ENGINEERING FOR impact

mit 6.900

Lecture 10

March 14, 2023

TODAY

- Passive occupancy sensors
  - Infrared
  - Thermal
  - Optical
  - Ultrasonic
  - MAC sniffing
  - RF/mm-wave/LIDAR

This is going to be a discussion…

…we don’t have all the answers!

Occupancy sensing requirements

From Valerie requirements:

*It should be able to measure how many people are waiting, and for how long.****

Occupancy sensing specifications

- Size
- Power
- Operating voltage
- Connectivity
- Privacy
- Distance

Depends somewhat on the approach…what do you have so far?

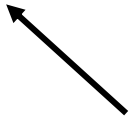
Occupancy sensing approaches

Teams have proposed two classes of approaches

interactive occupancy sensors incorporate user interaction

QR code, NFC scan, button pushing, etc.

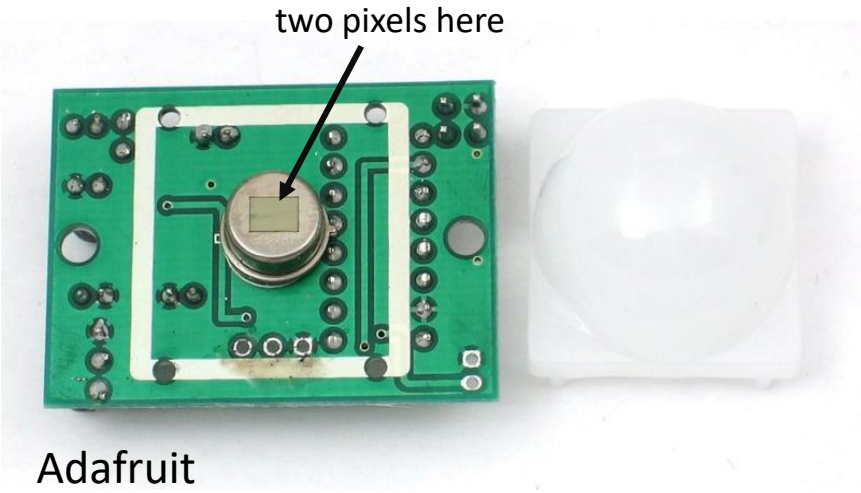
passive occupancy sensors do not require interaction from user



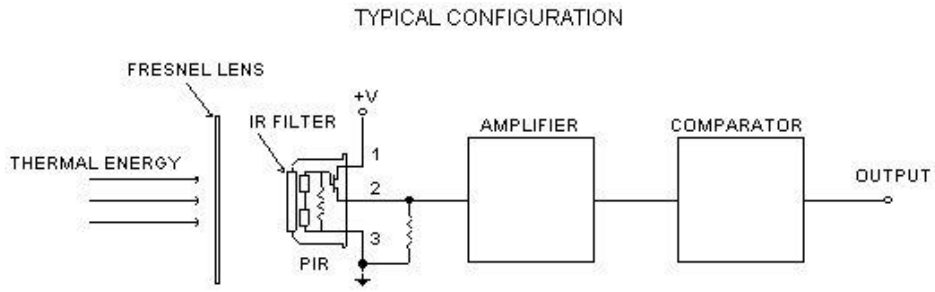
we'll focus on these here

Passive infrared (PIR) sensor

- The ones in office occupancy sensors, outdoor motion-activated lights, etc.
- Really, these are *motion* sensors
- Two pixels, each sensitive to ~9.4 um infrared radiation
  - Pyroelectric sensor: certain crystalline materials convert temperature changes into voltage changes
- Uses specialized IC to convert input voltage into output pulse (upon motion)
- Lens on top has array of Fresnel lens that bring adjacent incoming solid angles to alternating pixels → system can be sensitive to small motions



Adafruit



Glolab

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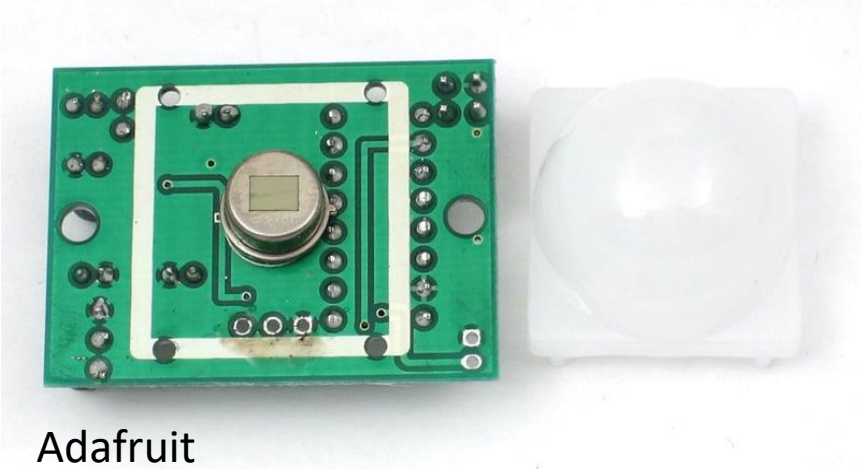
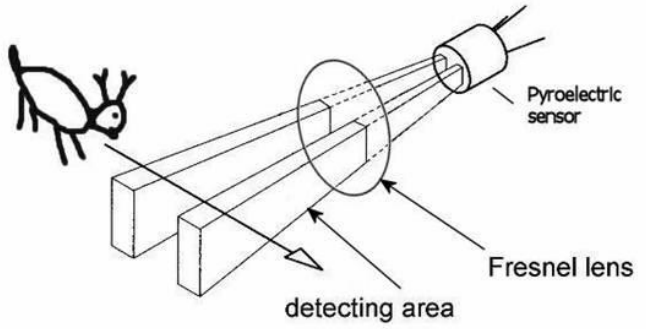
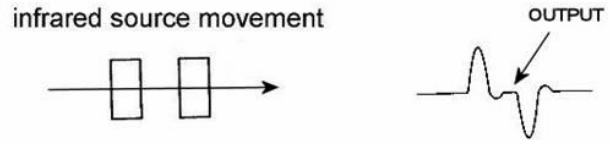


Adafruit

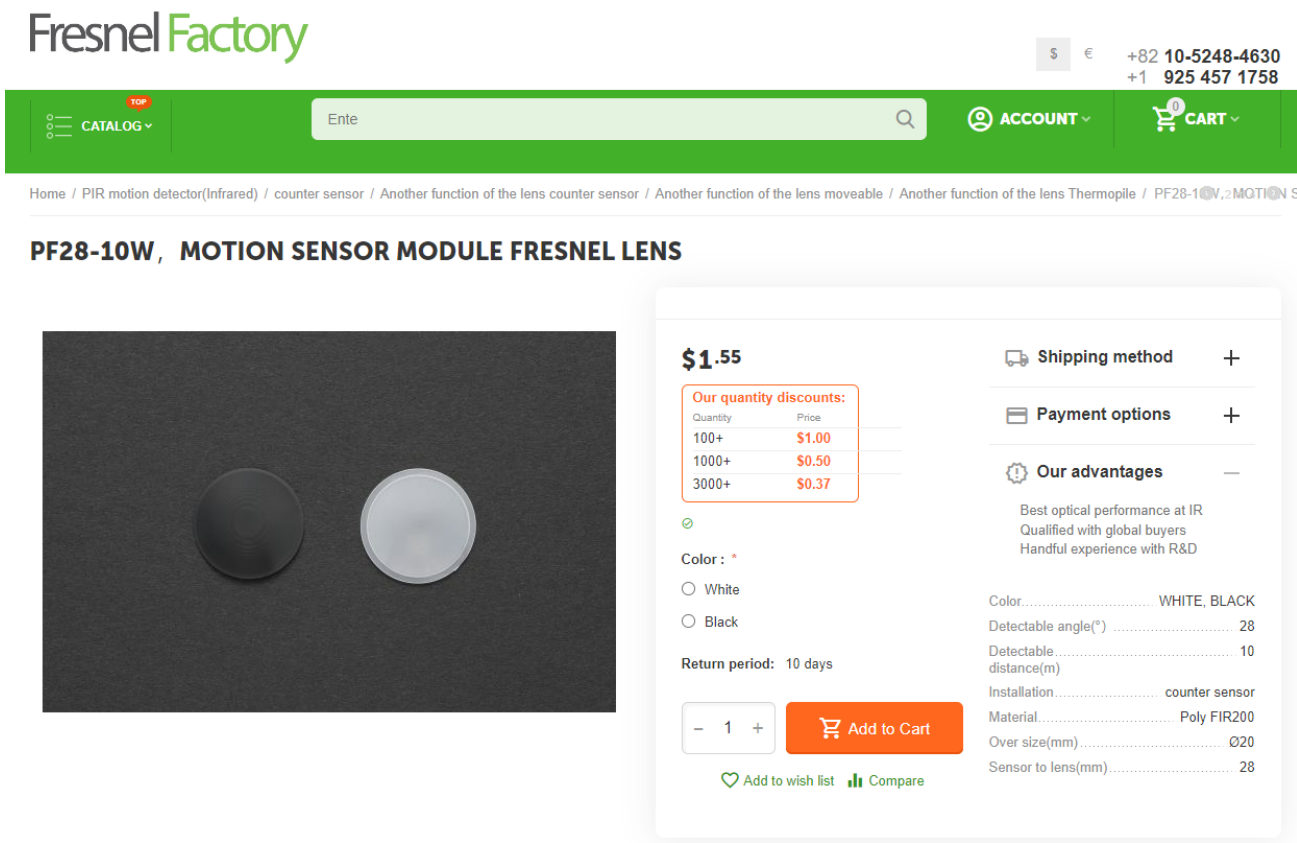




Glolab

Passive infrared (PIR) sensor

- Can potentially attach your own lens to get narrower band and detect motion/crossing in a smaller area…maybe



Passive infrared (PIR) sensor

- Cost: ~$3 @ 1
  - Presumably cheaper in bulk from China
- Size: 20-30 mm on a side
- Power/voltage: 3 mA active, ~100 μA idle @ 3-6V
- Connectivity: 1 pin into GPIO
- Privacy: excellent

What else should we be considering here?

all these values need to be double-checked

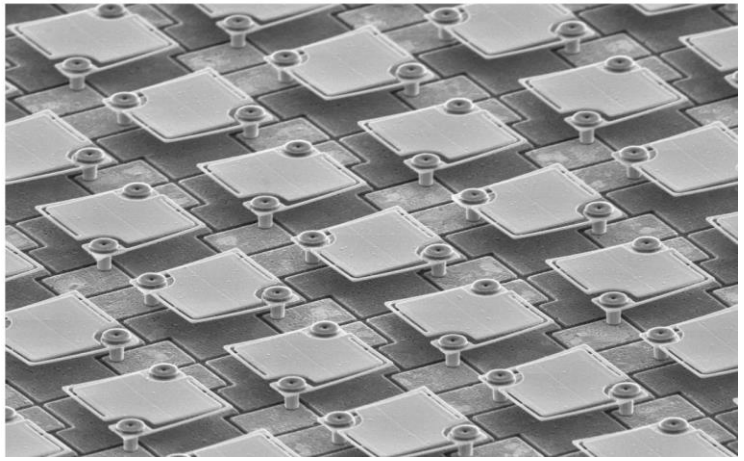
Thermal camera

- Instead of two pixels, what if we had many pixels of thermal information
- Original used bolometers: microscale (~5-10 μm on a side) thermistors that are thermally isolated from the substrate to allow small amounts of thermal radiation to cause measurable changes in R
- System includes lens, readout electronics, etc.

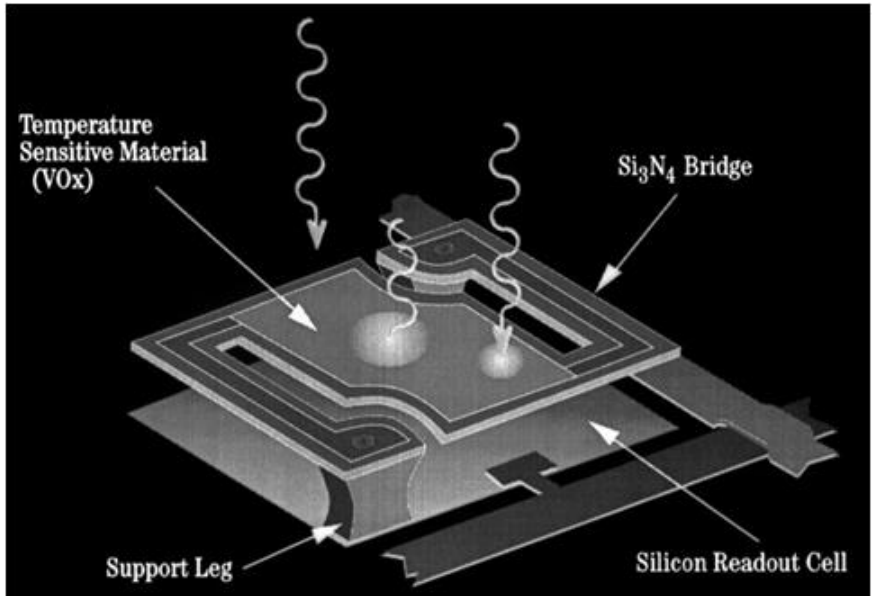
Teledyne FLiR

FLIR module

Note that many thermal images you see are upscaled…this sensor module only has 80x60 pixels



Array (not FLIR)

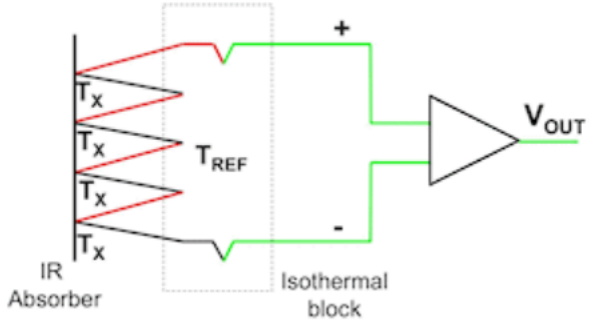


Unit cell (probably FLIR)

Thermal camera

- Thermopile array
  - Lower cost than microbolometer arrays
  - Array of series-connected thermocouples
    - Voltage change adds up
    - Need thermal isolation (like bolometer) so that small incident radiation results in reasonable ΔT ➔ reasonable ΔV

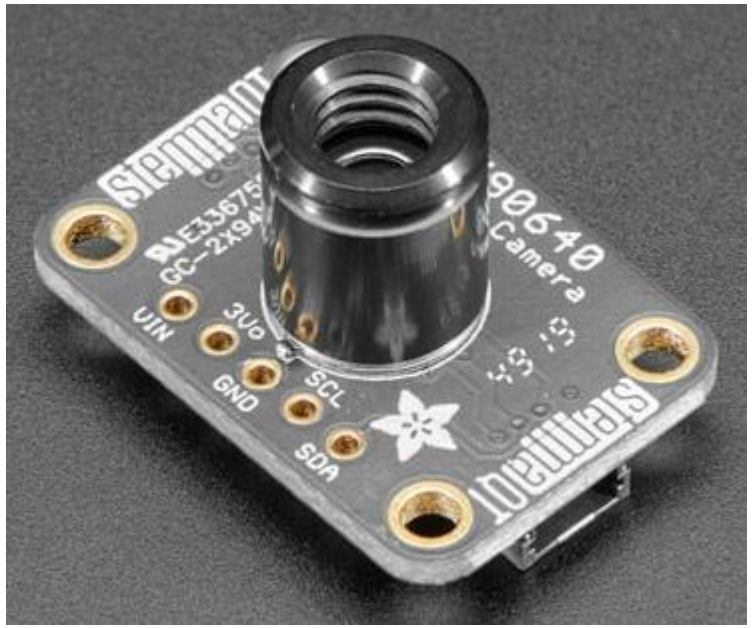
one thermopile pixel



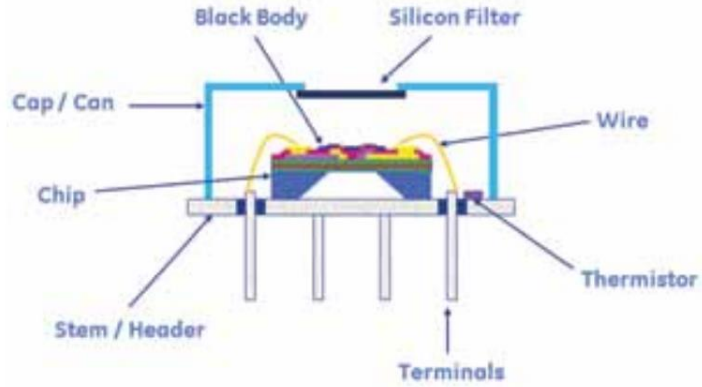
$V_{OUT} = N \cdot S \cdot (T_X - T_{REF})$

S: Seebeck coefficient
N: Number of thermocouples

Melexis MLX90640



Adafruit, based on Melexis MLX90640



Thermal camera

- Some comparisons

	Thermopile	Bolometer
Cost	$51.28 @ 100 bare IC $59.96 @ 100 Adafruit breakout	$121.58 @ 1 bare module
Pixels	32 x 24	80 x 60
Size	~6 x 10 x 10 mm	~10 x 10 x 10 mm
Power	20 mA typical @ 3.3 V	150 mW active, 5 mW standby 2.8-3.1V supply
Connection	I2C	I2C
Package	32-pin package, fits into commercial socket	4-pin thru-hole package
Privacy	Excellent	Excellent

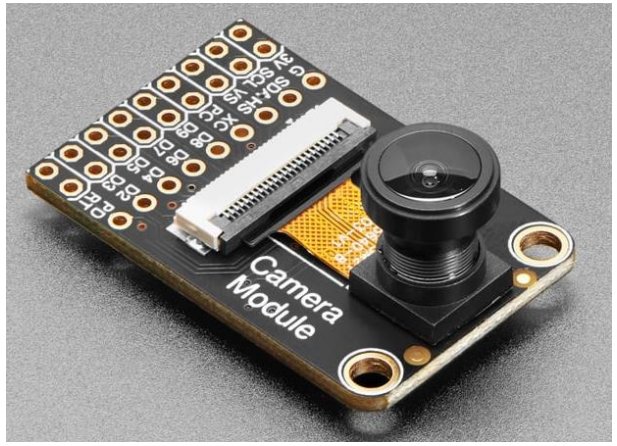
AMG8833 is also thermopile array sensor

What else should we be considering here?

all these values need to be double-checked

Visible-light camera

- Lots of options here
  - Easy to get 1MP+ for $10-20
  - Cheaper from China…
- Probably worth getting a module instead of a bare sensor
  - Avoids dealing with fine-pitch connector/cable
- Comms
  - I2C (for config)
  - Data comes out via 8 GPIO lines, SPI, etc.
- Power
  - ~30-100 mA depending on frame rate, etc.
  - 20 μA in standby
  - 3.3V [camera sensor uses lower voltage, so there's on-board LDO]
- Size
  - 36 x 23 x 18 mm
- Privacy
  - Problematic



Adafruit OV5640 breakout
$15.96 @ 100

Visible-light camera

- Camera data handling
  - Depending on frame rate, # of MPs, and processing, this can get difficult for MCU to handle
  - 1 megapixel grayscale @ 8 bits is 1 MB (uncompressed)…but ESP32C3 has (only) 8 MB of flash
  - Sending data to cloud to process has
    - Privacy implications
    - Will incur energy costs to transmit the data

What else should we be considering here?

MAC sniffing

- WiFi and BLE radios on your devices each have a unique ID
  - 48-bit Address
    - WiFi has Media Access Control (MAC)
    - BLE has Bluetooth Device Address (we'll call it MAC address)
    - 83:A2:4D:16:G1:D2 for example
  - This information is in the unencrypted header of a 802.11 (WiFi) or 802.15.1 (BLE) frame
  - They may also contain RSSI (Received Signal Strength Indicator): a measure of the signal strength, and thus related to distance
  - This is one reason most phones do address randomization – to prevent tracking!
- Your ESP32C3 can be set up as an access point (AP)
  - All WiFi radios in range will communicate with the AP and send their MAC address and RSS info
  - And it has a BLE radio

MAC sniffing

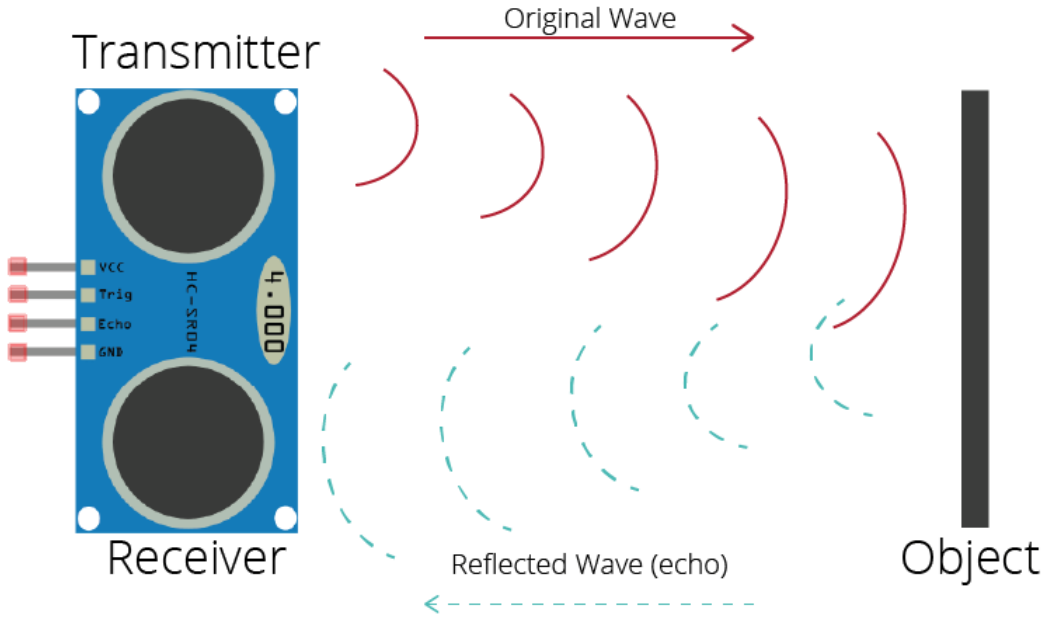
- Cost
  - Free, because it is already in your ESP32C3
- Size
  - 0
- Power
  - WiFi RX is ~80 mA peak
  - BLE RX not given, may need to be measured, but probably lower
- Privacy
  - Not bad, as long as you don't store/transmit MAC addresses
  - But may need to convince stakeholders that this is ok
- Distance
  - Probably going to be pretty inaccurate

Work mode	Description		Peak (mA)
Active (RF working)	TX	802.11b, 1 Mbps, @20.5 dBm	345
		802.11g, 54 Mbps, @18 dBm	285
		802.11n, HT20, MCS7, @17.5 dBm	280
		802.11n, HT40, MCS7, @17 dBm	280
	RX	802.11b/g/n, HT20	82
		802.11n, HT40	84

What else should we be considering here?

Ultrasonic sensors

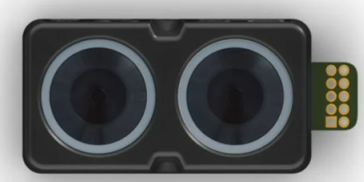
- Sender + receiver of ultrasound
  - Sends US pulses, measures time to return
- Power
  - 15 mA @ 5V
  - No sleep/idle, but can turn off
  - 1 pin input, 1 pin output
- Cost
  - ~$2-3/ea @ 1
- Distance
  - Rated at 4 m
  - 15 deg angle
- Size
  - ~20 x 45 x 10 mm
- Can get other modules with
  - Narrower angle
  - Larger distance



What else should we be considering here?

LIDAR/ToF

- Optical version of US distance sensor
  - Measures time of flight of light
- Can get single-pixel versions, or ToF cameras, or LIDAR cameras



LIDAR-Lite v4 LED

PART NUMBER 010-02022-00

$59.99 USD

4 interest-free payments of $16.49 with Klarna. Learn More

ADD TO CART

Available to ship in 1–3 business days.

940 nm LED → eye-safe
10 m range
Interface: I2C
Power (operating voltage): 4.75 – 5.25 VDC
Current consumption: 2mA idle, 85mA during acquisition
Beam divergence: 4.77°
Size (HxWxD): 52.2 x 21.2 x 24.0 mm

Home / Cameras for Raspberry Pi / Pivariety Camera Modules / Time of Flight Camera for Raspberry Pi

SKU: B0410

Time of Flight Camera for Raspberry Pi

$ 49.99

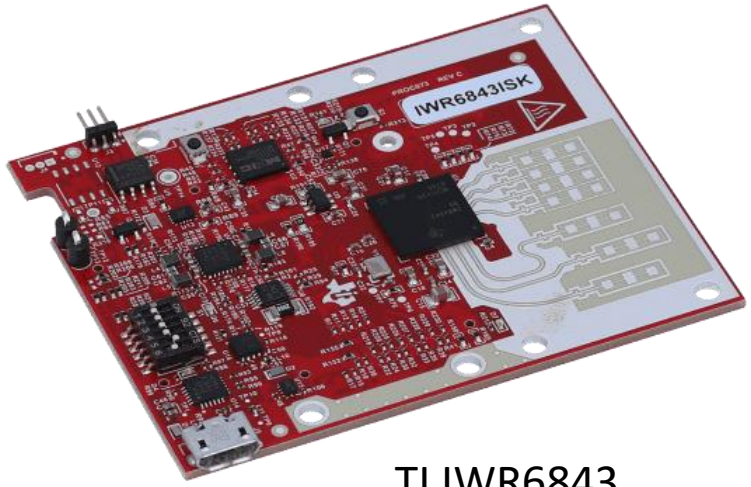
- Pixel-level accuracy: powerful depth/distance measurement.
- Large working range: 2m/4m optional, and a 10-meter broader coverage with our cable extension kit.
- Outdoor usable: No worry of interference from ambient light.
- Any MV library works: 3 languages applicable. C, C++ or Python.
- Affordable decency: 3D imaging with primed point clouds at an unexpectedly low cost.
- Note: **Raspberry Pi OS Bullseye** is required for this camera (04/04/2022 or later releases), a fresh install is highly recommended.

Number of Effective Pixels	240×180
Image Size	1/6"
Max. Frame Rate (Sensor)	120fps
Max. Depth Frame Rate (Raspberry Pi)	30fps, 4-phase
Raspberry Pi OS	Bullseye (32-bit/64-bit) 01/28/22 or later releases
TDP	3.5W Power supply for Pi should be at least 5V/4A
Supported Platforms	Pi 2/3/CM3/4B Zero W/Zero 2 W/CM4
Modulation Frequency	75MHz/37.5MHz
Viewing Angle	70° Diagonal
Measurement Distance	Far Mode: 4m Near Mode: 2m
Light Source	940nm VCSEL illuminator
Board Size	38mm x 38mm

What else should we be considering here?

RF/mmWave

- mmWave/RF version of US distance sensor
  - Operate using 20-70 GHz waves
  - Also used for autonomous vehicles
- Use antenna arrays to send out narrow beams of RF energy and record time of flight back, generating point cloud
- Cost
  - $30-40 @ 100
- Power
  - >1 W during operation
- Challenges
  - Processing to go from point cloud → people is non-trivial
    - Parts include MCU, DSP to help with this
  - Board design is going to be non-trivial, and not something we can assemble here (180 pin BGA)
    - Will need to use dev board for this project
- May be able to get TI engineers to help teams



TI IWR6843

What else should we be considering here?

RF/mmWave

- mmWave radar modules (20-70 GHz)
- TI is not the only manufacturer
- But you need to do some due diligence
  - What information does system provide?
  - What voltages, power are needed to use it?
  - Is there a reasonable way to interface to ESP32C3?

SEEED MR60FDA1 60GHz mmWave Sensor
$37

What else should we be considering here?