LOW-POWER, LOW-COST SMART CAMERAS

ISSUES AND CHALLENGES

IPPN Affordable Phenotyping Workshop
Plant Phenotyping with Minicomputers and Low-Cost Cameras

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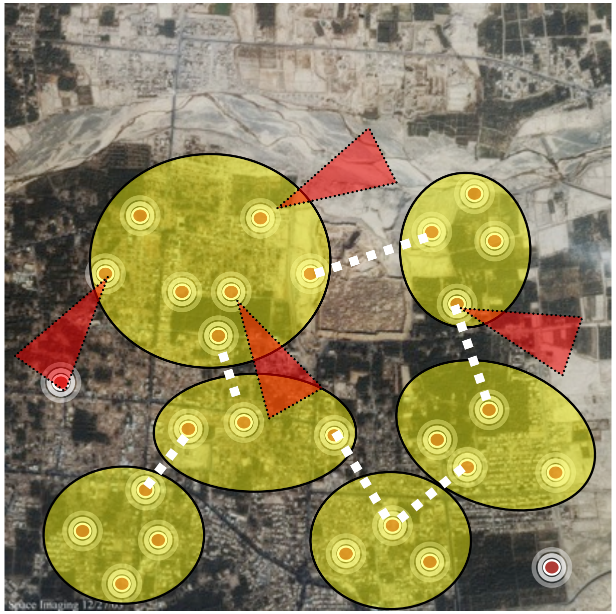
IoT – from idea to reality

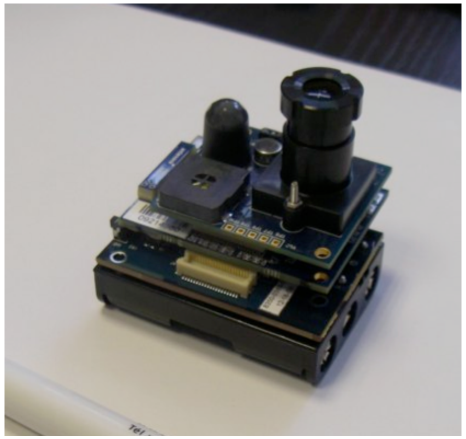
Background

- Wireless Sensor Network
- Surveillance applications (intrusion detection, alert propagation), distributed cameras
- Node scheduling, criticality & power mngt
- Multi-hop routing
- Multimedia traffic (image, sound) on resource-constrained device
- Internet–of-Things
- Radio technologies, channel access control
- Test-beds and performance evaluation



Low-power "IoT" Smart Cameras

- Combining the IoT concept with the smart camera concept usually implies the idea of a **small, autonomous and low-power visual IoT device** while the smart camera concept alone does not necessarily imply these core properties specific to IoT



iMote2 with IMB400 multimedia board

PIXY2

OpenMV

Powerfull recent microcontrollers

- Mostly 32-bit microcontroller (MCU), few 64-bit
- ARM Cortex-M0/M0+/M1 (ARMv6-M)
- ARM Cortex-M3 (ARMv7-M)
- ARM Cortex-M4/M7 (ARMv7E-M)
- >32MB RAM, FLASH, EEPROM
- Analog & Digital GPIO pins, including PWM
- Serial, I2C, SPI
- C/C++
- Python: MicroPython, CircuitPython,...
- Capable of running complex processing such as Machine Learning tasks

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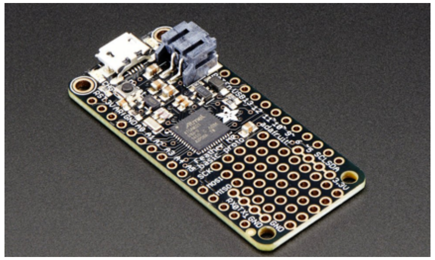
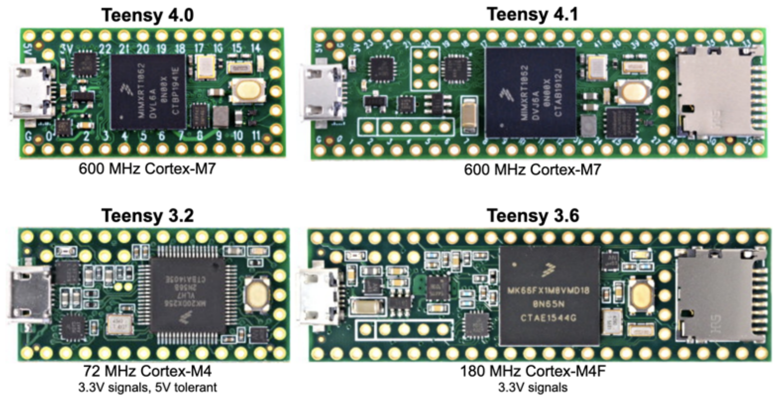
Powerfull microcontroller boards

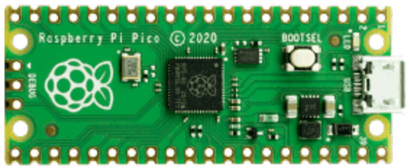
- Adafruit Feather M0 (M0+)



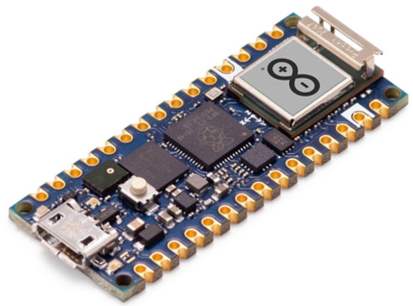
- Teensy32/36 (M4)
  Teensy40/41 (M7)



- RaspberryPI Pico
  RP2040 (M0+)



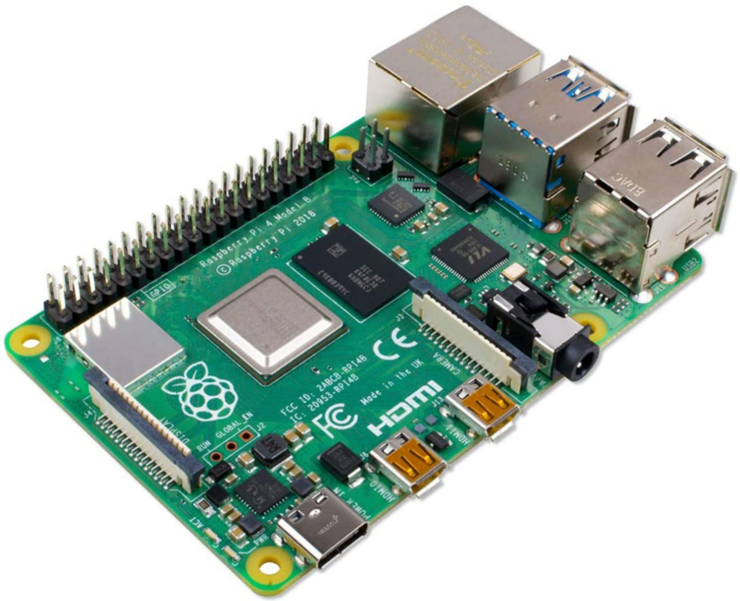
- Arduino Nano RP2040 Connect
  (Bluetooth+WiFi+Sensors…)

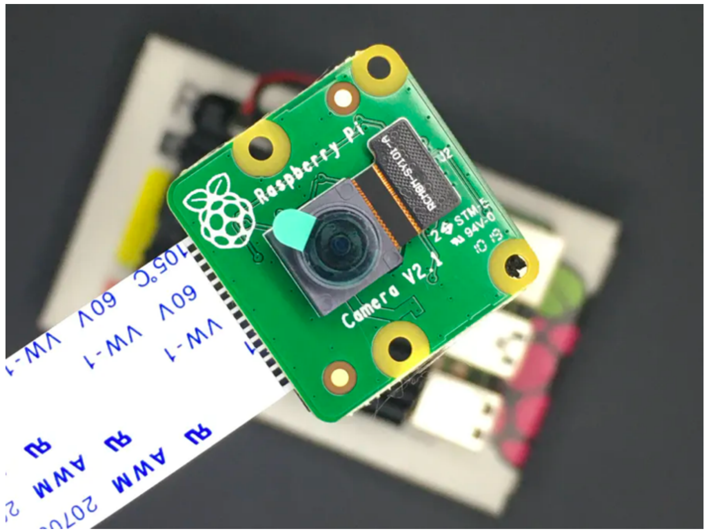


- …and a lot more!

No RaspberryPI?

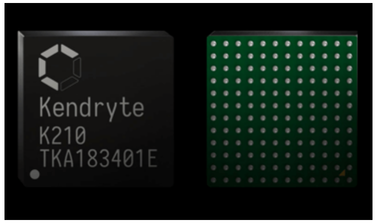
- RaspberryPI is in the Single-Board-Computer category
- It is too power consuming to be considered as an IoT smart camera device!
- It is more suitable as an edge device or IoT versatile gateway



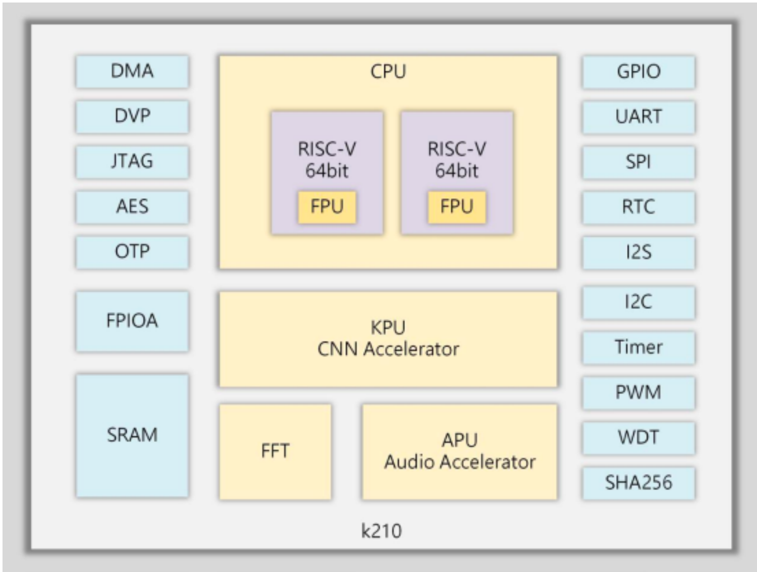


Embedding AI?

- Convolutional Neural Networks (CNN) are efficiently used in many applications for image classification or object detection
- There are new generation of MCUs with embedded AI accelerator such as the Kendryte K210



- "The K210 is an MCU launched by Canaan. It features a self-developed neural network hardware accelerator KPU that can perform CNN operations with high performance." [seeedstudio]



- "K210 is the most powerful edge computing chip, designs for both visual and semantic recognition" [Canaan]

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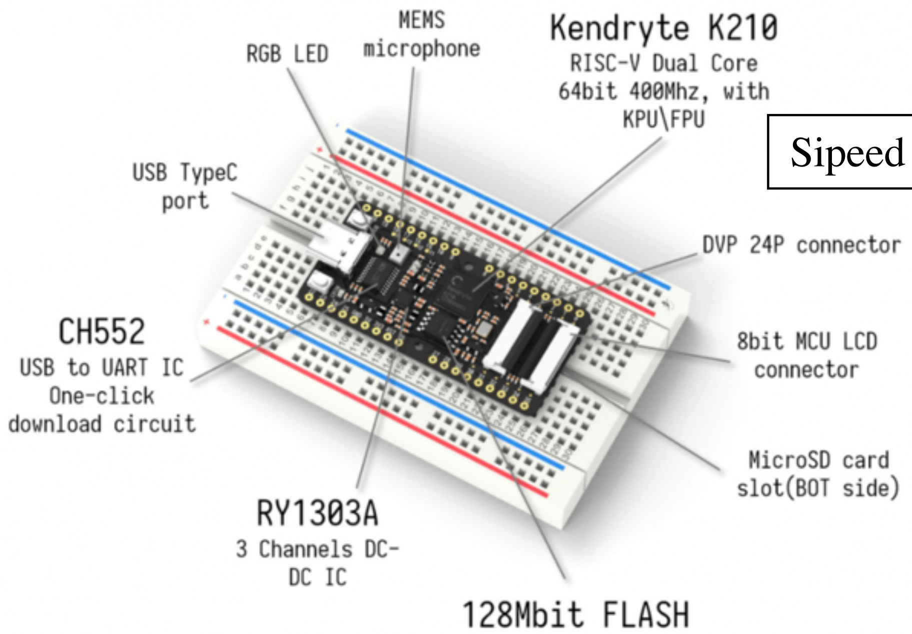
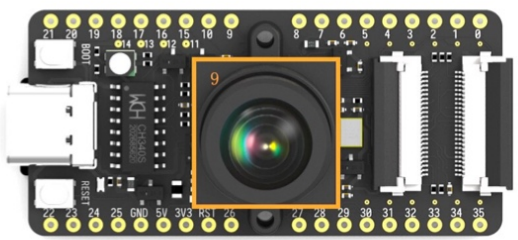
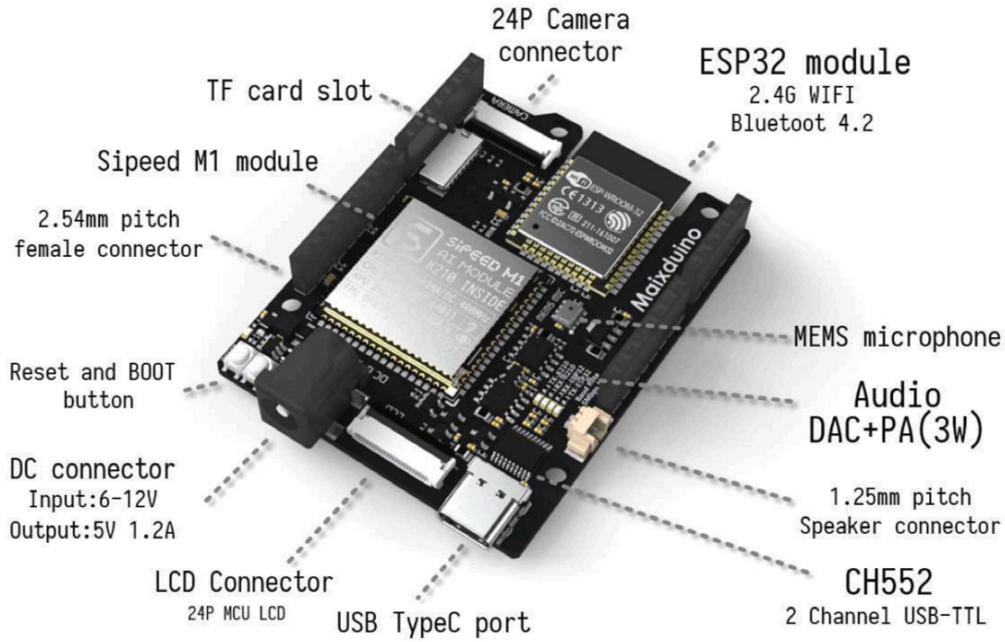
Sipeed Kendryte210-based



Sipeed MAIX Bit



Sipeed MAIX Bit +
LCD & Camera



Sipeed MAIXduino

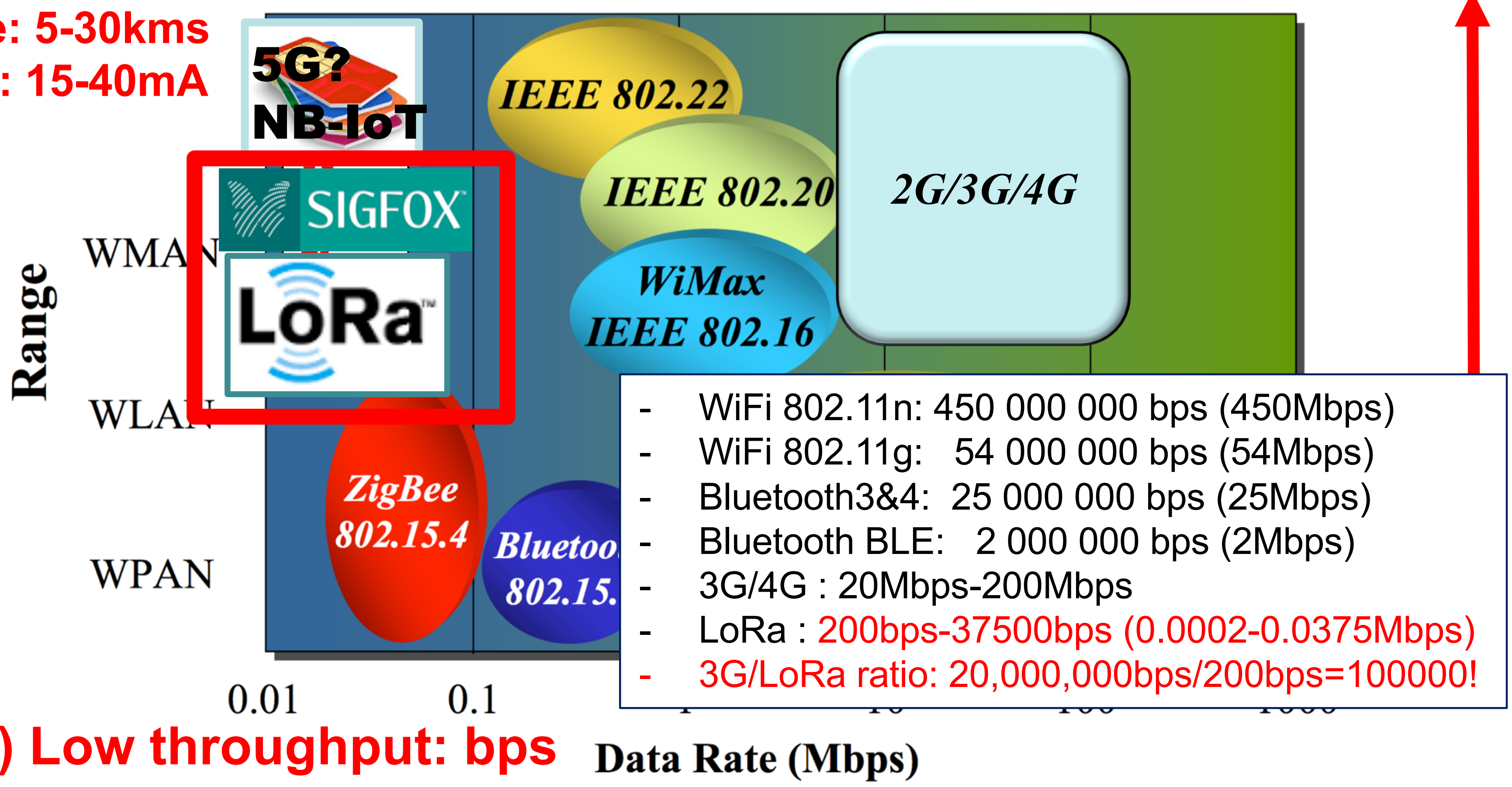
Issues & challenges

- Low-cost, low-power & powerfull microcontroller board is a first step towards IoT smart camera
- Operating mode: periodic, on-demand?
- If periodic, what frequency? For what purpose/event? Detection quality?
- Can all processing be realized locally? Reliability?
- Transmission of image for disambigation and more advanced image processing?
- If transmission, robust encoding is mandatory!
- Unlicensed bands are subject to restriction. Image size is a critical issue!
- Sharing transmission medium is also challenging with LPWAN technologies

Low-power & long-range radios

Energy-Range dilemma

Long-range: 5-30kms
Low-power: 15-40mA



- WiFi 802.11n: 450 000 000 bps (450Mbps)
- WiFi 802.11g: 54 000 000 bps (54Mbps)
- Bluetooth3&4: 25 000 000 bps (25Mbps)
- Bluetooth BLE: 2 000 000 bps (2Mbps)
- 3G/4G : 20Mbps-200Mbps
- LoRa : 200bps-37500bps (0.0002-0.0375Mbps)
- 3G/LoRa ratio: 20,000,000bps/200bps=100000!

(Very) Low throughput: bps

How slow is it?

Very low throughput
Transmission time can be several seconds!

Range ↑ ↓ Throughput

LoRa mode	BW	CR	SF	time on air in second for payload size of: 5 bytes	55 bytes	105 bytes	155 Bytes	205 Bytes	255 Bytes	max thr. for 255B in bps
1	125	4/5	12	0.95846	2.59686	4.23526	5.87366	7.51206	9.15046	223
2	250	4/5	12	0.47923	1.21651	1.87187	2.52723	3.26451	3.91987	520
3	125	4/5	10	0.28058	0.69018	1.09978	1.50938	1.91898	2.32858	876
4	500	4/5	12	0.23962	0.60826	0.93594	1.26362	1.63226	1.95994	1041
5	250	4/5	10	0.14029	0.34509	0.54989	0.75469	0.95949	1.16429	1752
6	500	4/5	11	0.11981	0.30413	0.50893	0.69325	0.87757	1.06189	1921
7	250	4/5	9	0.07014	0.18278	0.29542	0.40806	0.5207	0.63334	3221
8	500	4/5	9	0.03507	0.09139	0.14771	0.20403	0.26035	0.31667	6442
9	500	4/5	8	0.01754	0.05082	0.08154	0.11482	0.14554	0.17882	11408
10	500	4/5	7	0.00877	0.02797	0.04589	0.06381	0.08301	0.10093	20212

Transmitting: `TC/22.5/HUM/67.7` ; about 20 bytes with packet header
Time on air can be 1.44s with LoRa

Unlicensed sub-GHz spectrum constraints

- It is shared medium so long-range transmission in dense environments can create lots of interference!
- Activity time is constrained from 0.1% to 1% duty-cycle depending on frequency: 3.6s to 36s/hour
- Time-on-Air (ToA) is the main constraint

Band	Edge Frequencies		Field / Power	Spectrum Access	Band Width
	Fc-	Fc+			
g(Note 7)	865 MHz	868 MHz	+6.2 dBm /100 kHz	1 % or LBT AFA	3 MHz
g(Note 7)	865 MHz	870 MHz	-0.8 dBm / 100 kHz	0.1% or LBT AFA	5 MHz
g1	868 MHz	868.6	14 dBm	1 % or LBT AFA	600 kHz
g2	868.7 MHz	869.2 MHz	14 dBm	0.1% or LBT AFA	500 kHz
g3	869.4 MHz	869.65 MHz	27 dBm	10 % or LBT AFA	250 kHz
g4	869.7 MHz	870 MHz	7 dBm	No requirement	300 kHz
g4	869.7 MHz	870 MHz	14 dBm	1 % or LBT AFA	300 kHz

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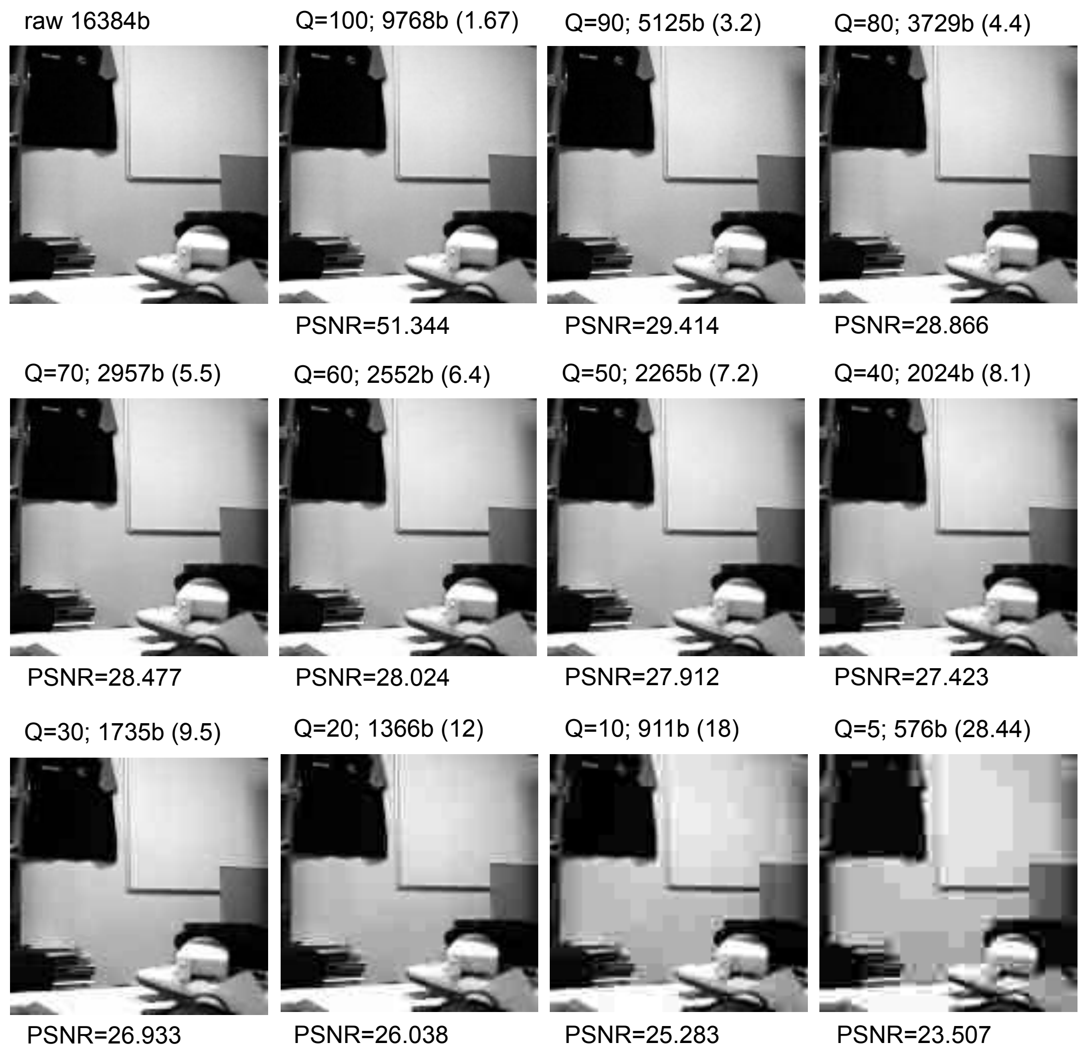
Adaptive image encoding

Scientific cooperation with V. Lecuire from CRAN laboratory for the optimized image encoding algorithm

ADJUSTABLE IMAGE QUALITY FACTOR Q



Robust image encoding?

Scientific cooperation with V. Lecuire from CRAN laboratory for the optimized image encoding algorithm

427 PACKETS, 64 BYTES PAYLOAD, ONE HOP
LOSS RATE: 20%, NO LOSS BURSTS (RADIO), NO DUTY-CYCLING

ORIGINAL 320X320
256 GRAY LEVELS,
JPG 27303 BYTES

348 OUT OF 427
PACKETS RECEIVED

351 OUT OF 427
PACKETS RECEIVED

9 OUT OF 12 IMAGES
COULD NOT BE DECODED

349 OUT OF 1617
PACKETS RECEIVED

WITH LOSS BURSTS (RADIO)

258 OUT OF 427
PACKETS RECEIVED

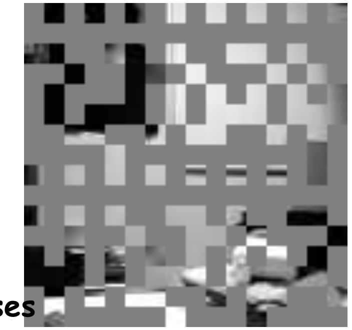
270 OUT OF 427
PACKETS RECEIVED

8 OUT OF 12 IMAGES
COULD NOT BE DECODED

269 OUT OF 427
PACKETS RECEIVED

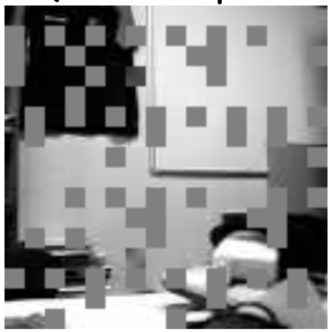
Packet loss-tolerant bit stream

Long-range transmission



Q=50; 10% pkt losses

Q=50; 20% pkt losses



Q=50; 30% pkt losses

any reception order

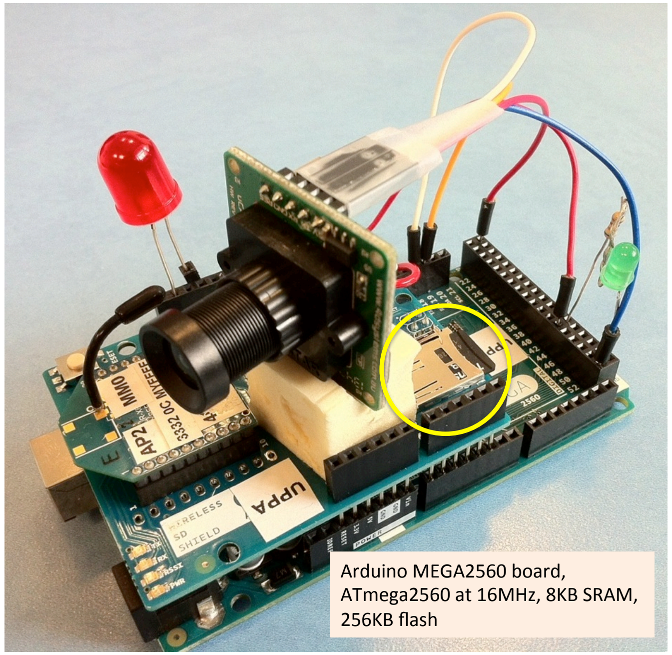
Q=50; 40% pkt losses

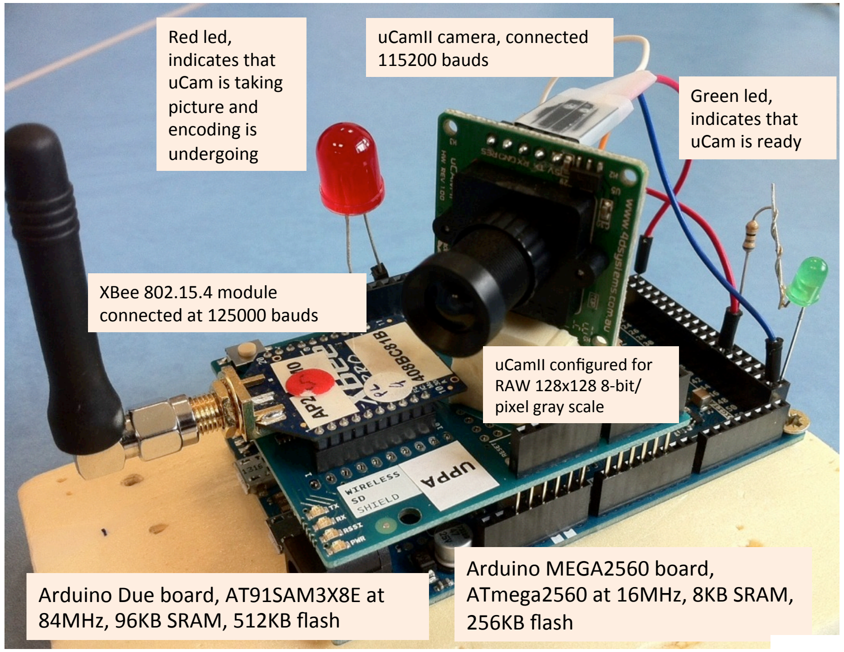
Q=50; 50% pkt losses

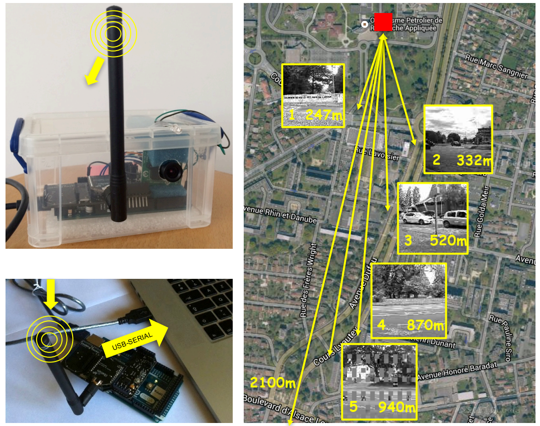
Q=50; 60% pkt losses

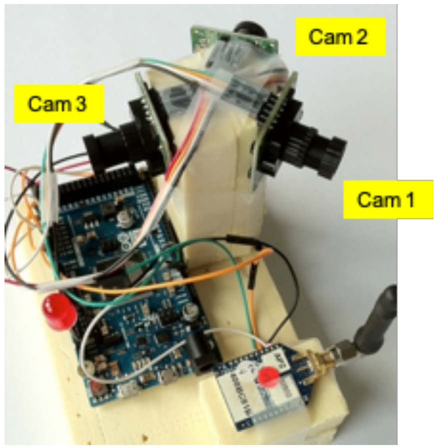
Our early development platforms

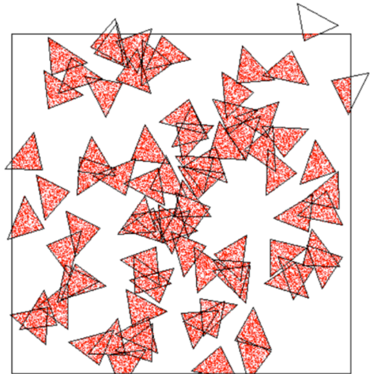
uCAMII, 128x128 8bpp raw images



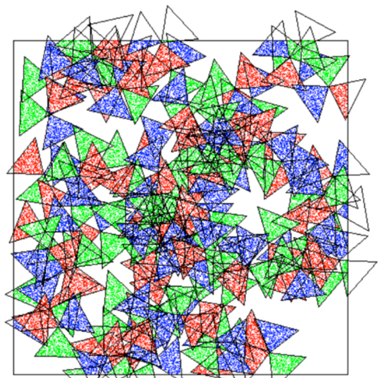




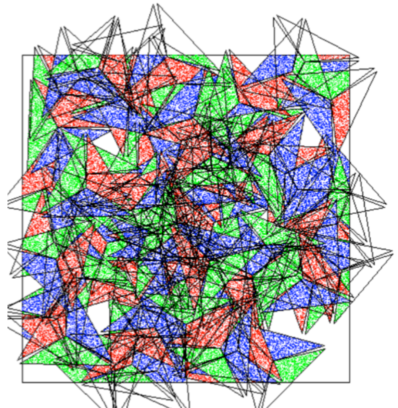




80 image sensors,
1 camera/sensor aov=76°

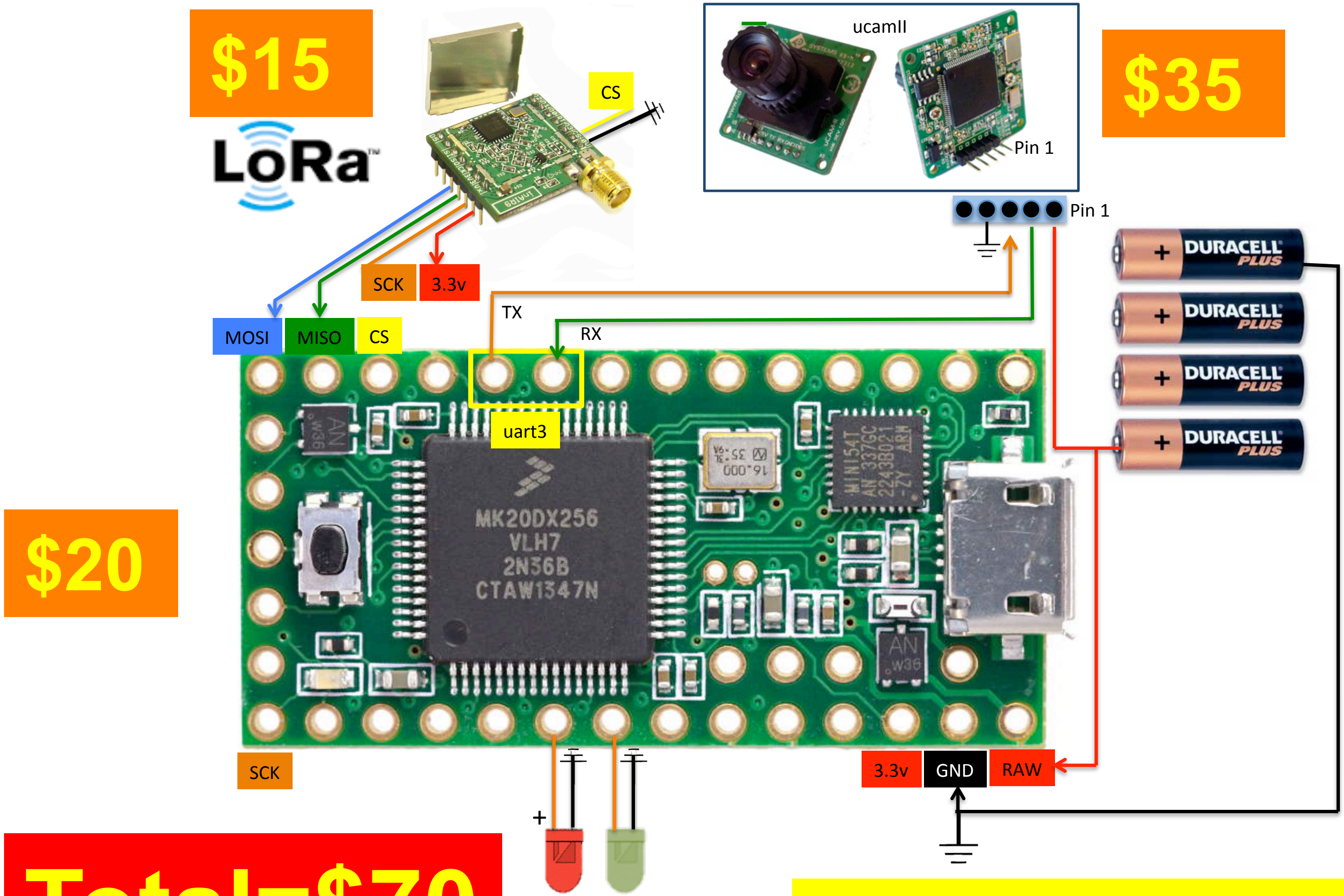


80 image sensors,
3 camera/sensor aov=76°



80 image sensors,
3 camera/sensor aov=116°

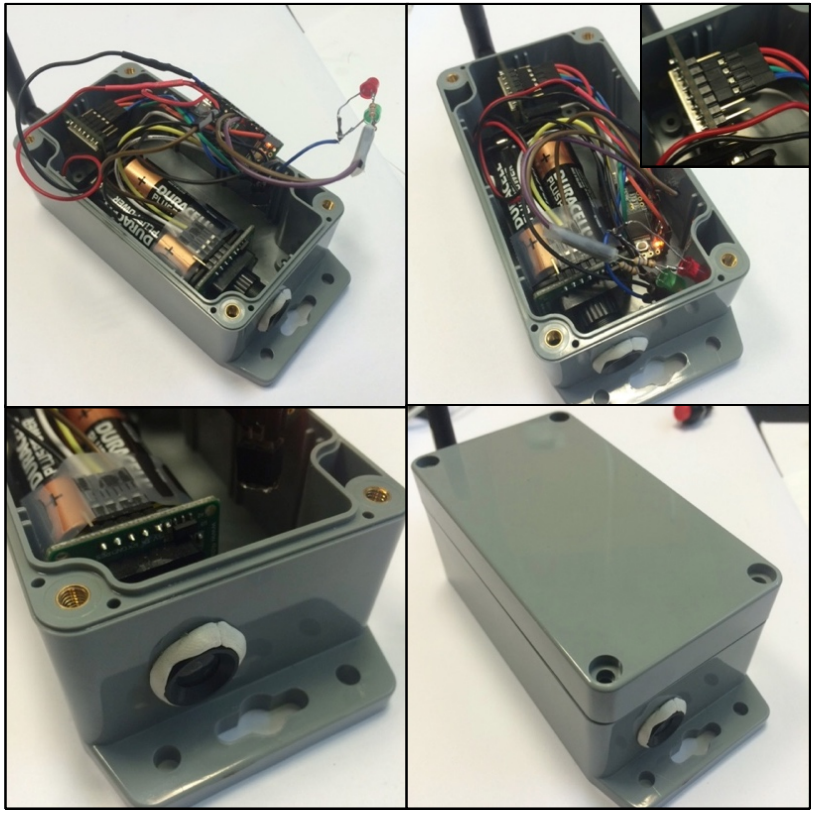
Current platform: Teensy32

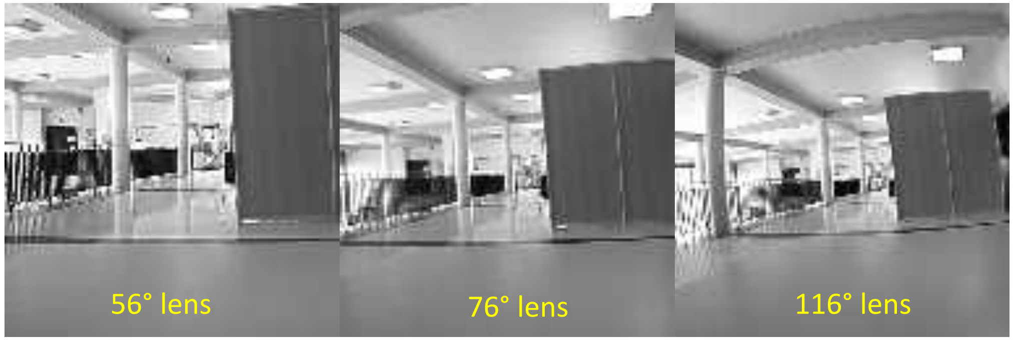


Total=$70

Teensy32, MK20DX256 Cortex-M4
at nominal 72MHz, 64KB SRAM

Targeting surveillance applications





- Fully autonomous
  - Reference image
  - Criticality-based scheduling
  - Luminosity correction
  - Periodic difference detection
  - Image transmission

Time-on-Air of Image transmissions

				time on air in second for payload size of					
LoRa mode	BW	CR	SF	5 bytes	55 bytes	105 bytes	155 Bytes	205 Bytes	255 Bytes
1	125	4/5	12	0.95846	2.59686	4.23526	5.87366	7.51206	9.15046
2	250	4/5	12	0.47923	1.21651	1.87187	2.52723	3.26451	3.91987
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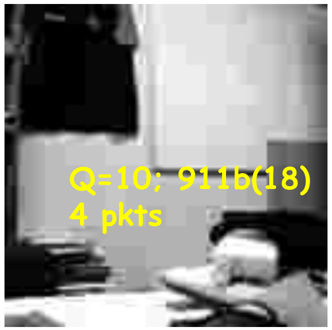


Image encoded at low quality: 16384b down to 911b (ratio 18).

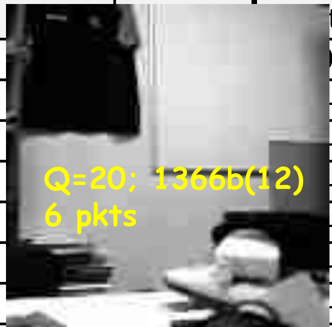
Will generate 4 pkts using 250 max payload

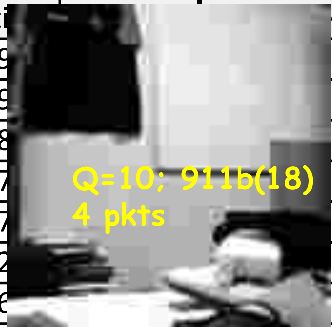
4*9.15= 36.6s

4*1.96 = 7.84s

Image encoding performances

	96MHz		72MHz		48MHz		24MHz		MSS=240	
									N	S
Quality Factor Q	encode	packetiza	encode	packetiza	encode	packetiza	encode	packetiza tion time	number of packets	size in bytes (compression ratio)
100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	813	47	9982 (1.64)
90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	322	23	5090 (3.21)
80	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	218	16	3595 (4.55)
70	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	178	13	2842 (5.76)
60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	162	11	2461 (6.65)
50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	150	10	2129 (7.69)
40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	139	9	1898 (8.63)
30	224	33	260	44	345	64	637	127	7	1608 (10.19)
20	223	31	260	39	345	58	636	115	6	1279 (12.81)
10	223	26	260	31	345	50	636	99	4	824 (19.88)
5	223	23	259	31	344	45	635	89	3	503 (32.57)





- Capturing an image and encoding it roughly take 2.3s
  - Time to sync & config ucam is about 400ms
  - Time to read raw image data from ucam is 1512ms
  - Time for encoding and packetization is about 300ms

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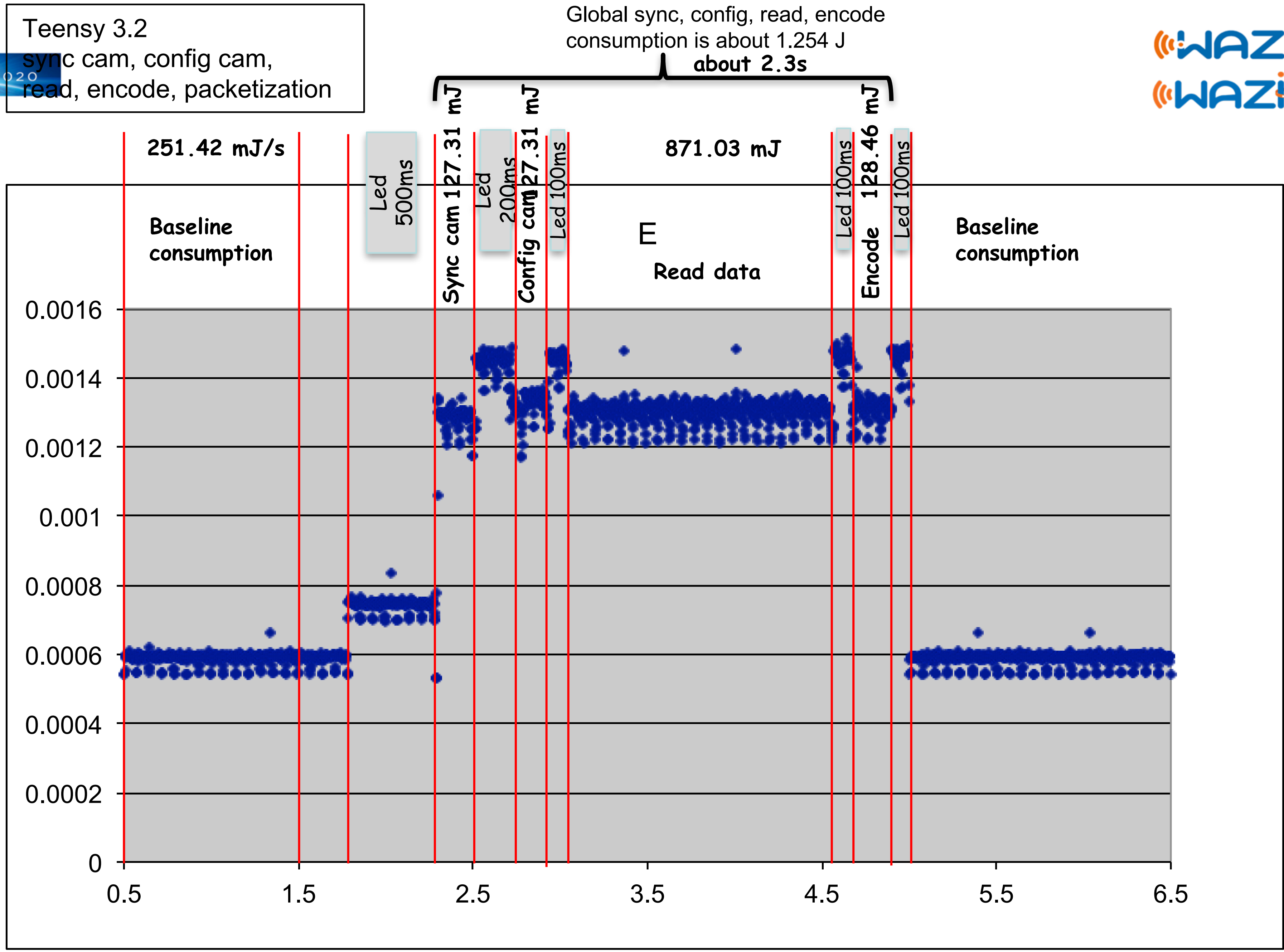
Teensy 3.2
sync cam, config cam,
read, encode, packetization



Power consumption

	baseline (mJ/s)	baseline, hibernate (mJ/s)	read (mJ)	encode (mJ)	Read+encode (mJ)
96MHz	251.42	0.834	871.03	128.46	999.49
72MHz	219.54	0.834	834.97	143.58	978.55
48MHz	211.19	0.834	813.30	185.58	998.88
24MHz	160.95	0.834	719.09	302.48	1021.57

- Using the nominal 72MHz mode minimizes consumption
- Hibernate mode when idle consumes about 167uA
- When transmitting the board consumes about 68mA
- Assuming
  - 1 image/hour (2s)
  - Image encoding with Q=10 (300ms)
  - Transmission of 4 packets (8s)
- Then can run for 268 days on 4 AA batteries

Conclusions

- Visual information will definitely unlock new possibilities for a large variety of IoT applications
- Recent hardware platforms provide a tremendous opportunity to develop efficient IoT smart camera with heavy local processing
- Huge oppotunity for plant phenotyping, providing much more information than "traditional" sensors
- Will low-cost hyperspectral IoT smart camera be a reality?
- For real-world deployment there are still issues and challenges on power consumption, image encoding and compression, transmission performance, radio channel sharing,...

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ISSUE ... ENG

IPPN Affordable ... p
Plant Phenotypi... with M... n

IPPN

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HORIZON 2020

WAZIUP
IoT – from idea to reality
WAZIHUB