TECHNICAL UNIVERSITY OF CRETE

Embedded System for Photographic FLASH Triggering

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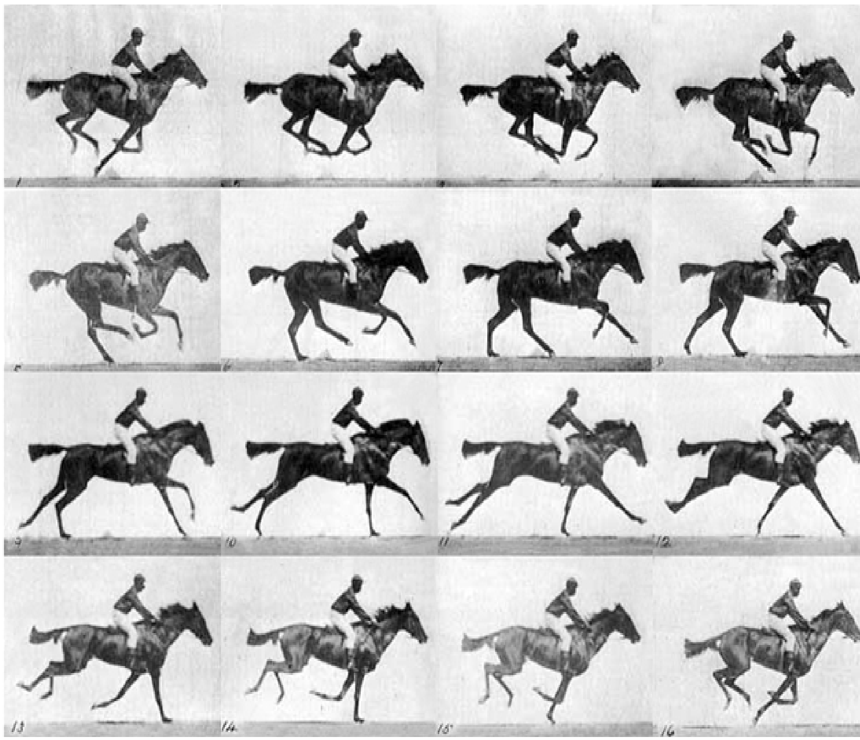
Aims

- Design of photographic flash triggering system
- Wireless sensor triggers
- Low cost (< 60$)
- Open Source
- Readily available components
- Easy construction

High Speed Photography

- Multiple consecutive shots at high frequency
- Single image capturing a specific moment in time

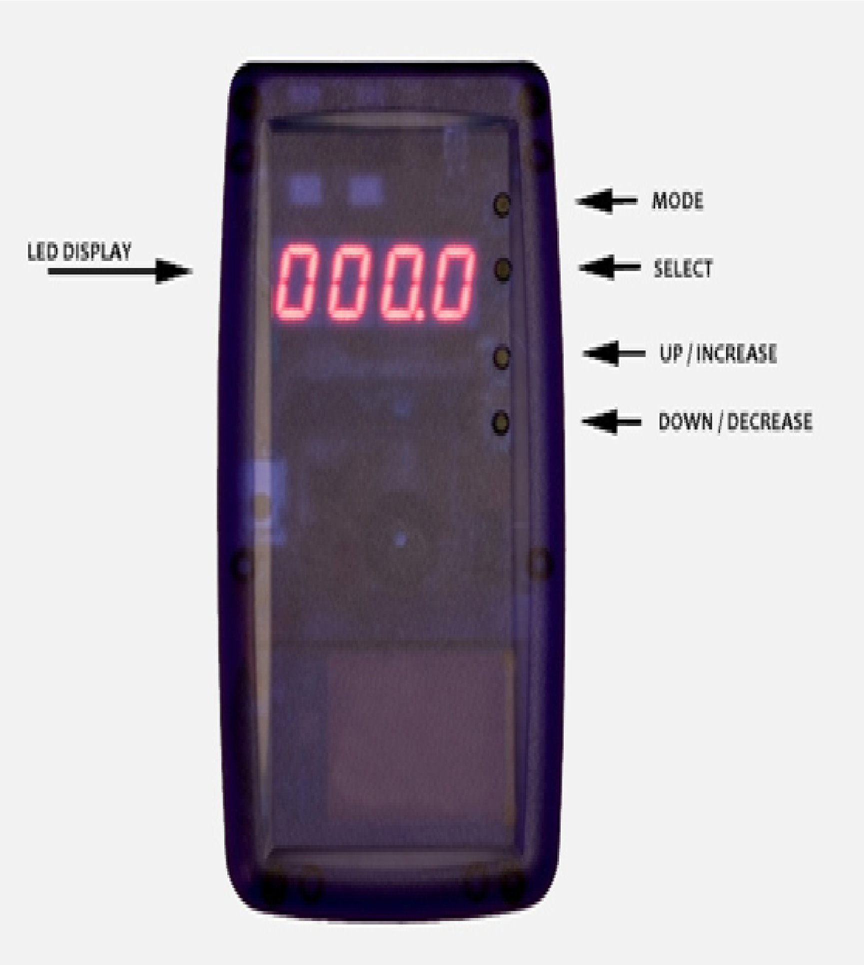


E. Muybridge, Descriptive Zoopraxography

http://www.cameraaxe.com/wp/

- *SMPTE, “Society of Motion Picture and Television Engineers”, www.smpte.org/home, 2007. [Online]. Available: http://www.smpte.org/home*
- *J. E. Field, “High-speed photography,” Contemporary Physics, 1983. [Online]. Available: https://en.wikipedia.org/wiki/High-speed_photography#Notes*

Triggering Systems



http://www.universaltimer.com/info1.html

Common Principles and Similar Architectures

- Microcontrollers → computing units
- Sensor Measurements → Triggers

Human Reaction Time

- Slow (mean 250 ms)
- Reaction Time (Tr) = Stimulus Time to Brain (Ts) + Brain to Body Command Time (Tb)
- Age, Health State, Gender and Type of Stimulus as Factors for Reaction Times

- *A. Jain, R. Bansal, A. Kumar, and K. D. Singh, "A comparative study of visual and auditory reaction times on the basis of gender and physical activity levels of medical first year students.," Int. J. Appl. basic Med. Res., vol. 5, no. 2, pp. 124–7, 2015.*
- *A. T. Welford, "Speed-accuracy trade-off and information processing dynamics," Academic Press, 1934.*
- *F. Mawase, D. Lopez, P. A. Celnik, and A. M. Haith, "Movement Repetition Facilitates Response Preparation," 2018.*
- *R. J. Kosinski, "A Literature Review on Reaction Time."*

Duration of Interesting Phenomena




- Animals (98 – 389 km/h)
- Popping balloons (5-10 ms)
- Bullets (120 – 1700 m/s)
- Lightning (100 – 200 ms)
- Objects Breaking (no specific value)

- *N. C. C. Sharp, "Timed running speed of a cheetah (Acinonyx jubatus)," J. Zool., vol. 241, no. 3, pp. 493–494, Mar. 1997.*
- *High-Velocity Falcon | National Geographic, National Geographic , 2007.*
- *B. Wilburn, N. Joshi, V. Vaish, M. Levoy, and M. Horowitz, "High-speed* videography *using a dense camera array," Proc. 2004 IEEE Comput. Soc. Conf. Comput. Vis. Pattern Recognition, 2004. CVPR 2004., vol. 2, pp. 294–301, 2004*

Features and Specifications

Main Features

- 2 sensors with changeable threshold
- Triggering of one flash/camera
- Wireless Sensor Connection
- Two trigger functions
- Selectable Trigger Delay

Specifications

- System Latency : < 5 ms
- Hardware:
  - 3 computing units
  - 3 wireless nodes
  - 1 OLED screen
  - 1 button
- Total Cost : < $60
- Computing Units’ I/O : > 9 I/O Pins

Technology Mapping : Criteria

- Performance
- Cost and Availability
- Power Consumption
- Latency (for Wireless Communication)

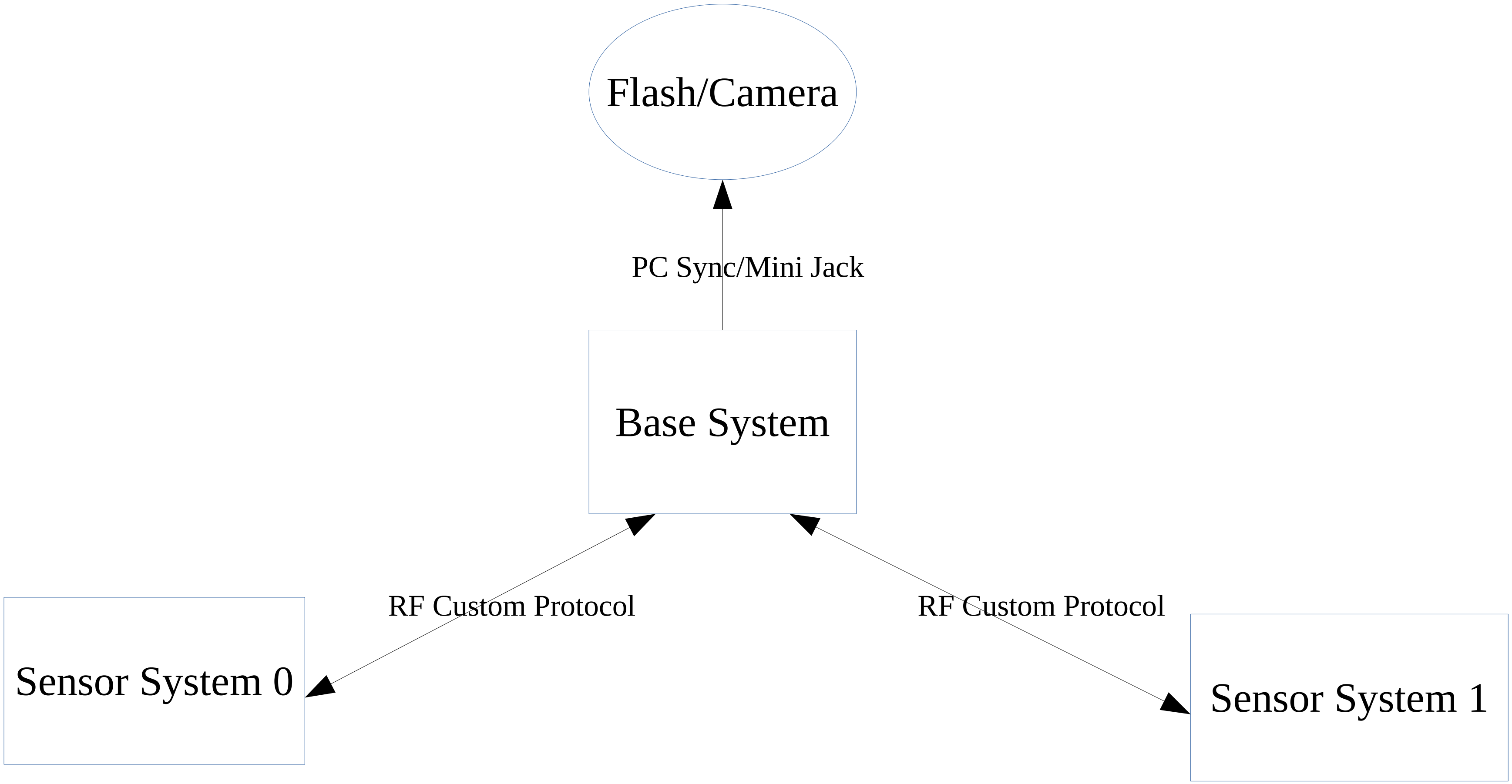
Technology Mapping : Computing Units

Technology	**Frequency**	**Cost**	**Power Consumption**
CPU	> 1 GHz	> $40	> 25 W (min 5 W)
FPGA	> 100 MHz	> $80	> W
MCU	***> 10 MHz***	***> $1-5***	***< 500 mW***
Goal	> 1 MHz	< $60	< W

Technology Mapping : Wireless Communication

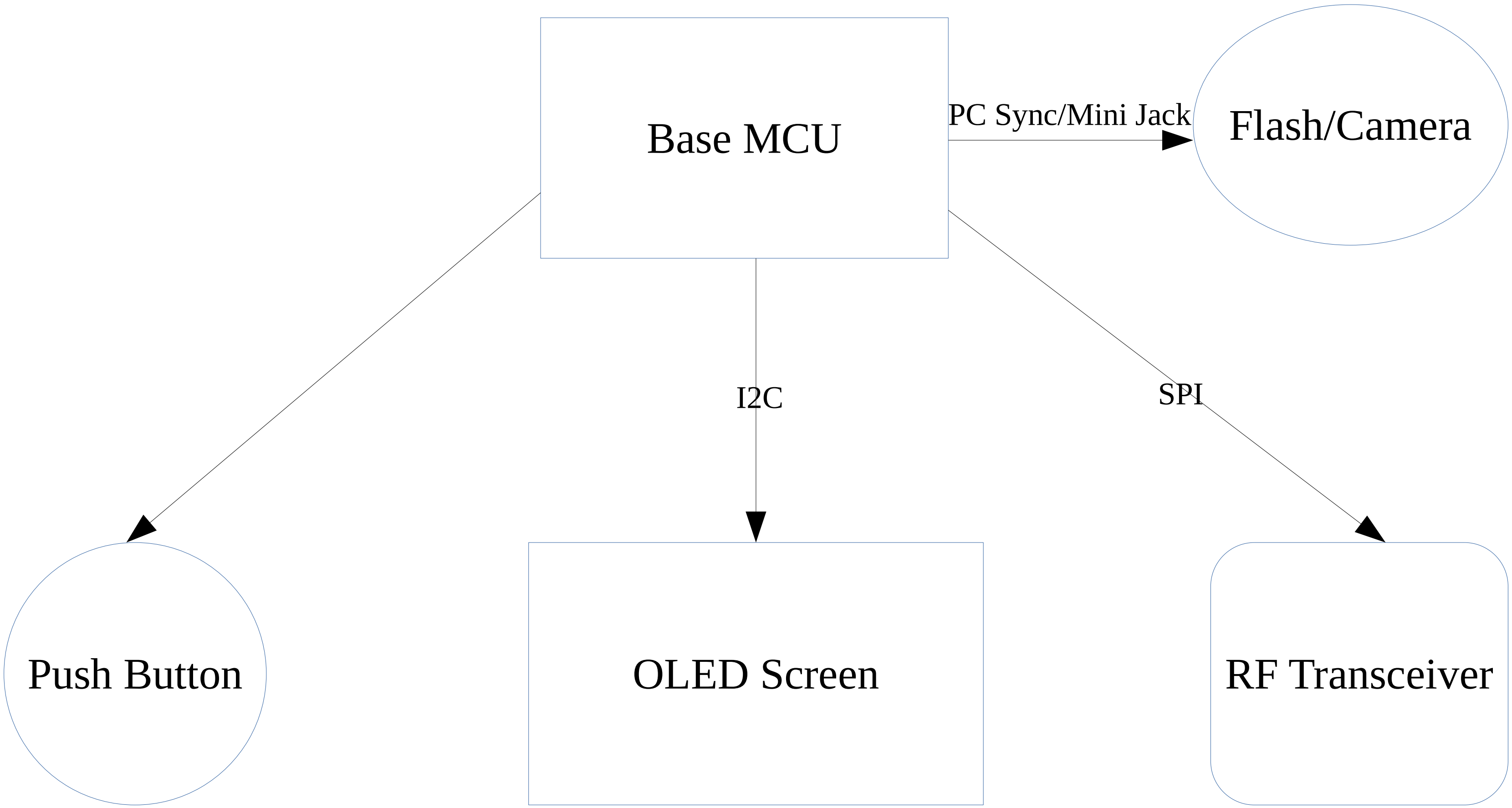
Technology	Estimation of Maximum Latency	Mandatory Optical Contact	Cost	Versatile	Typical Latency Value
Optical	Yes	Yes	> $3	No	< 100 us
WiFi	No	No	> $3.6	No	> 25 ms
Bluetooth	No	No	> $6.3	No	> 25 ms
Zigbee	No	No	> $45	No	> 25 ms
RF	Yes	No	> $2.4	Yes	< 1 ms

General System Model



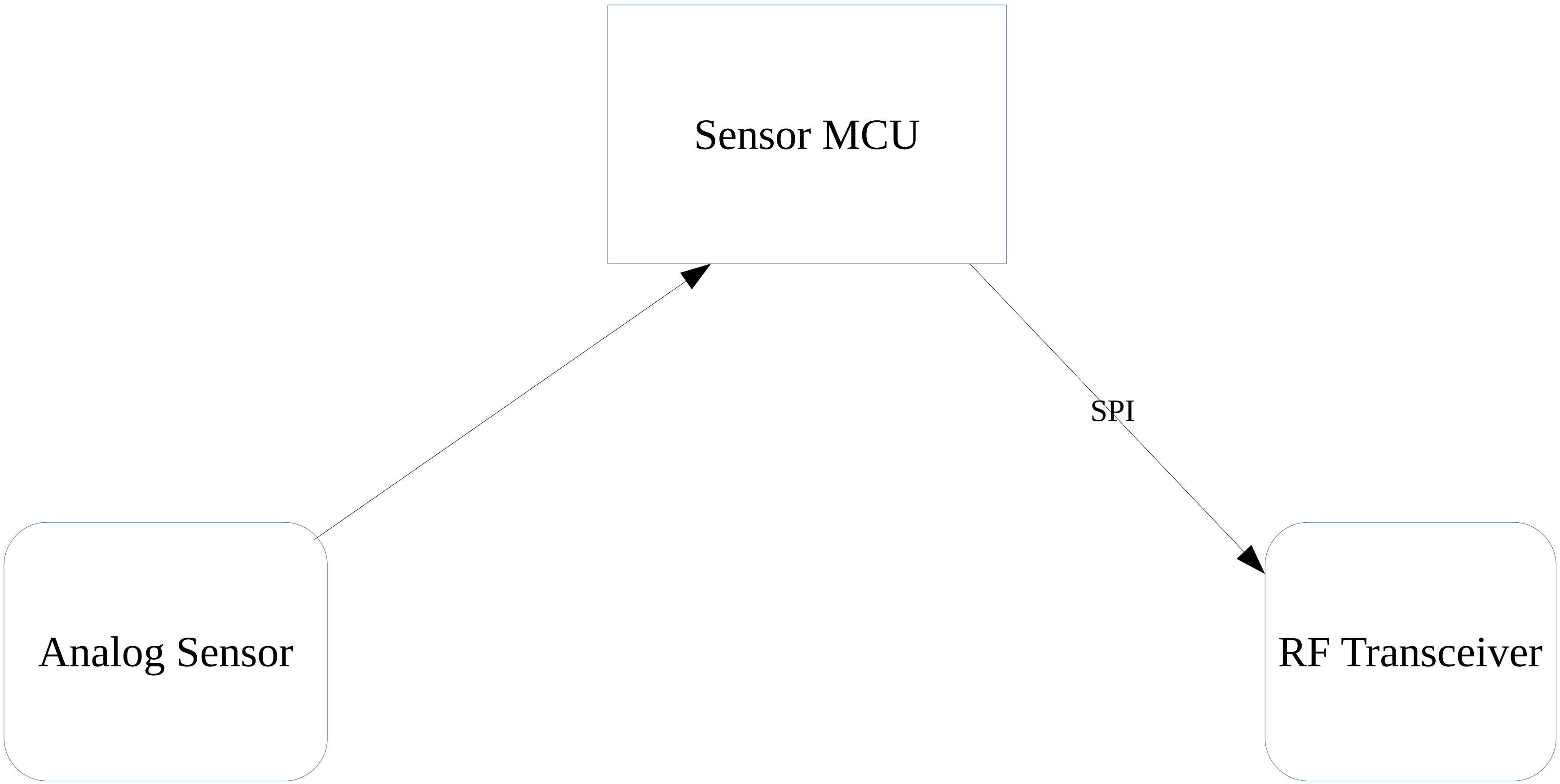
System Model Diagram

Base Subsystem Model



Base Subsystem Model Diagram

Sensor Subsystem Model



Sensor Subsystem Model Diagram

Comparison with Other Systems

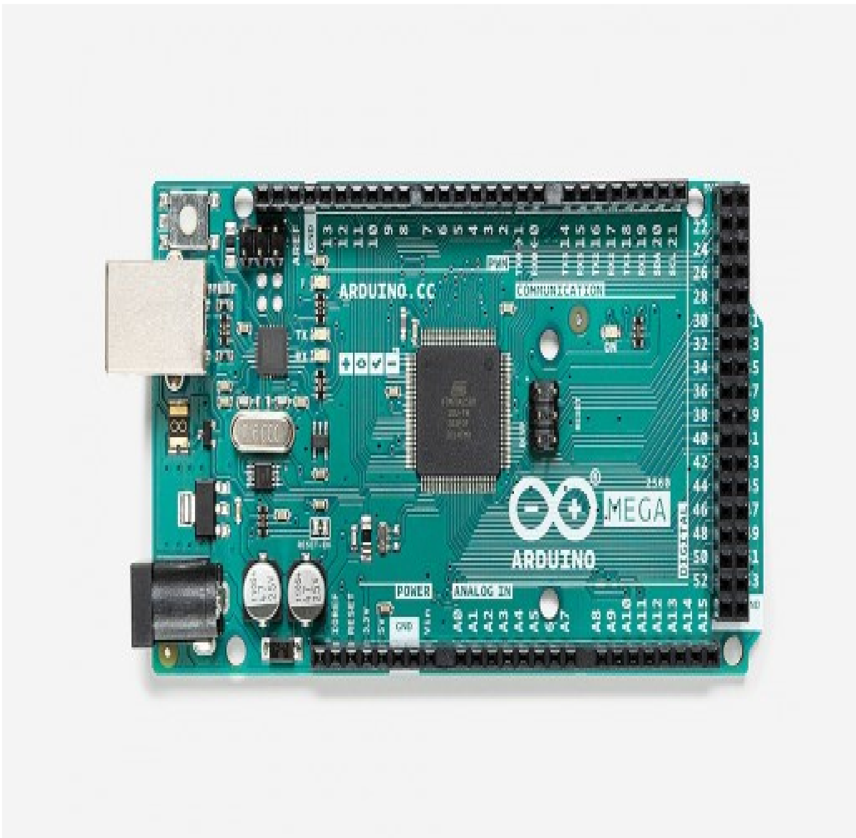
Similarities

- Use of sensors for triggers
- Base responsible for:
  - user interface
  - checking trigger function
  - triggering

Differences

- Less centralized system
- Dedicated MCU for each sensor
- Wireless communication

Base Subsystem MCU



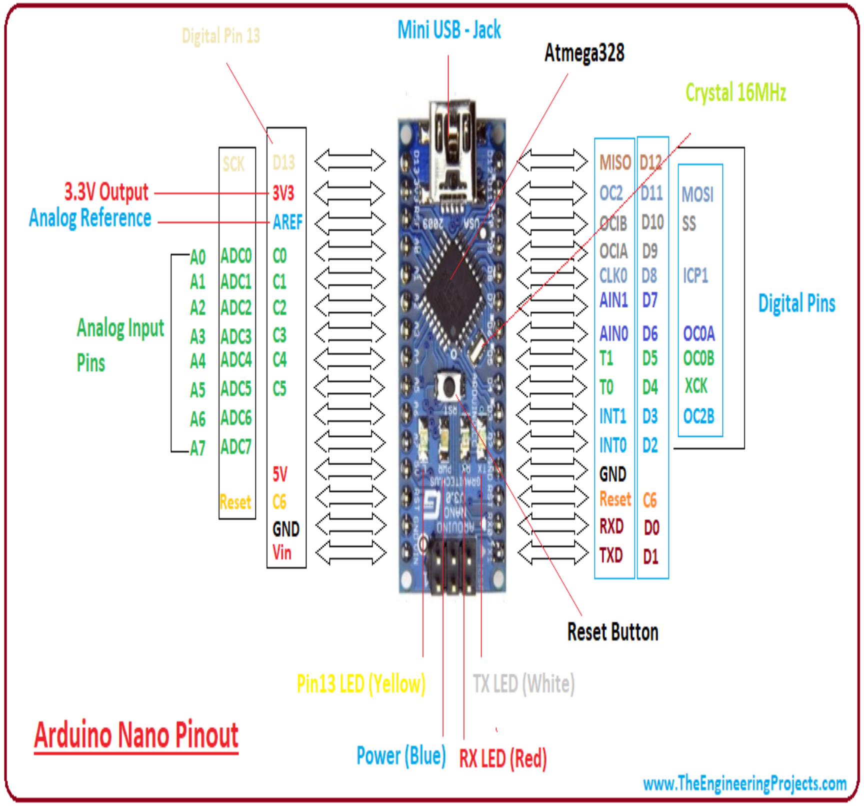
https://www.microchip.com/wwwproducts/en/ATmega2560

Arduino Mega 2560

- 16 MHz
- 16 Analog Inputs, 54 Digital I/O
- I2C, SPI, Serial support
- Four 16-bit timers and two 8-bit timers
- 256 kbyte Flash/8 kbyte SRAM
- Open platform → Well supported libraries
- Low price (< 8$)

- *Arduino, "Arduino Mega 2560 Rev3 | Arduino Official Store," Arduino. [Online]. Available: https://store.arduino.cc/arduino-mega-2560-rev3*
- *Microchip Technology Inc., "ATmega640/V-1280/V-1281/V-2560/V-2561/V." Microchip Technology Inc., p. 436.*

Sensor Subsystem MCU



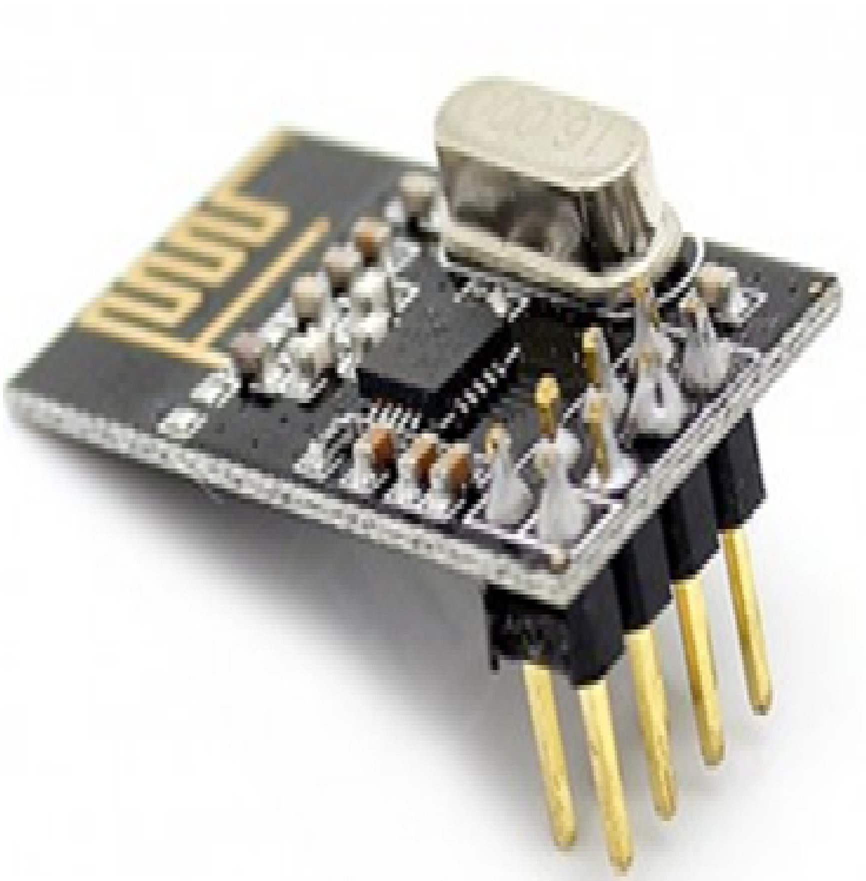
https://www.theengineeringprojects.com/2018/06/introduction-to-arduino-nano.html

Arduino Nano V3

- Same architecture with Arduino Mega 2560
- 16 MHz
- 8 Analog Inputs, 22 Digital I/O pins
- 32 kbyte Flash/2 kbyte SRAM
- Low price (< 3$)

- *Arduino, “Arduino Nano.” [Online]. Available: https://store.arduino.cc/arduino-nano*
- *Microchip Technology Inc., “ATmega328P 8-bit AVR.” Microchip Technology Inc., p. 294.*

RF Transceiver Module



http://robotechshop.com/shop/module/nrf24l01/?v=f214a7d42e0d

nRF24L01+ by Nordic Semiconductors

- RF Transceiver
- SPI Interface
- 2.4 GHz band, 126 channels, 2 Mbps
- Low Power Consumption (max 13.5 mA)
- RX→TX or TX→RX in 130 us, total time < 230 us

- *Nordic, "nRF24L01+ Single Chip 2.4GHz Transceiver Product Specification v1.0," Build. Res., no. 1, p. 78, 2008*

Other Hardware

Generic 0.92 inch I2C OLED Screen

- OLED → Low Power Consumption
- High contrast
- Easily available
- Low cost (< 3$)

Sensors

- Analog
- 3-pin
- Support for 2-pin simple components
- 0-5 V Voltage Range
- Draw current < 40 mA

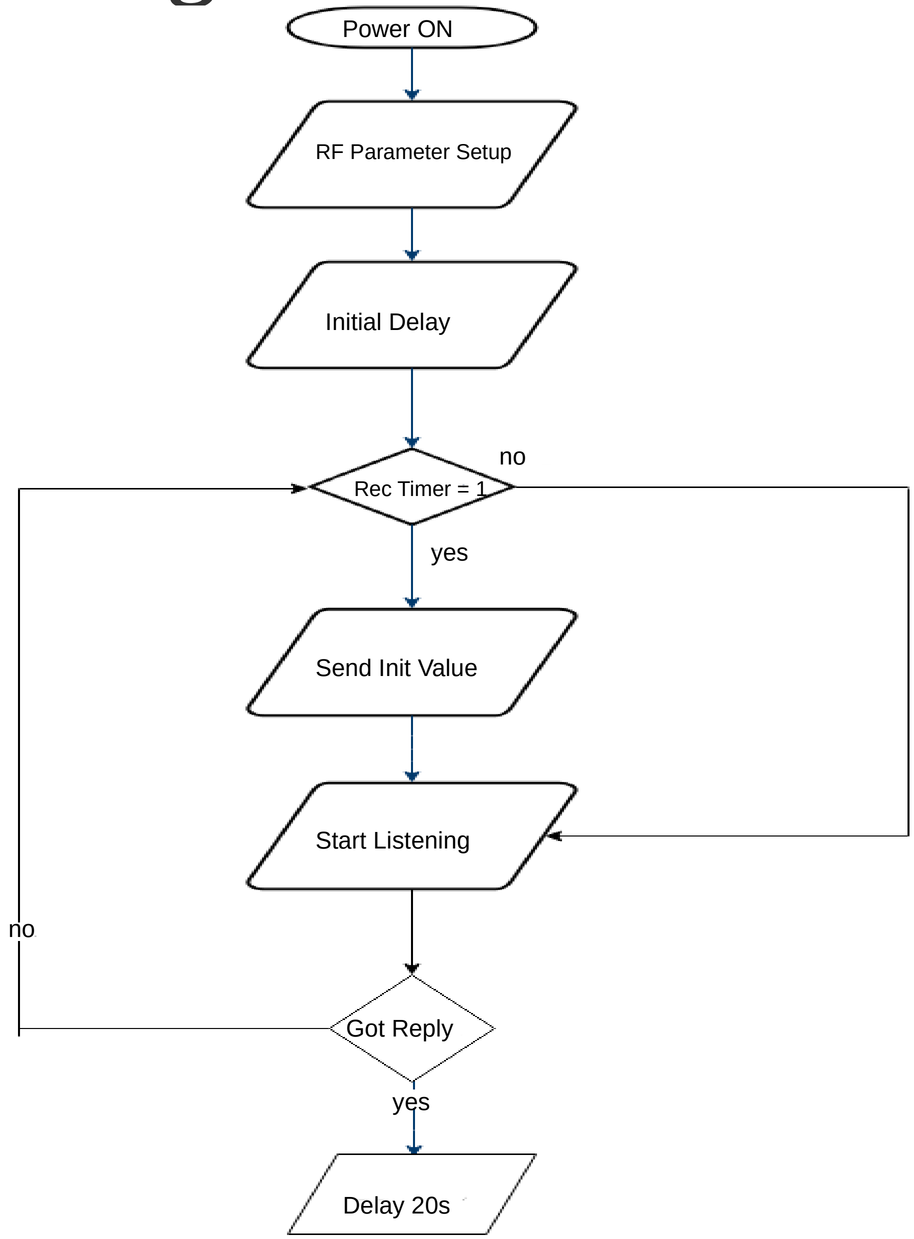
Bypassing Enhanced ShockBurst

- Automatic ACKs → Less Determenistic
- Need for ACKs only during:
  - Sensor Recognition
  - Change of system state
- Fewer packet transmissions
- Reduced power consumption

Custom Protocol

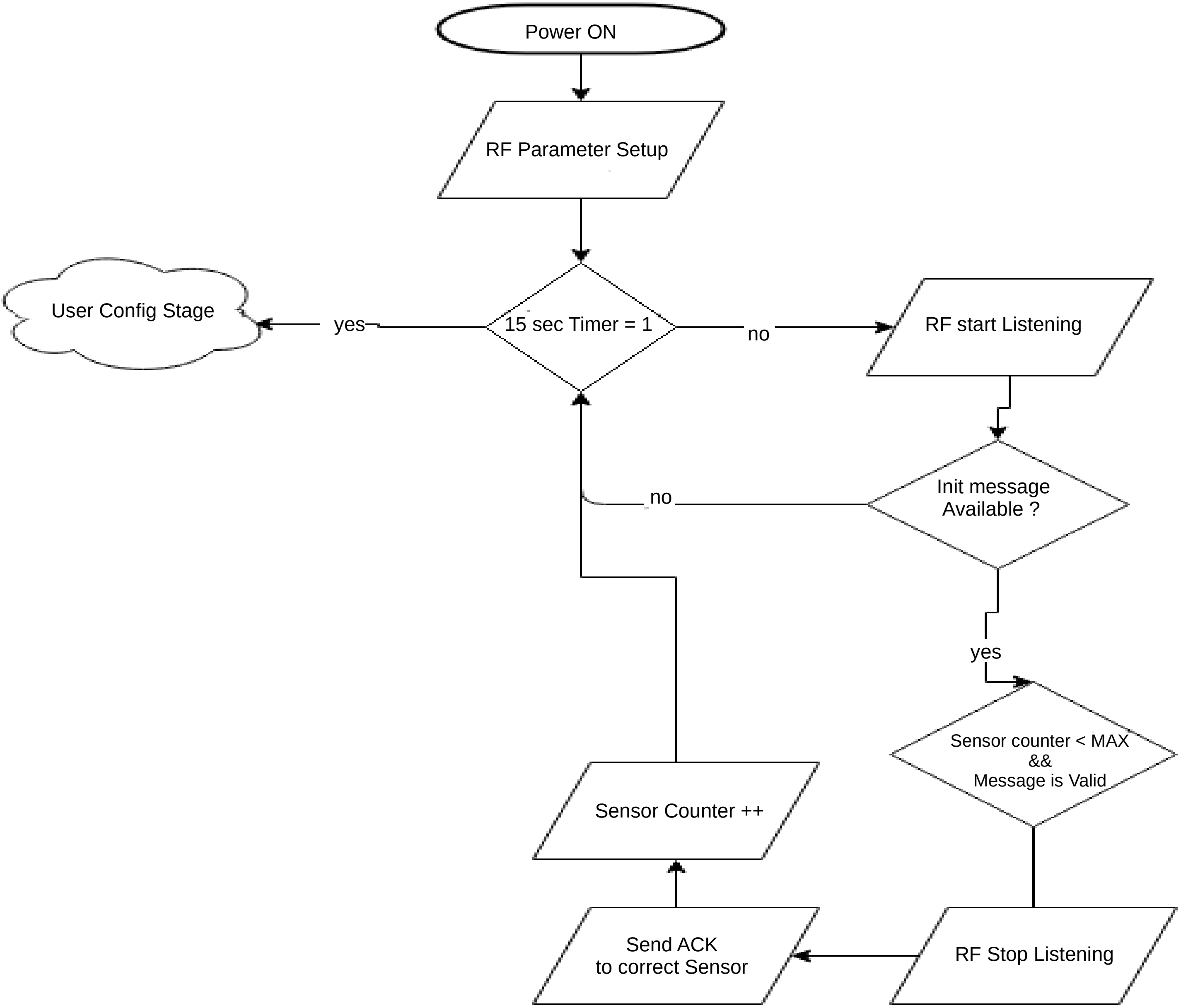
- Low latency communication
- Event based changes
- Event representation → Predetermined value
- Same state for every subsystem

Sensor Recognition : Sensor Subsystem



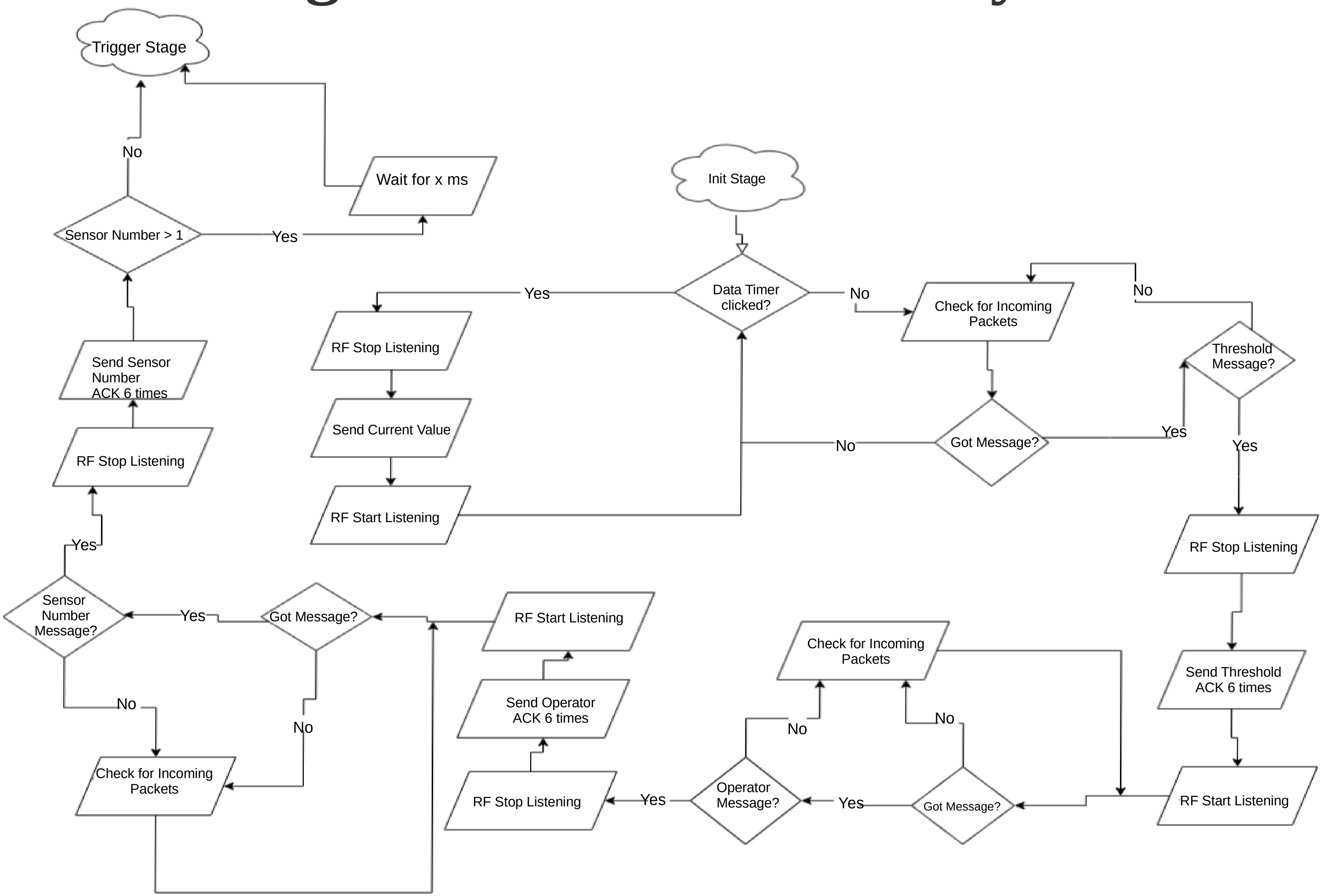
Sensor recognition state flowchart for sensor subsystem

Sensor Recognition : Base Subsystem



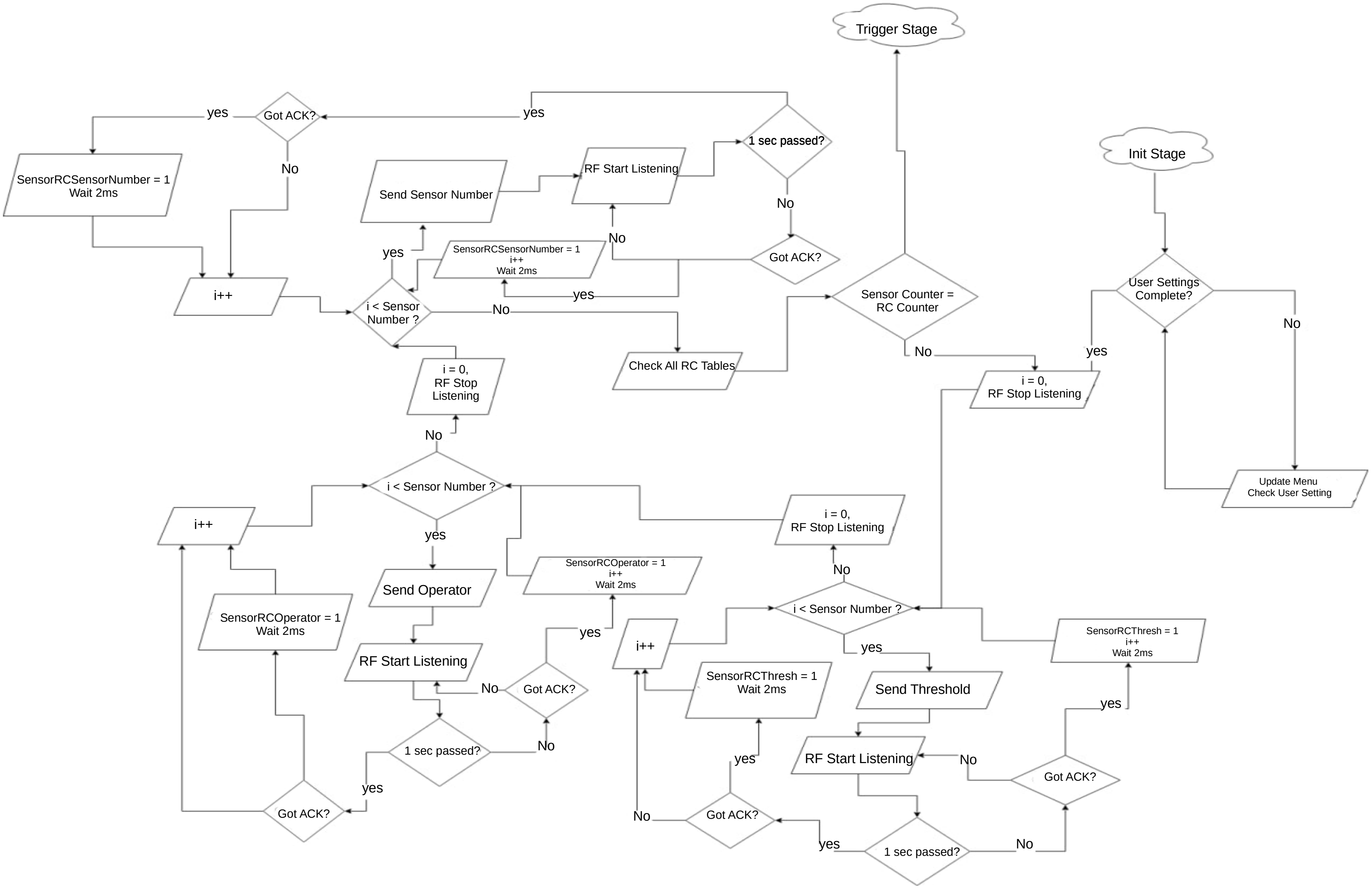
Sensor recognition state flowchart for base subsystem

Configuration : Sensor Subsystem



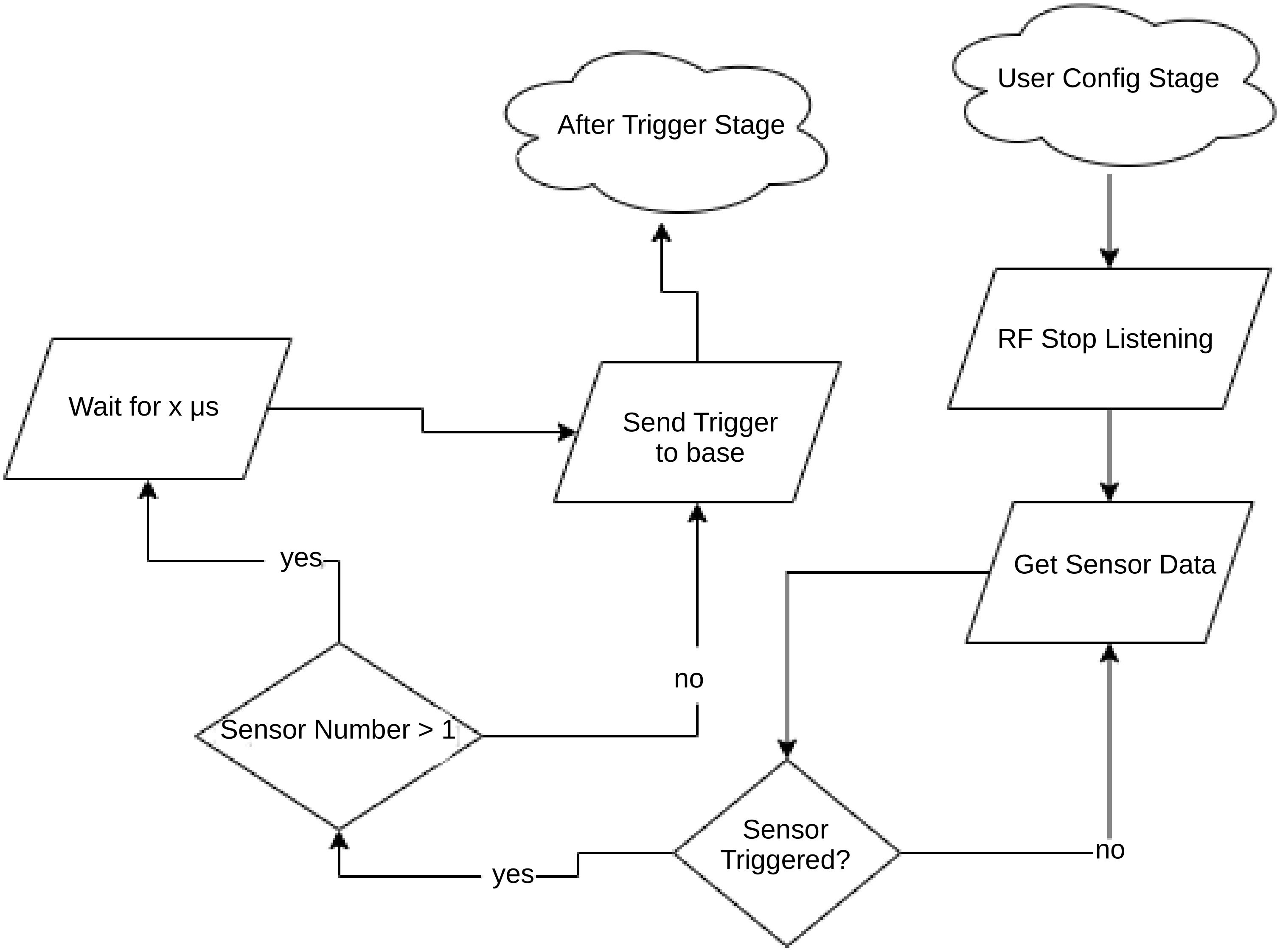
Configuration state flowchart for sensor subsystem

Configuration State : Base Subsystem



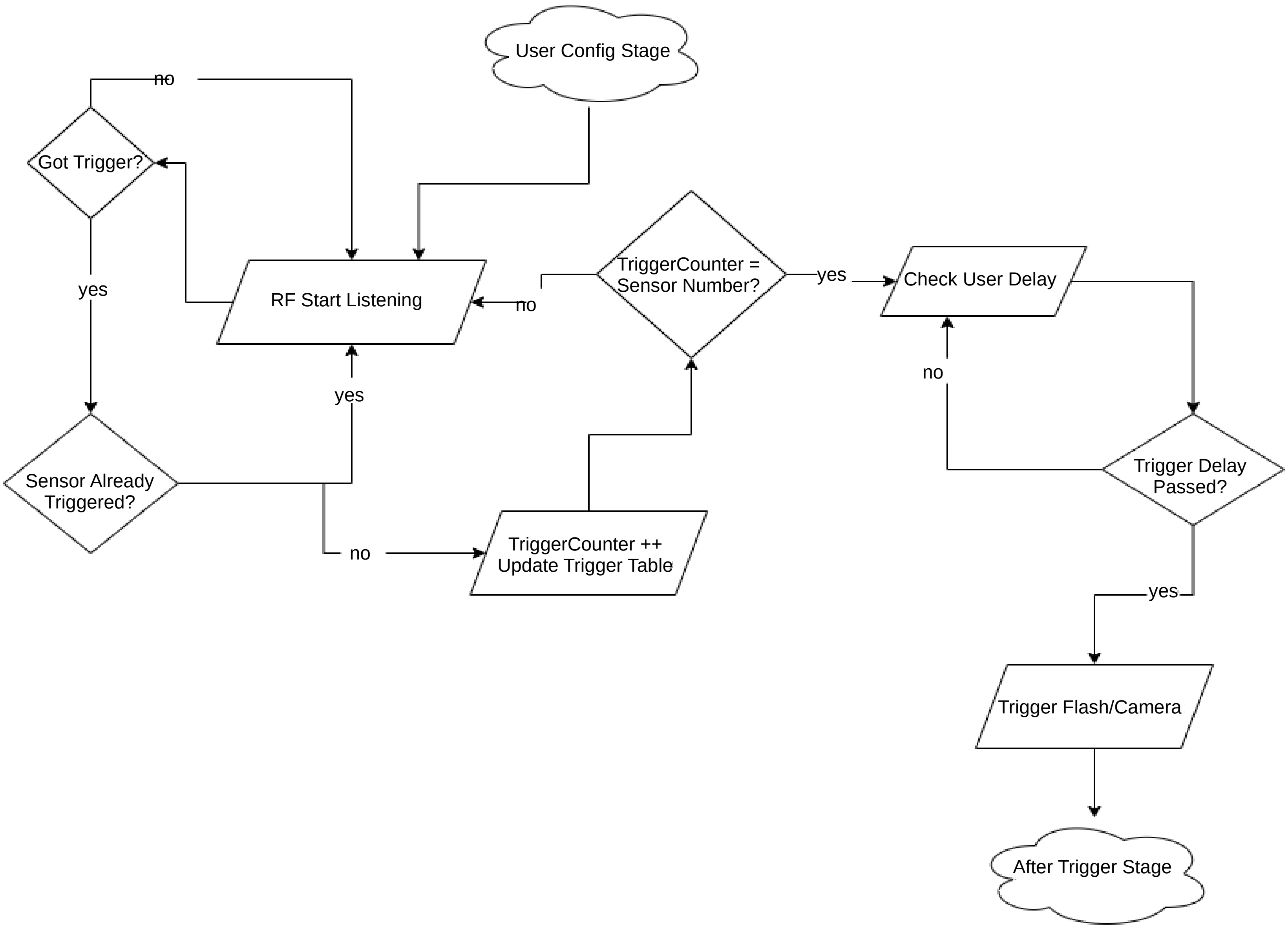
Configuration state flowchart for base subsystem

Triggering : Sensor Subsystem



Triggering stage flowchart for sensor subsystem

Triggering : Base Subsystem



Triggering stage flowchart for base subsystem

Photographic Equipment

https://www.sony.com/electronics/interchangeable-lens-cameras/ilce-6000-body-kit

https://www.pinterest.co.uk/pin/299630181460781731/

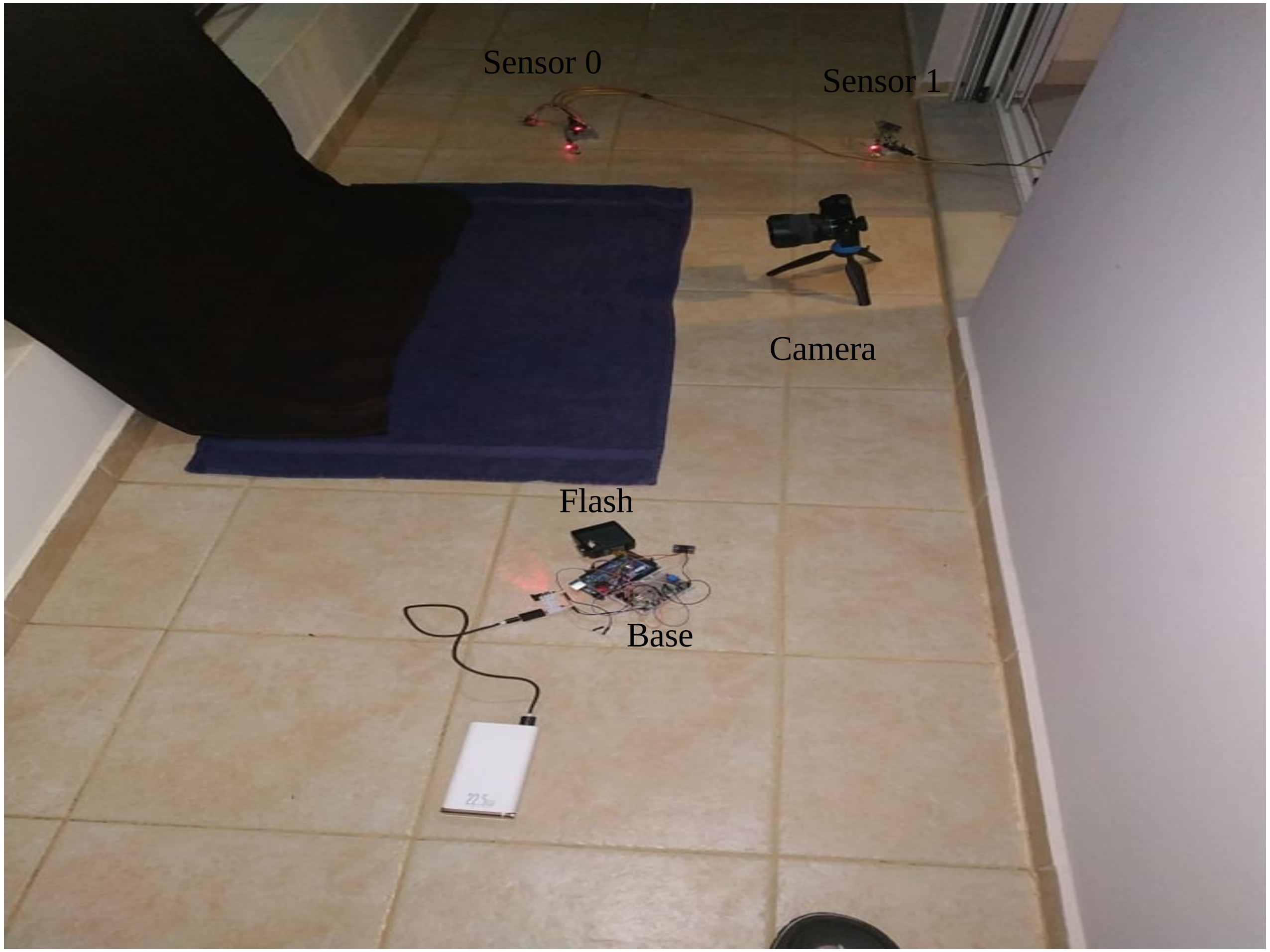
Camera

- Sony a6000
- Canon EOS 300D

Flash

- Fotomatic 140
- Yongnuo Speedlite YN560 IV
- Vivitar Auto 2600

Experimentation Site And Tested Cases



System Setup

Tested Cases

- Popping balloons
- Breaking of objects
- Falling objects on liquid surface

Inability to test

- Lightning
- Projectiles/Bullets
- Wild animals

Testing Parameters

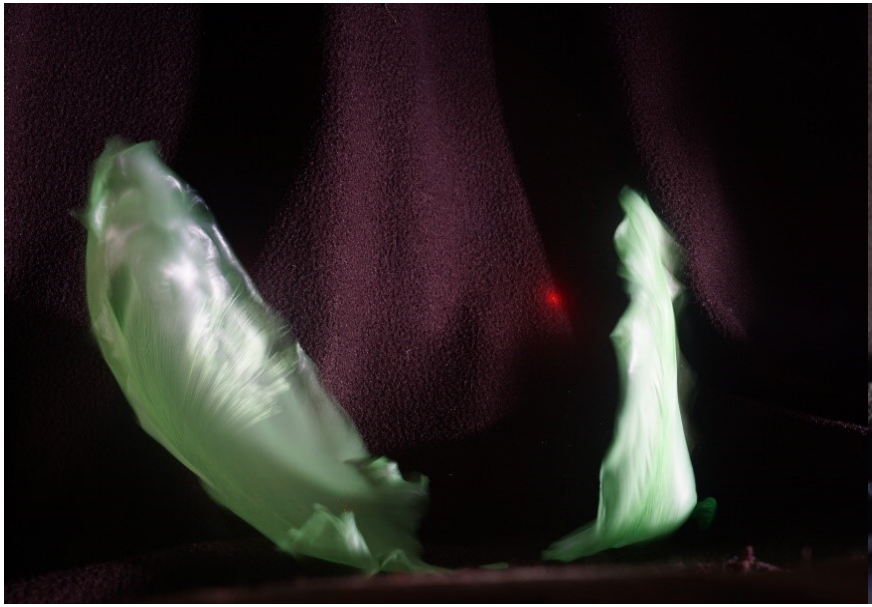
Sound Sensors only

- Variable distances from objects → Change in total response time
- Slow response time → Correct operation on worst cases

Example with selected delay

- Better visual effect
- Test for the selected delay functionality

Images From Our System



Popping balloon	*Popping balloon (filled with flour)*

Phenomenon	Sensors	Distance	Selected delay
Popping balloon	1	5 cm	0 ms
Popping balloon (flour)	1	25 cm	0 ms

Images From Our System

Breaking vase

Breaking vase (with delay)

Phenomenon	Sensors	Distance	Selected delay
Breaking vase	1	15 cm	0 ms
Breaking vase (with delay)	1	15 cm	50 ms

Images From Our System

Falling object on liquid surface

Breaking egg

Phenomenon	Sensors	Distance	Selected delay
Falling object on liquid surface	2	30 cm/45 cm	0 ms
Breaking egg	1	30 cm	0 ms

Latency Measurement Method

Estimation :

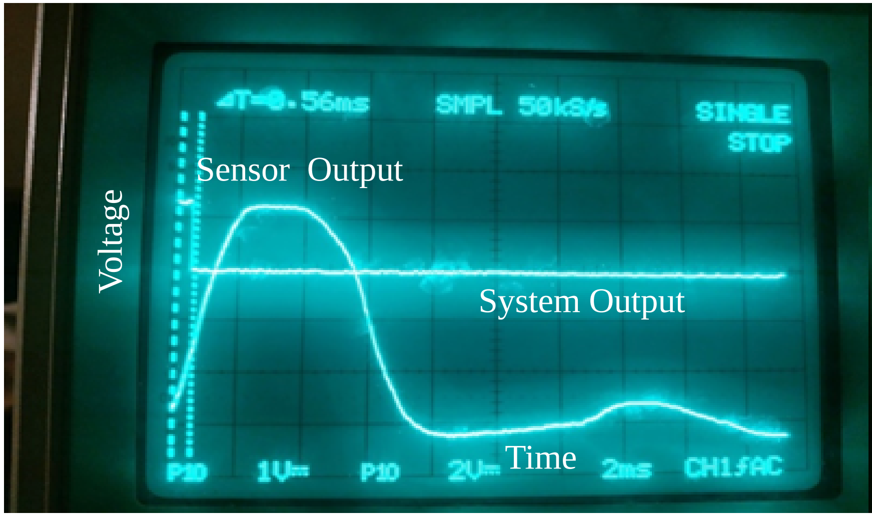
- Sensor data collection (~ 100 us)
- SPI communication with transmitter MCU (~ 16-32 us)
- RF Transceiver settling (~ 230 us)
- RF transmission (~ 90 us)
- SPI communication with receiver MCU (~ 32 us)
- Electrical Isolation Circuits and Triggering (~ 50 us)

Total : ~ 530 us

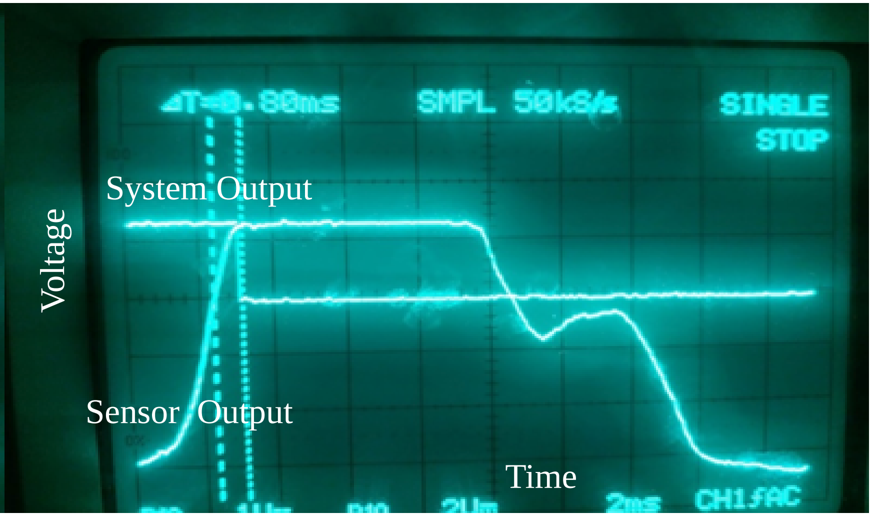
Measurements from oscilloscope waveforms

Use of LED instead of flash

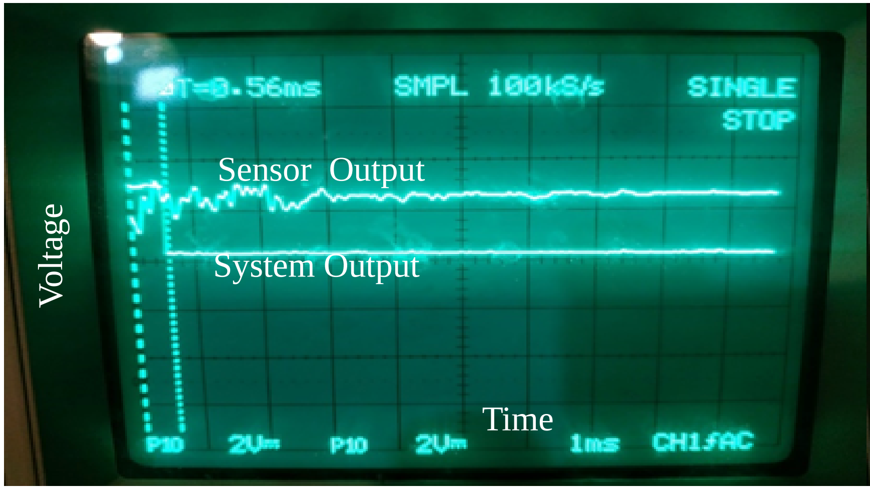
System Latency



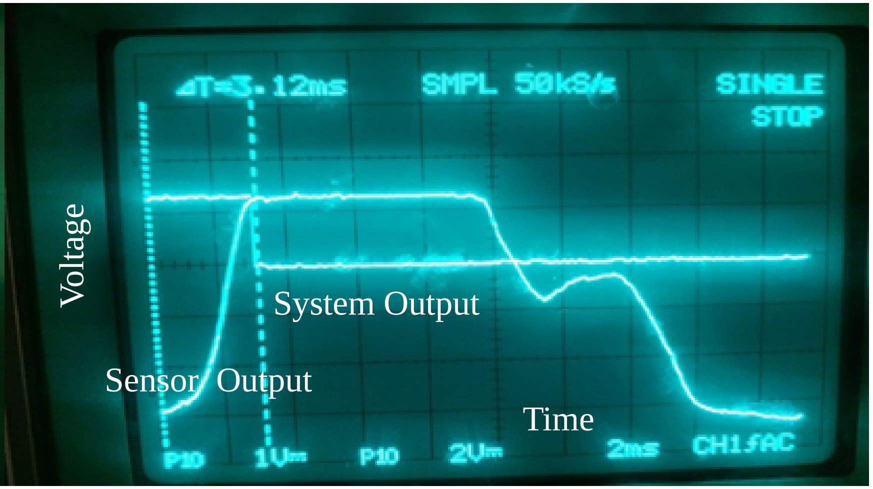
Example 1: Photodiode, Delay 0.56 ms



Example 2: Photodiode, Delay 0.8 ms



Example 3: Microphone, Delay 0.56 ms



Example 4: Photodiode, Delay 3.12 ms (sensor response)

Challenges

Resolved

- Constraining the program memory footprint to the available SRAM
- Support wide variety of flash voltages → Use of Opto TRIAC and SCR

Unresolved

- Maintain system consistency at all times
- Define a recovery procedure in case of system crash
- Changing trigger parameters after entering Triggering state

Conclusion

	Sensor Connection	Supported Sensors	System Latency	Voltage	Cost
Goal	Wireless	2	< 5 ms	3.3-5 V	< $60
Achievement	Wireless	2	< 1 ms	5 V	< $30

Other Achieved Goals

- Open source system
- Availability of used components
- Support for any flash up to 300 V

Concerns

- Higher latency compared to a wired system
- Risk of lost messages
- Need for more components

Outlook

Perspectives

- Recovery from system crash
- Parameters change after Configuration state
- Addition of more sensors
- Combination of wireless and wired sensors
- Fine tuning of libraries for even lower latency
- Design of custom PCB
- Improvement of user interface

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