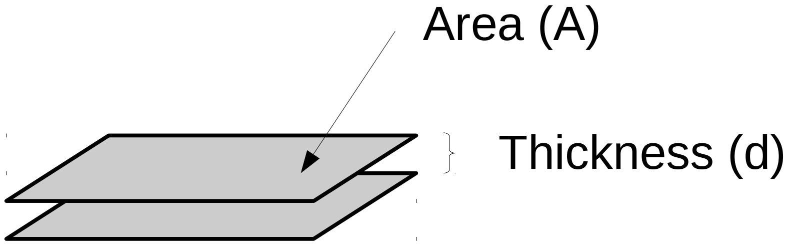
Capsense techniques

Eindhoven University of Technology
Industrial Design – Wearable Senses

Admar Schoonen
2016-07-24

Contents

Capacitor model



First order parallel plate model:

$C = \varepsilon_r * \varepsilon_0 * A / d$

$\varepsilon_r = 1$ (for air)

$\varepsilon_0 = 8.1$ nF / m

Self and mutual capacitive sensing

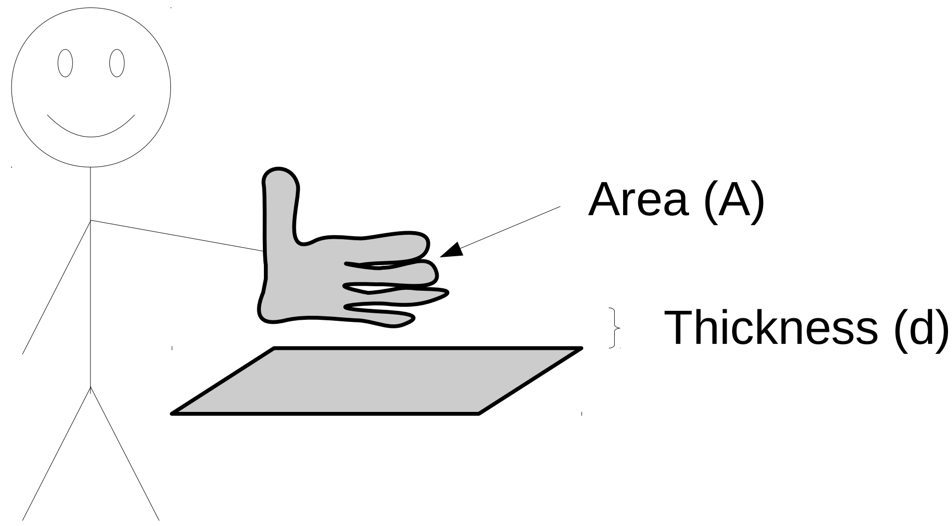
Self capacitive sensing:

- Sensor uses only 1 electrode
- 2nd electrode is human hand / finger
- Strong signal
- Simple measurement techniques
- Can be used in matrix, but only for 1 finger

Mutual capacitive sensing:

- Sensor uses 2 electrode
- 3rd electrode is human hand / finger
- Weak signal
- Requires advanced measurement techniques
- Can be used to detect unlimited number of fingers in matrix

Self capacitance



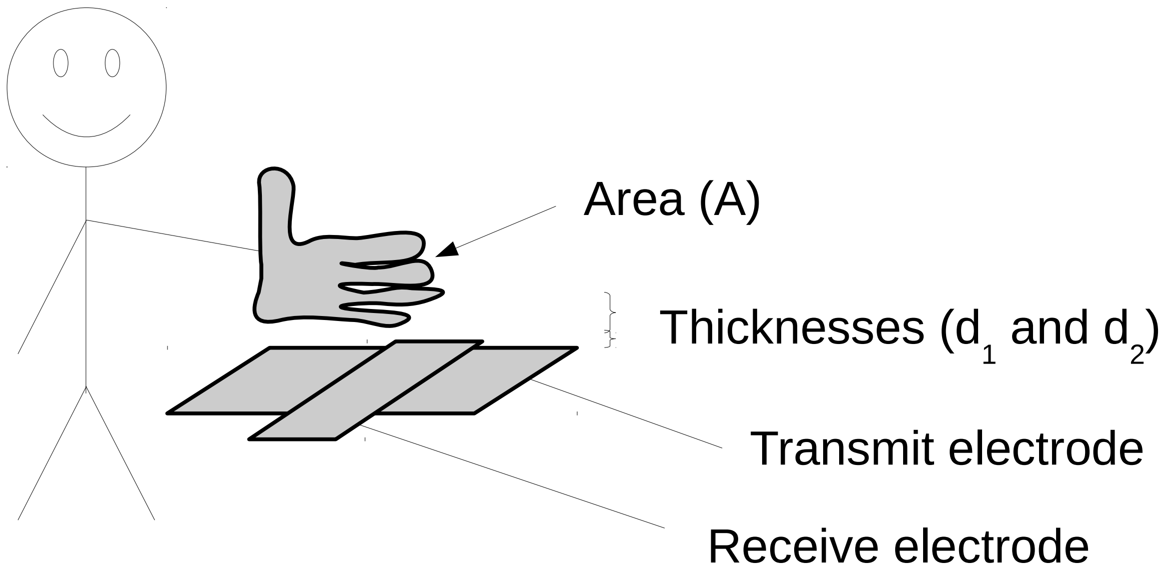
First order parallel plate model:

$C = \varepsilon_r * \varepsilon_0 * A / d$

$\varepsilon_r = 1$ (for air)

$\varepsilon_0 = 8.1$ nF / m

Mutual capacitance



First order parallel plate model:

$C = \varepsilon_r * \varepsilon_0 * A / (d_1 + d_2)$

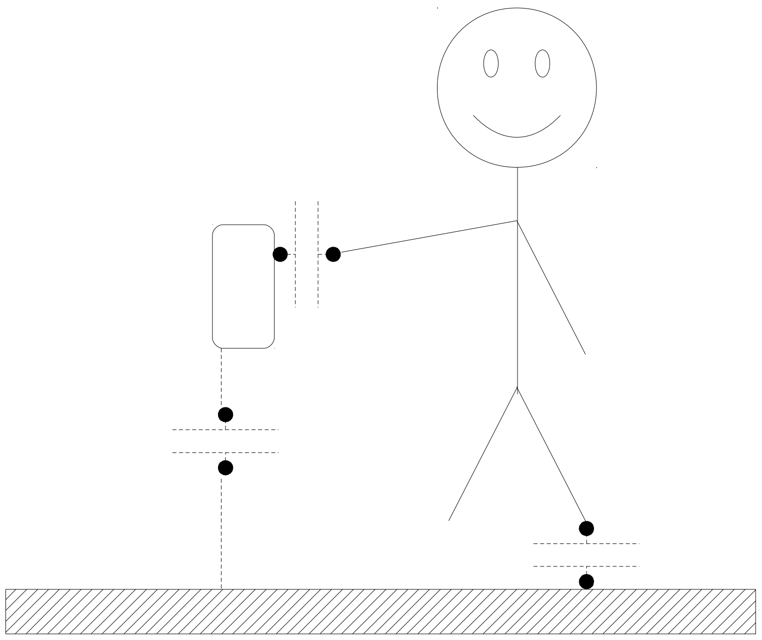
$\varepsilon_r = 1$ (for air)

$\varepsilon_0 \approx 8.85$ pF / m

Capsense model

Capacitive connections:

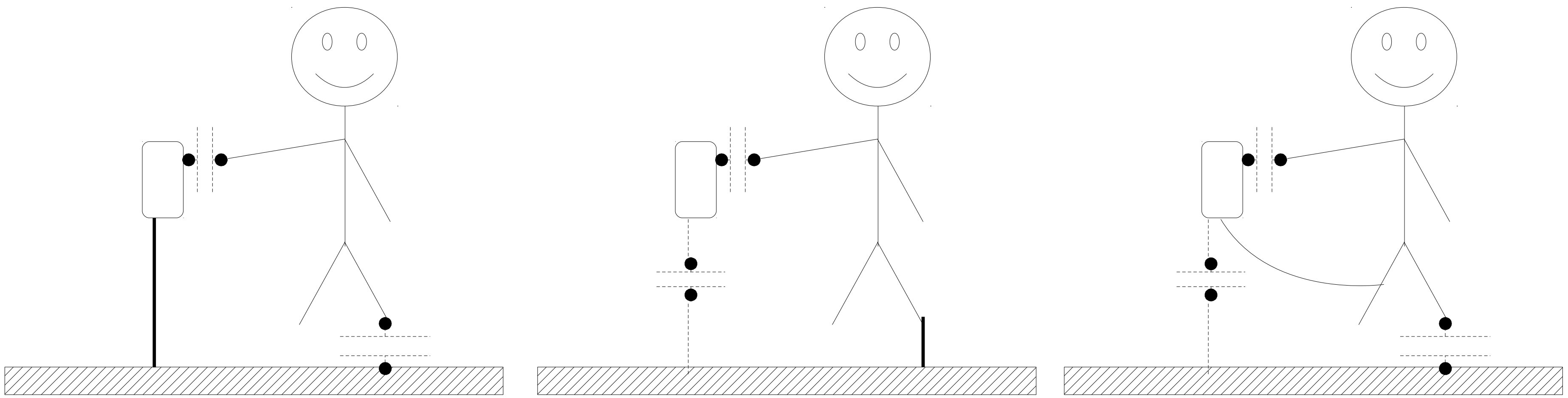
- From sensor to user
- From user to earth
- From earth to sensor



Capsense model

Improve signal strength:

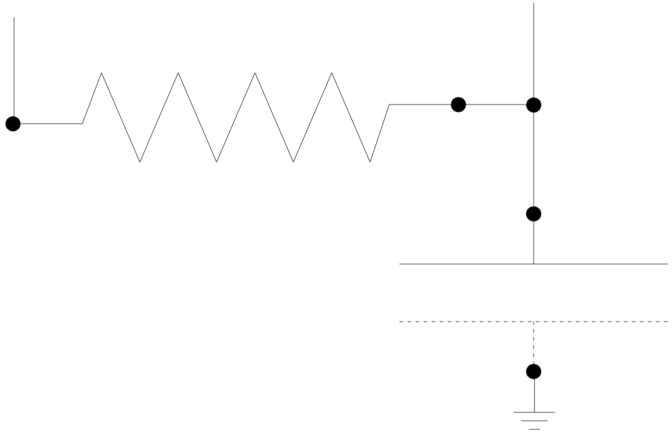
- Connect ground from device to earth, and / or
- Connect user to earth, and / or
- Connect ground from device to user

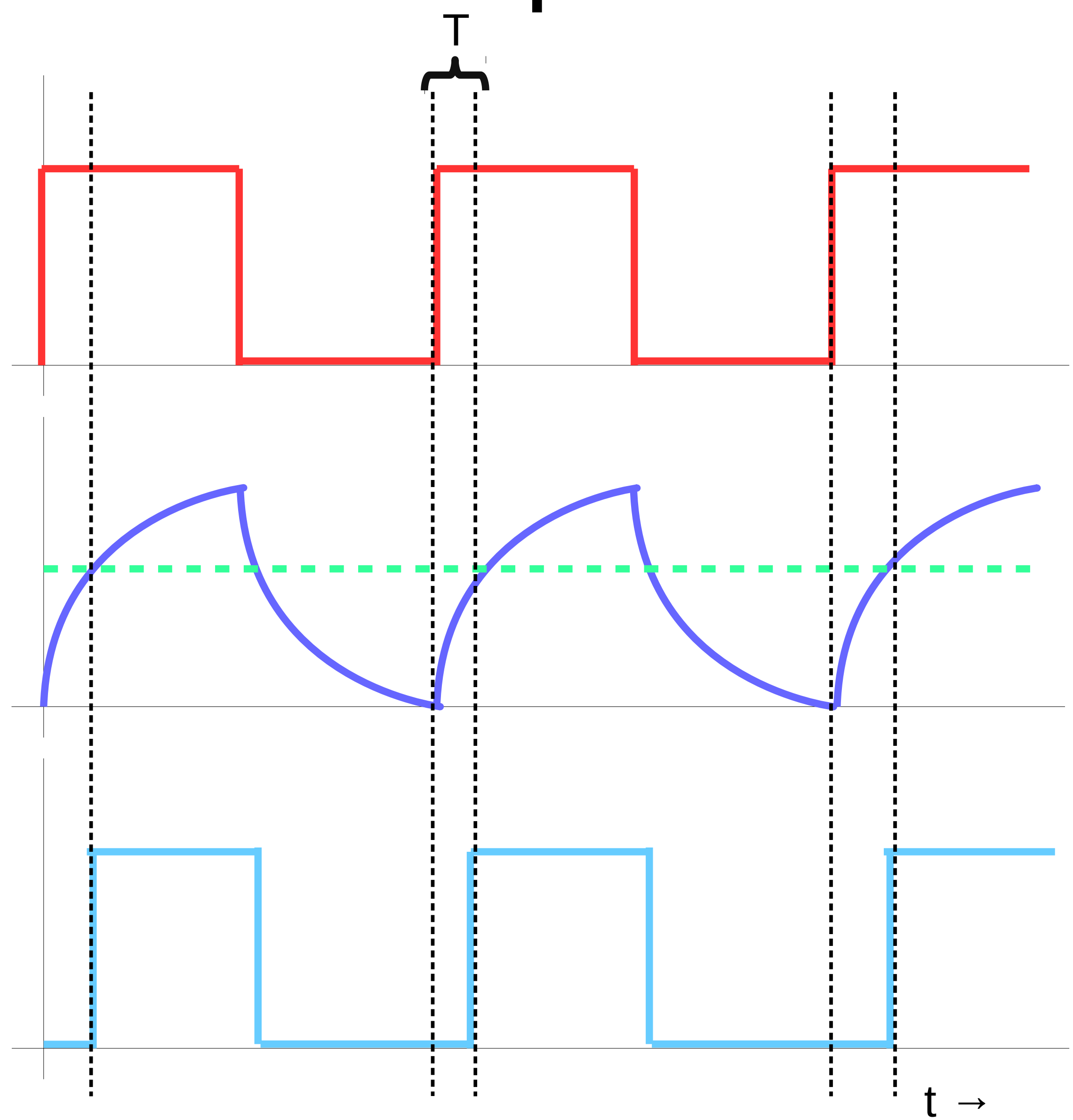


Self cap. RC method: operation

To Arduino transmit pin

To Arduino receive pin



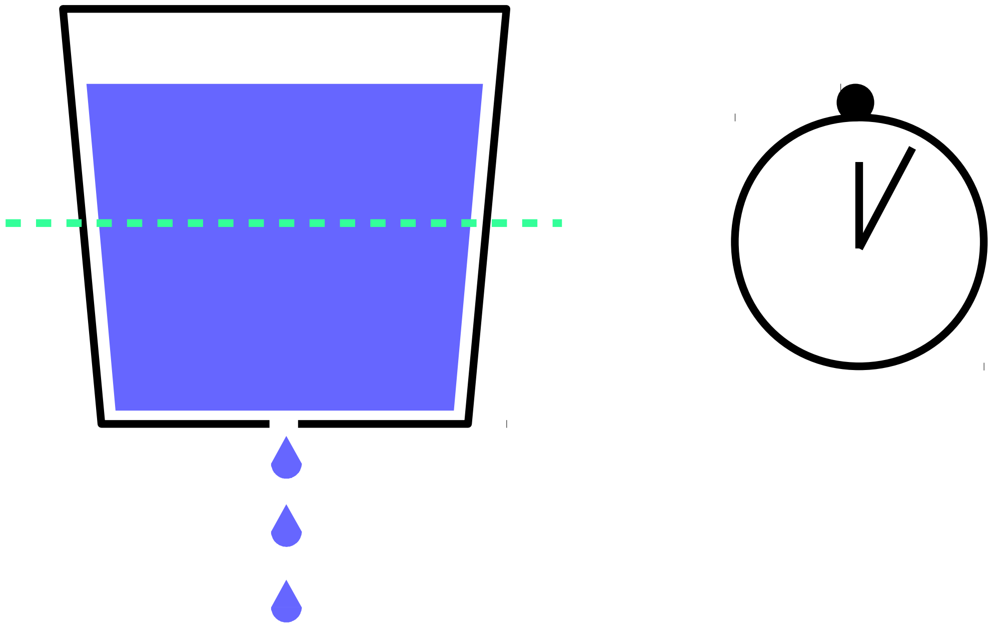


Reference voltage (~ 2.5V): above this level, signal is high ("1"), below it is low ("0")

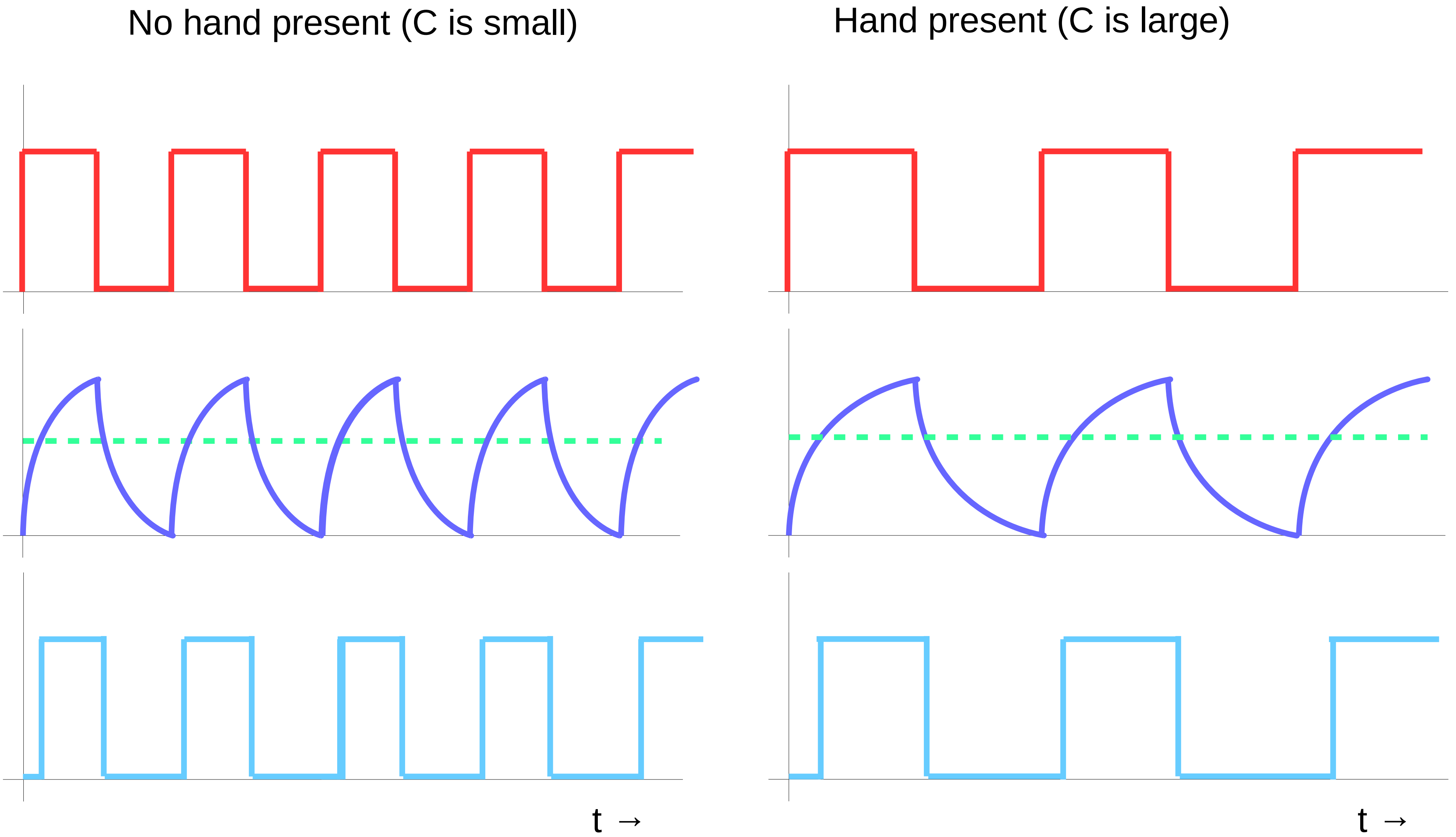
Digital input as seen by Arduino

Time T between transmit pin going up and digital input going up is measure of capacitance

Self cap. RC method: water bucket analogy



Self cap. RC method: signals



Self cap. RC method: issues

- Time between pulses can vary a lot depending on presence of hand (can vary from ~ 1us to ~ 500 us)
- Update rate at 500 us is very slow → limited filtering possible
- Variable update rate makes filtering difficult

Self cap. RC method: pros & cons

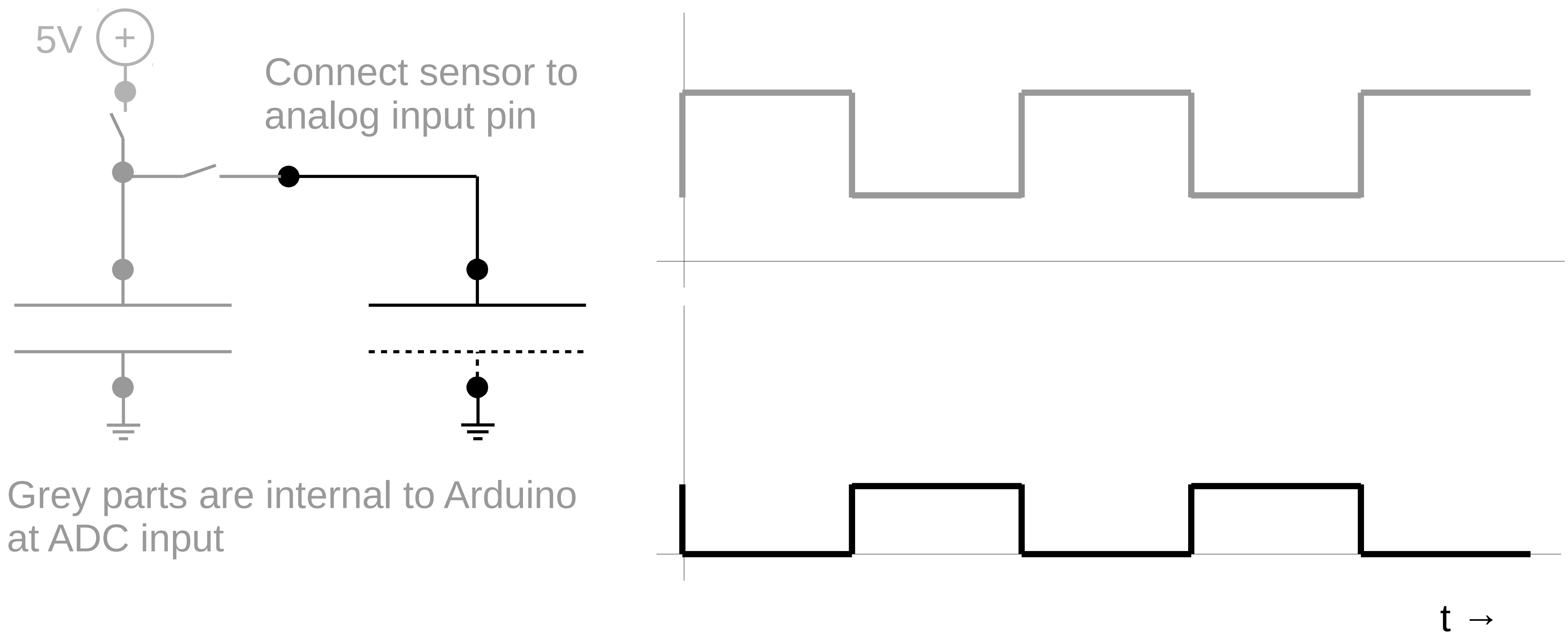
Pros:

- Works on any 2 digital pins
- Simple
- Low cost
- Open source

Cons:

- Slow or variable update rate
- Filtering is limited or difficult

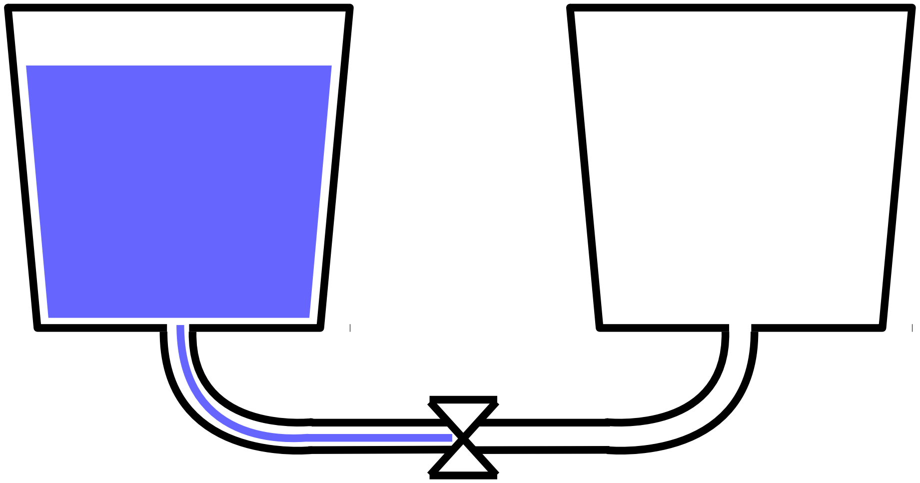
Self cap. CVD method: operation



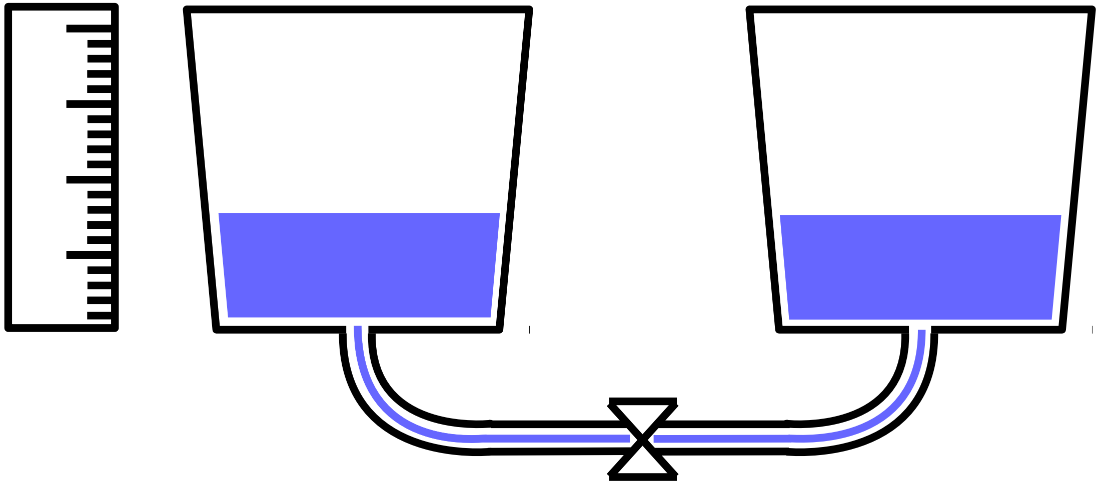
Use internal sample & hold capacitor of ADC as reference capacitor. Charge internal C&H, then spread charge over C&H and sensor and finally measure voltage.

Self cap. CVD method: water bucket analogy

- Close valve
- Fill reference bucket (charge S&H capacitor)

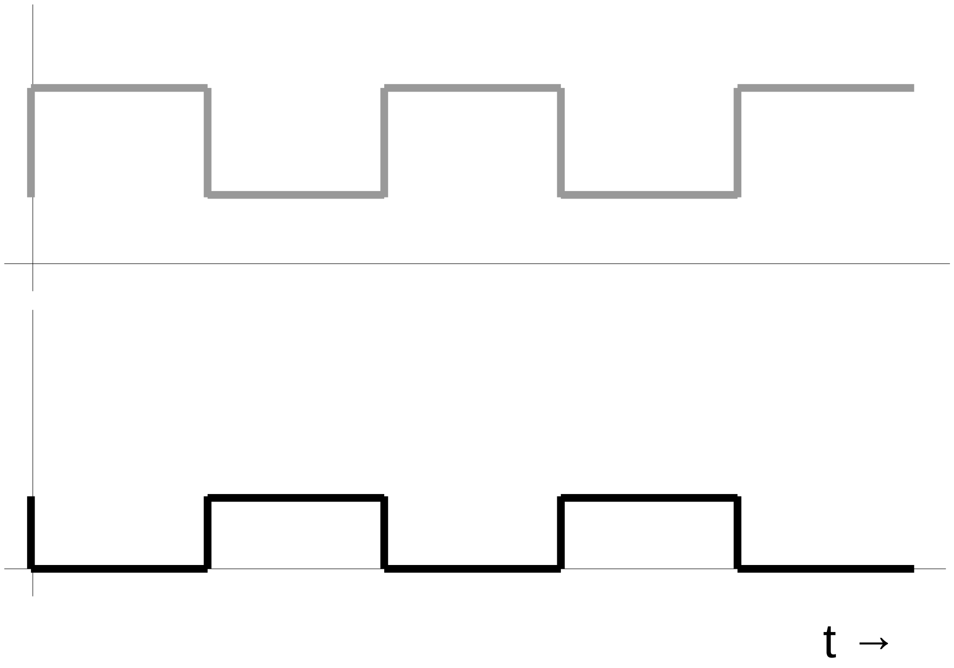


- Open valve: water will distribute over both buckets (charge distributes over S&H and sensor)
- Measure water level

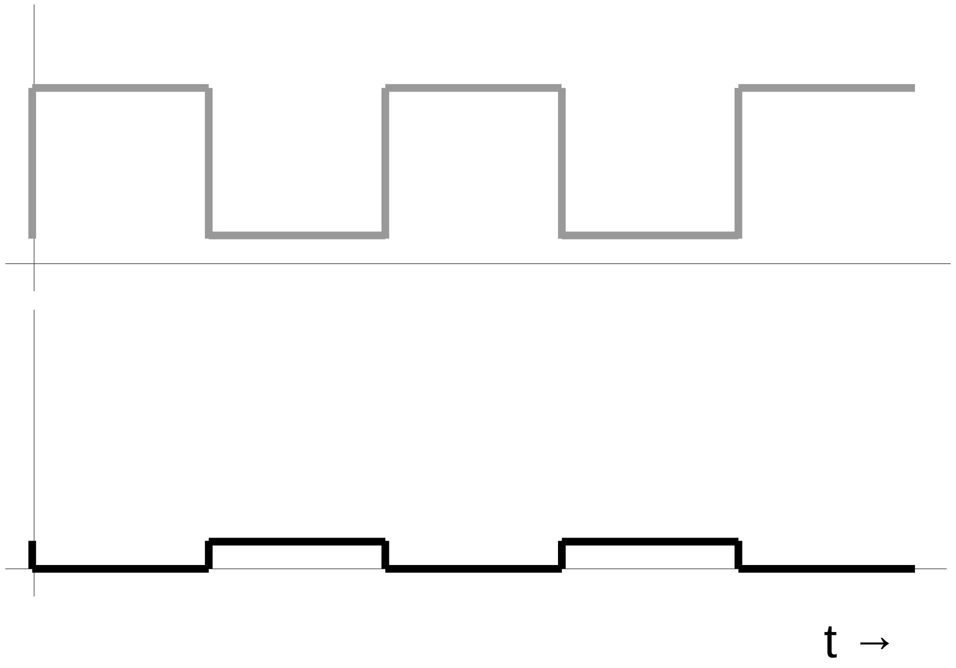


Self cap. CVD method: signals

No hand present (C is small)



Hand present (C is large)



Self cap. CVD method: issues

- Requires an internal ADC that is connected to a GPIO
- MCU should be able to switch pin between digital output and analog input while ADC is connected
- Works with most MCUs that have an ADC connected to GPIO through a multiplexer
  - Including Arduino
  - Does not work with ESP8266 (?)

Self cap. RC method: pros & cons

Pros:

- Works on any analog input
- Fast and predictable timing
- Allows diverse filtering
- Ultra low cost

Cons:

- Does not work if MCU does not have analog multiplexer / GPIO combination
- Patent by Microchip (but Arduino uses Atmel and Microchip recently bought Atmel)

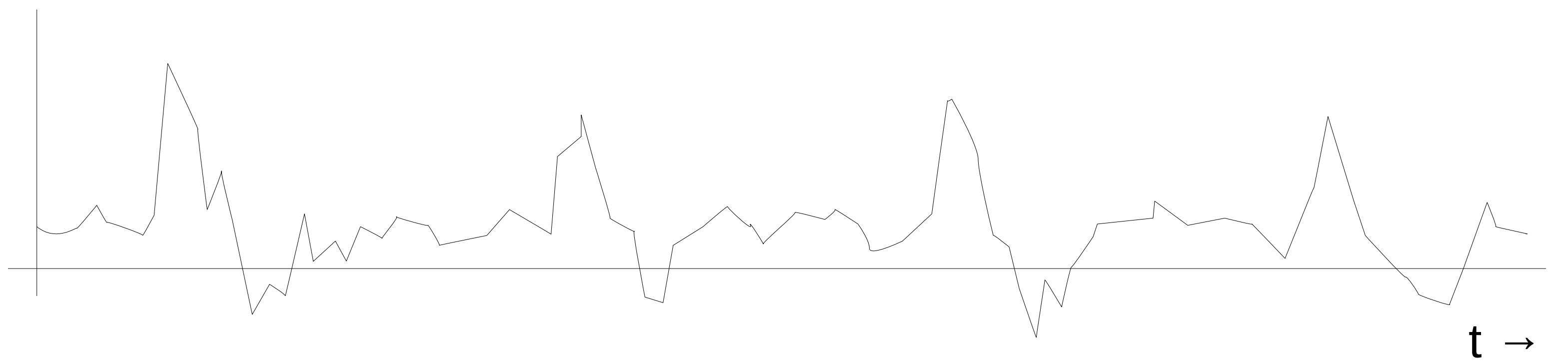
Filtering

- Signals are very weak / easily disturbed
- Filtering can help a lot to improve detection of touch
- Filtering can work on multiple levels:
  - Acquisition level
  - Signal level
  - Interpretation level

Acquisition level: reduce periodic noise

Often periodic noise is present in actual systems. Can be caused by:

- Power supply
- Motors
- LEDs (PWM signals)
- ...



Sensor nr	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4

In this example, sensor 2 always measures a value that is too high.

Acquisition level: reduce periodic noise

CVD is very fast. This allows to take sum acquisitions and use as one measurement. Example for 4 sensors, using 2 acquisitions per measurement:

Sensor nr	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Measurement nr	Measurement 0								Measurement 1							

t →

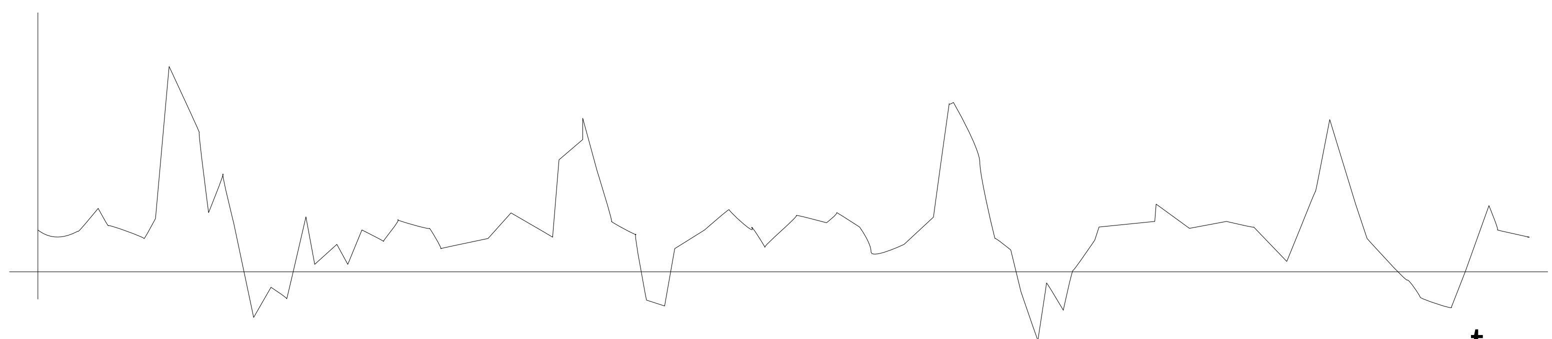
- Lowers update rate (but CVD is very fast, so a little slower is OK)
- Can be used to spread out noise (see next slide)

Acquisition level: reduce periodic noise

Use a (pseudo-)random acquisition order to spread out the noise over all channels:

Sensor nr	1	4	2	3	4	3	1	2	1	4	2	3	4	3	1	2
Measurement nr	Measurement 0								Measurement 1							

t →

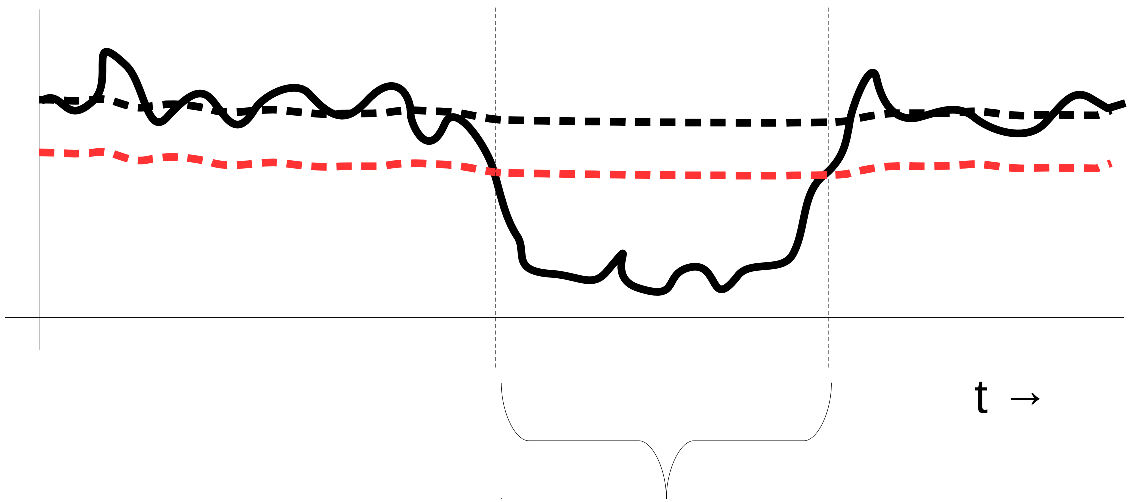


t →

Channel nr	1	4	2	3	4	3	1	2	1	4	2	3	4	3	1	2
	Measurement 0								Measurement 1							

Noise is spread out over sensor 3 and 4.
Works very well when combining large number of acquisitions (16 or more), since you have more spreading.

Signal level: tracking slow changes



Touch detected: do not
update background level

Raw signal

Filtered signal (background level)

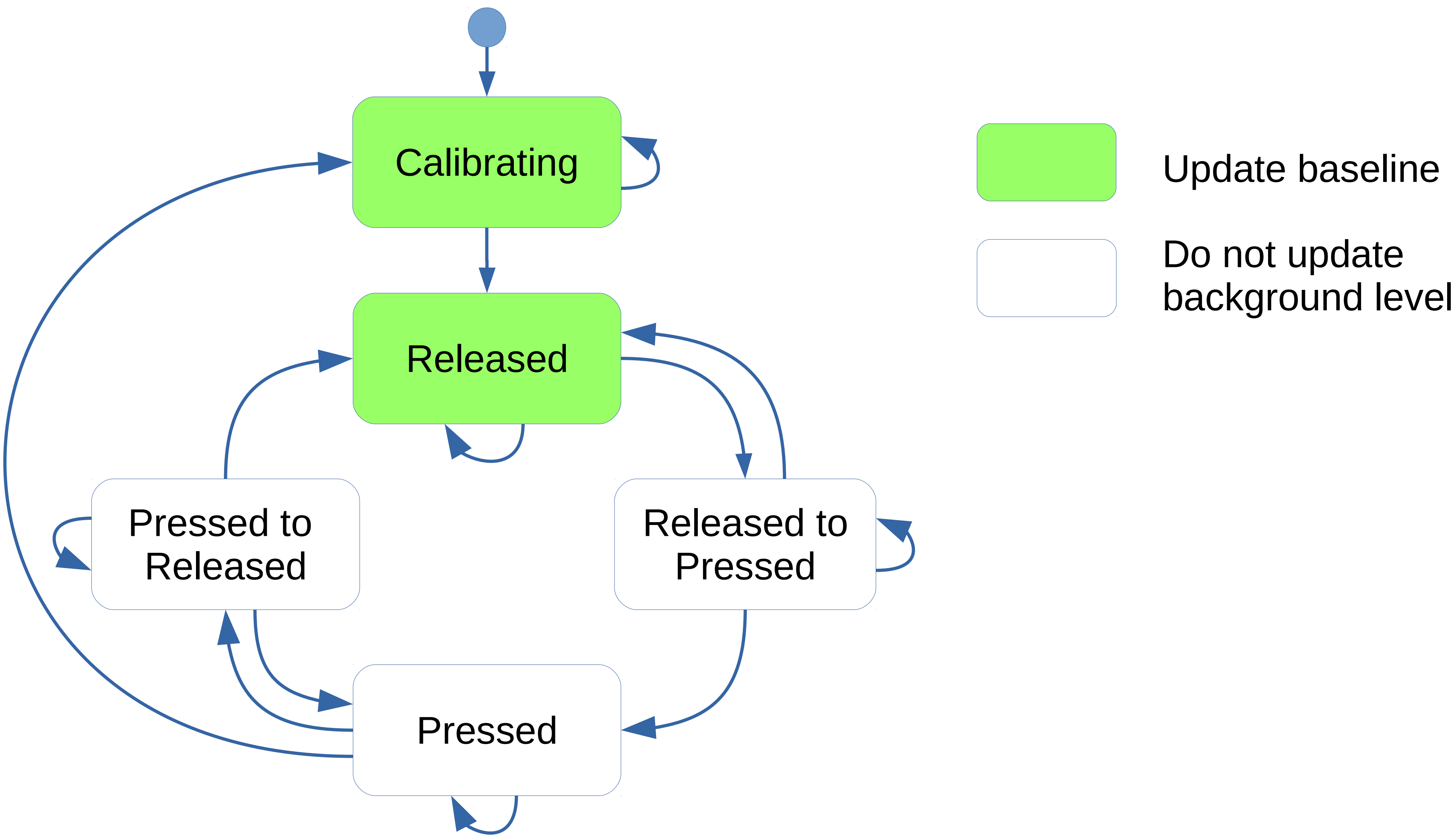
Threshold (background level – fixed value)

Signal level: tracking slow changes

Possible filters:

- Simple single pole exponential decaying filter
  - This is what I usually use
  - This is also only filter available at my github
- FIR filter
- Median filter
- Rate limiting filter
  - Slow but very good against noise from power supply (smartphone chargers)

Interpretation level: button state machine



Summary

- Self capacitance:
  - Relatively simple (can be done with Arduino)
  - Good for a few buttons, a slider or a wheel. Not good for matrix (can only detect 1 finger)
- Mutual capacitance:
  - Very complicated to get reliable (no Arduino)
  - Good for matrix with multi-touch (2 fingers, 5 fingers, 10 fingers ...)
- Connnect device and/or user to earth for stronger signal
- CVD allows much faster sampling rate at higher resolutions than RC method
- Noise reduction can take place on several levels:
  - Acquisition level (combine multiple acquisitions into a single measurement)
  - Signal level (track slow changes in background level)
  - Interpretation level (remove large fast spikes)
- Filtering on signal level and interpretation level is strongly coupled