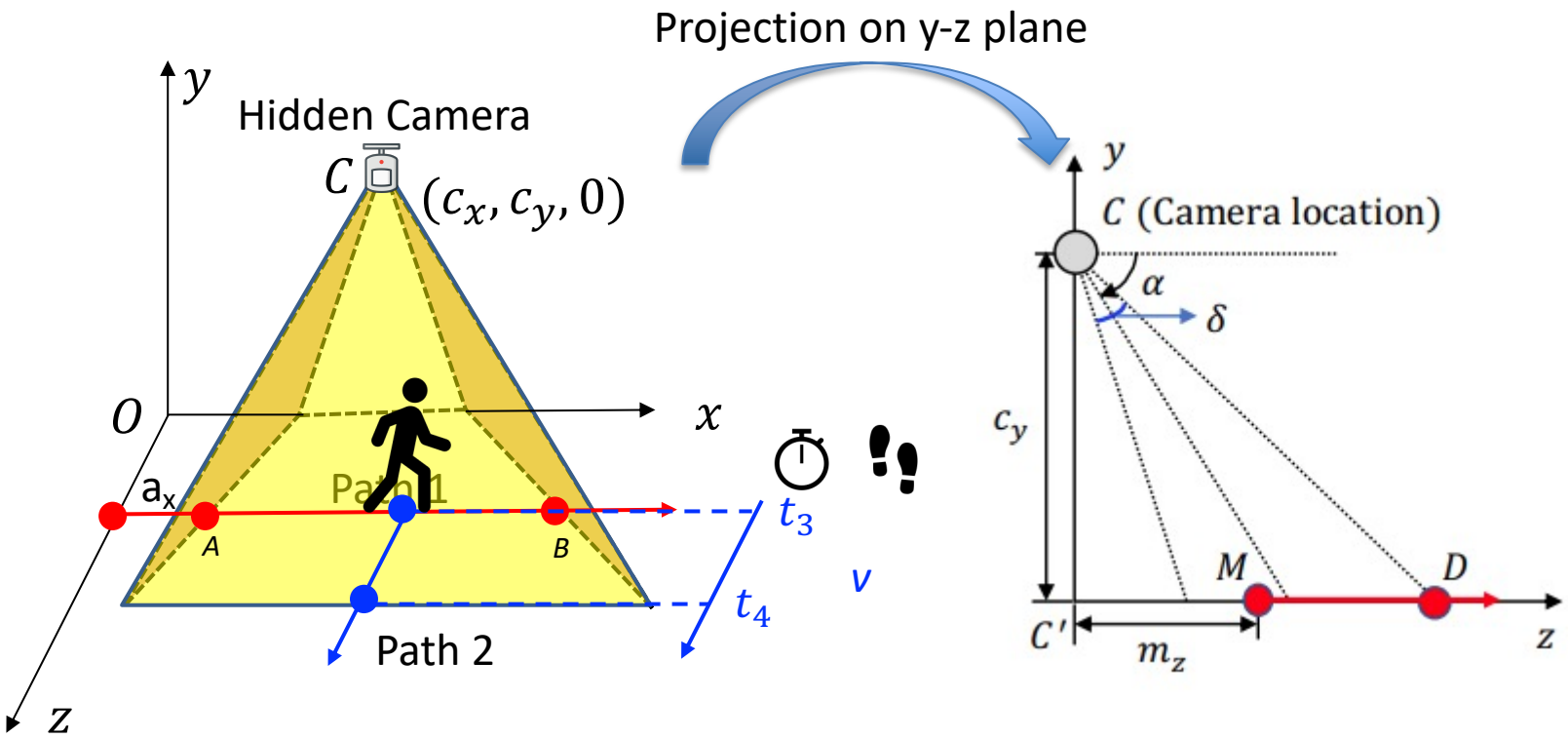
Projection on x-z plane



- Path1 length: $s = |AB| = v \cdot (t_2 - t_1)$
- x-coordinate: $c_x = a_x + s/2$

Special case: two-step procedure (2)

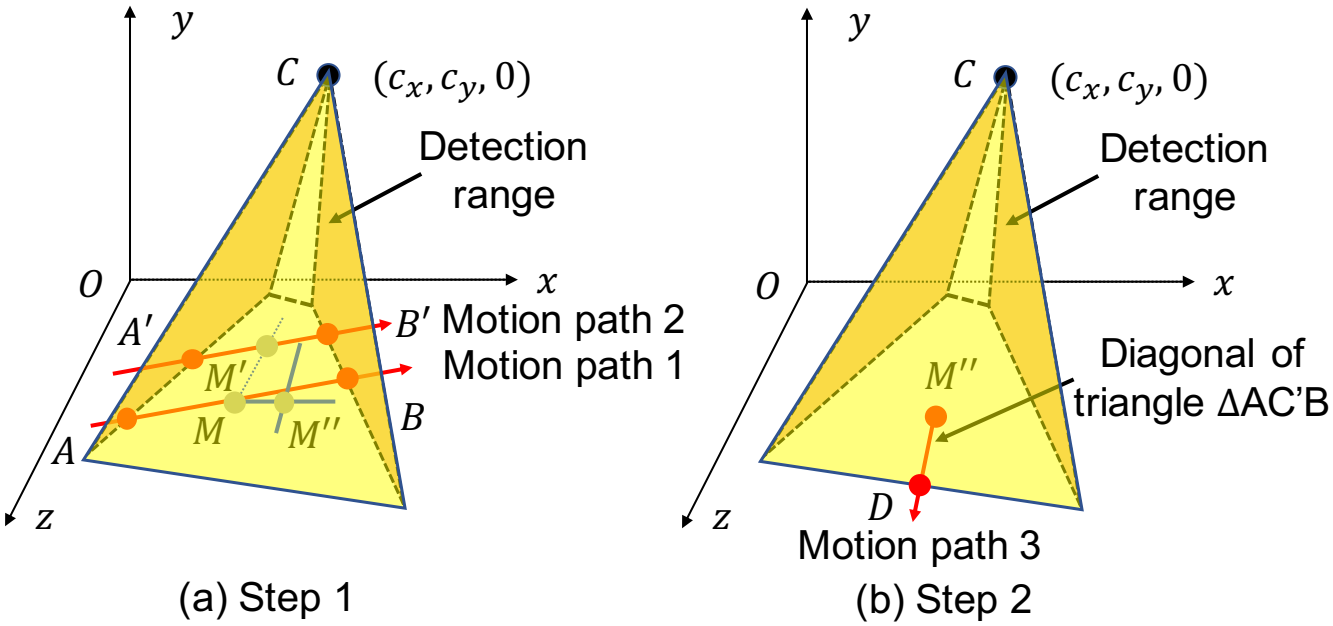
- Vertically get out of the detection range



- Path2 length: $s' = |MD| = v \cdot (t_4 - t_3)$
- y-coordinate: $c_y = \dfrac{m_z + s'}{\tan\angle DCC'}$

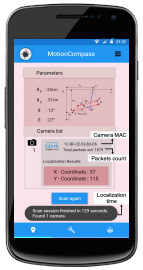
General case: improved two-step procedure

- Perform motion along three paths



The camera's coordinate $(c_x, c_y, 0)$ can be then computed

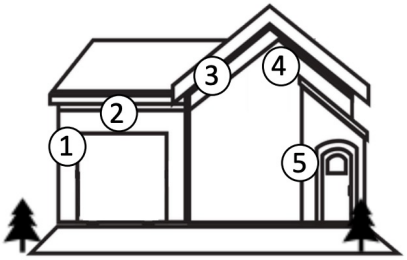
Evaluation setup



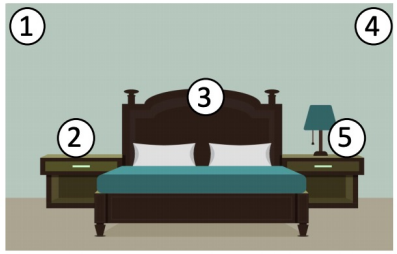
- Android app: run on a phone with the NIC in monitor mode
- Testing cameras: 18 cameras: G1 - with one motion sensor; G2 - with two motion sensors (ID 16-18)

Camera ID	Model	Amount of PIR Sensors
1	AIVIO Cam	1
2	Arlo Essential	1
3	Arlo Pro 2	1
4	Arlo Pro 3	1
5	Blink Indoor	1
6	Blink XT2	1
7	Blue by ADT	1
8	Canary Flex	1
9	Conico Cam	1
10	EufyCam 2C	1
11	Reolink Argus 2	1
12	Reolink Argus Pro	1
13	Ring Door View	1
14	Simplisafe Cam	1
15	Swann Wireless	1
16	Arlo Ultra	2
17	Ring Spotlight	2
18	Ring Stickup Cam	2

- Testing Scenarios: outdoor & indoor



(a) Outside a house

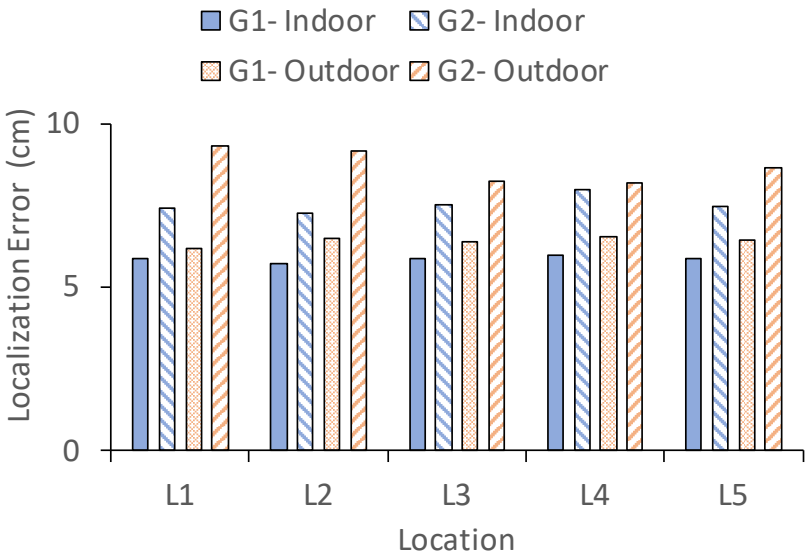


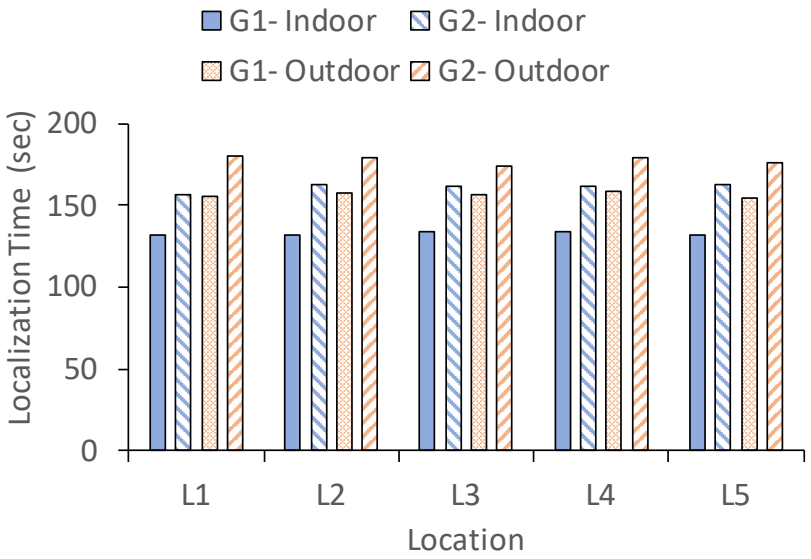
(b) Bedroom

- Metrics: (1) localization error; (2) localization time

Performance across different locations

- Mean localization error (E) and time (T)

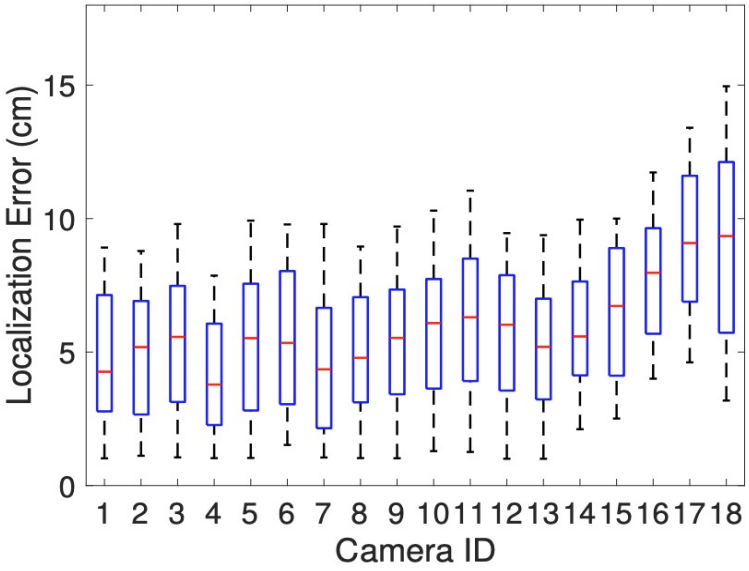




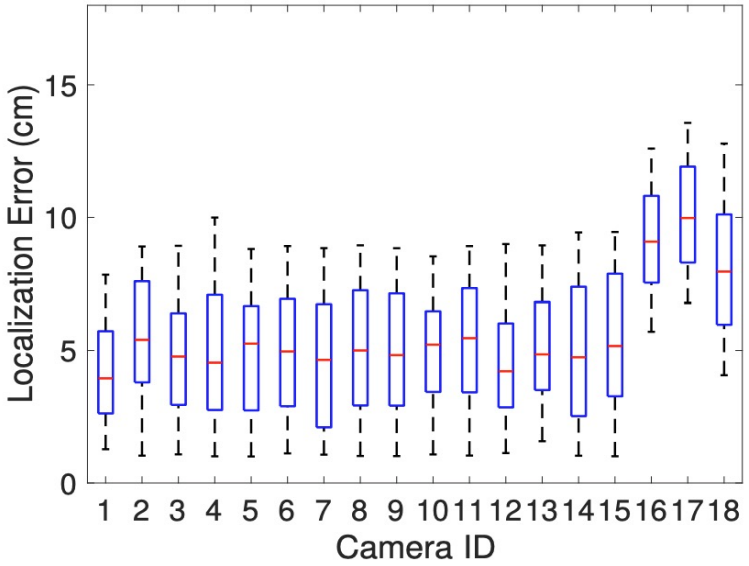
- ✓ Consistently, we observe $E < 9.2$ cm, $T < 178$ sec
- ✓ G2 shows larger E and T, in either environment
- ✓ Outdoor shows larger E and T, for each group of cameras

Localization accuracy for different cameras

- A high localization accuracy can be always achieved



Outdoor localization error



Indoor localization error

- ✓ The minimum localization error ranges:
  - 1.0 - 2.3 cm for cameras 1-15;
  - 3.1 - 4.5 cm for cameras 16-18

Conclusion

- Propose *MotionCompass*
  ➔ to **pinpoint** a motion-activated wireless camera

- Build a model
  ➔ to **correlate** manipulated motion with the resultant wireless traffic

- Develop an Android app
  ➔ to implement *MotionCompass* and **validate** its effectiveness and efficiency