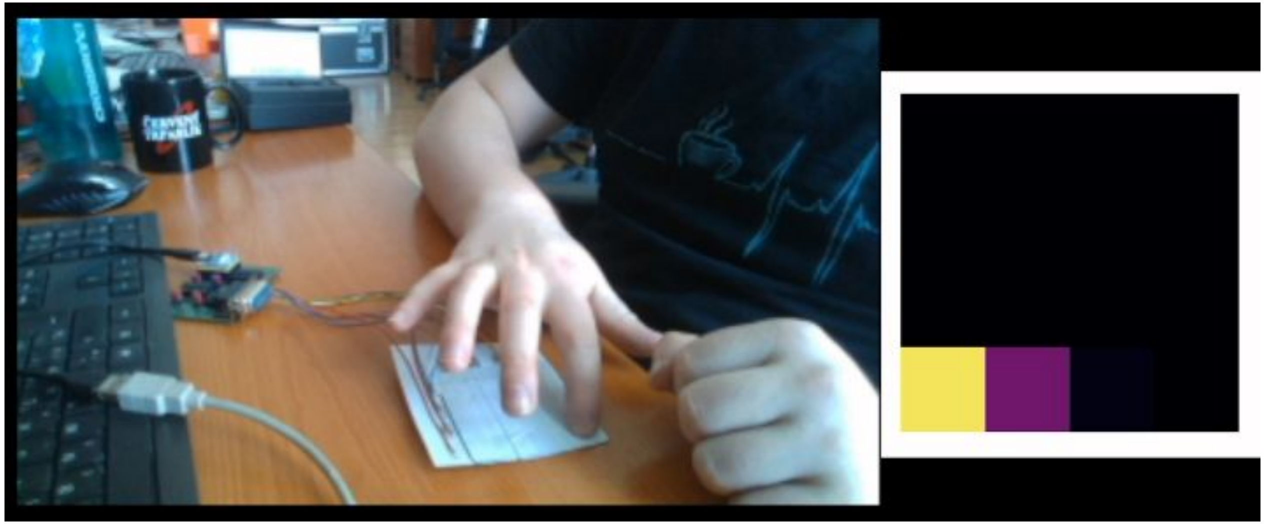
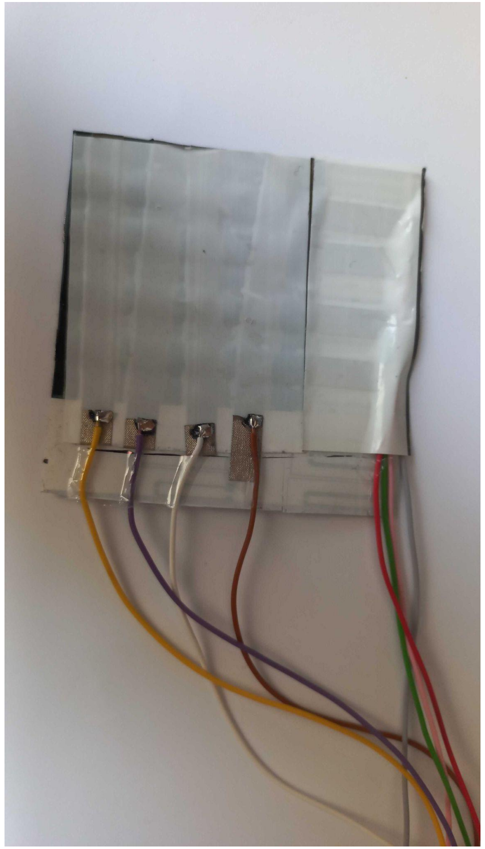
e-skin lab @ Humanoids

What we will make and use

- e-skin based on Velostat foil
- electronics based on RP2040 and MicroPython



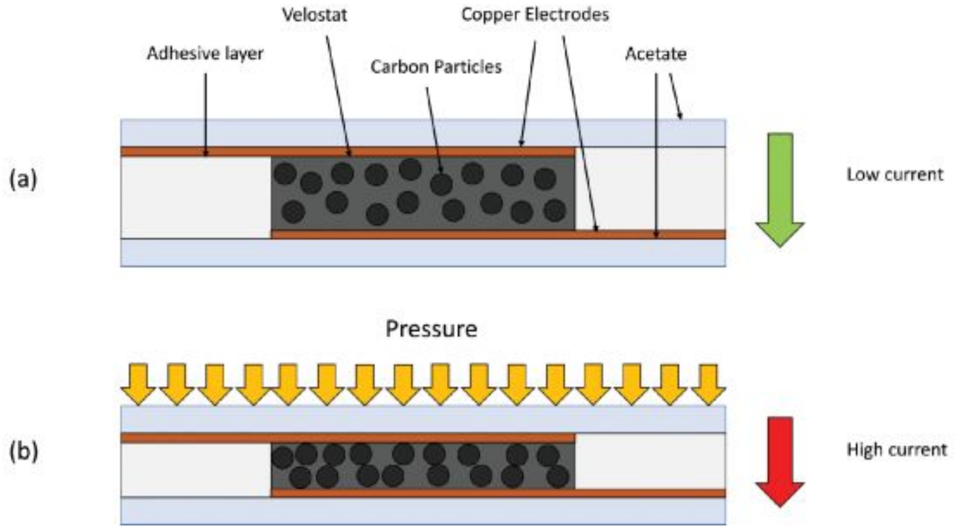


Velostat

- Velostat = Polymeric foil filled with conductive carbon particles
- Primary developed for packaging
- Piezoresistive = Resistance dependent on deformation

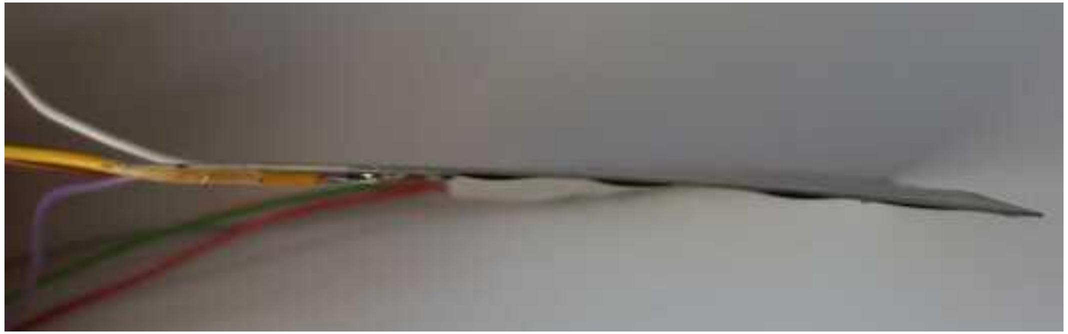
Velostat as a sensor

- Electric conductivity thanks to
  - Percolation traces (randomly formed conductive paths)
  - Tunneling of electrons (even though particles are insulated by the polymer, they can still tunnel through with certain probability)
- **When pressed**:
  - particles moves closer together → more percolation traces + smaller distance between insulated particles → more current flowing → **lower resistance**



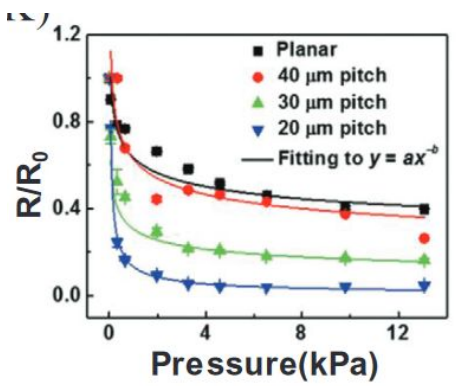
Additional sources of piezoresistivity - Surface effects

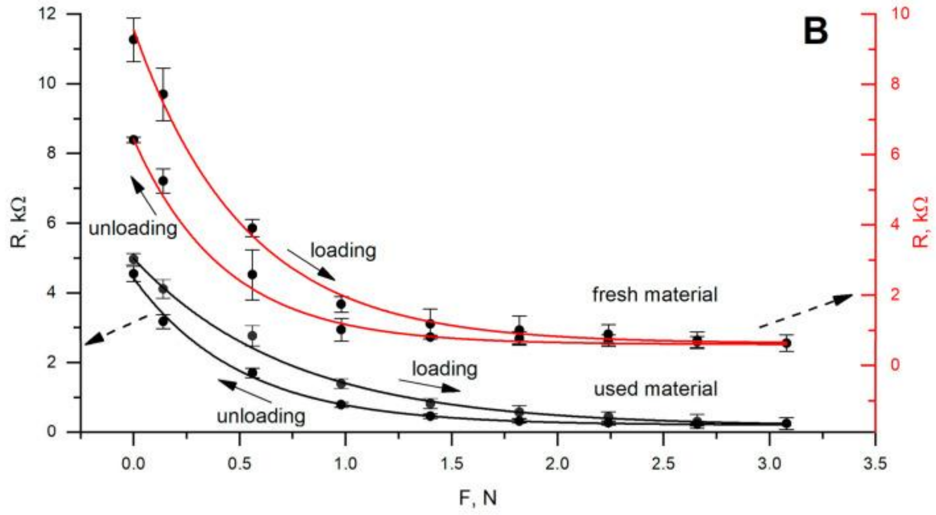
- Skin patch is warped
  - with pressure contact area between velostat and electrodes increases
- Roughness of surfaces
  - with pressure microscopic structures are deformed increasing contact area



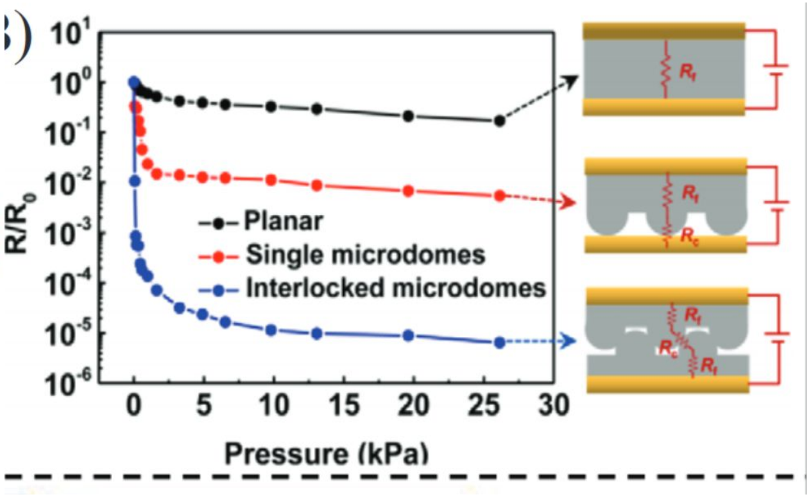
Typical response

- Generally shown as R to pressure or force
- Typically relative resistance R/R0 is used





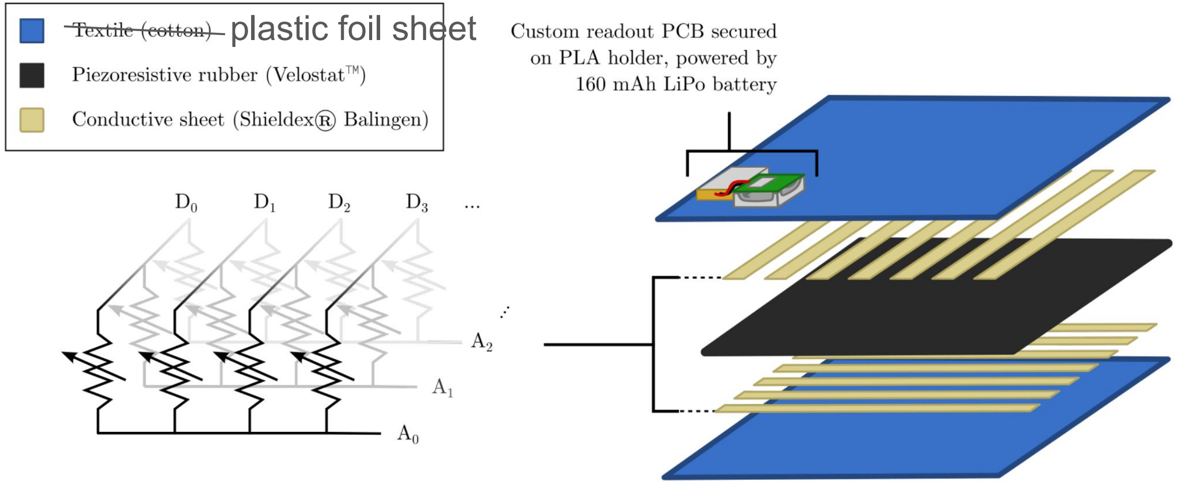
Velostat



SoTA microstructural sensors

Construction - Resistive array

- Sandwich structure
- Row and column electrodes
- One sheet of velostat
- Insulation layers

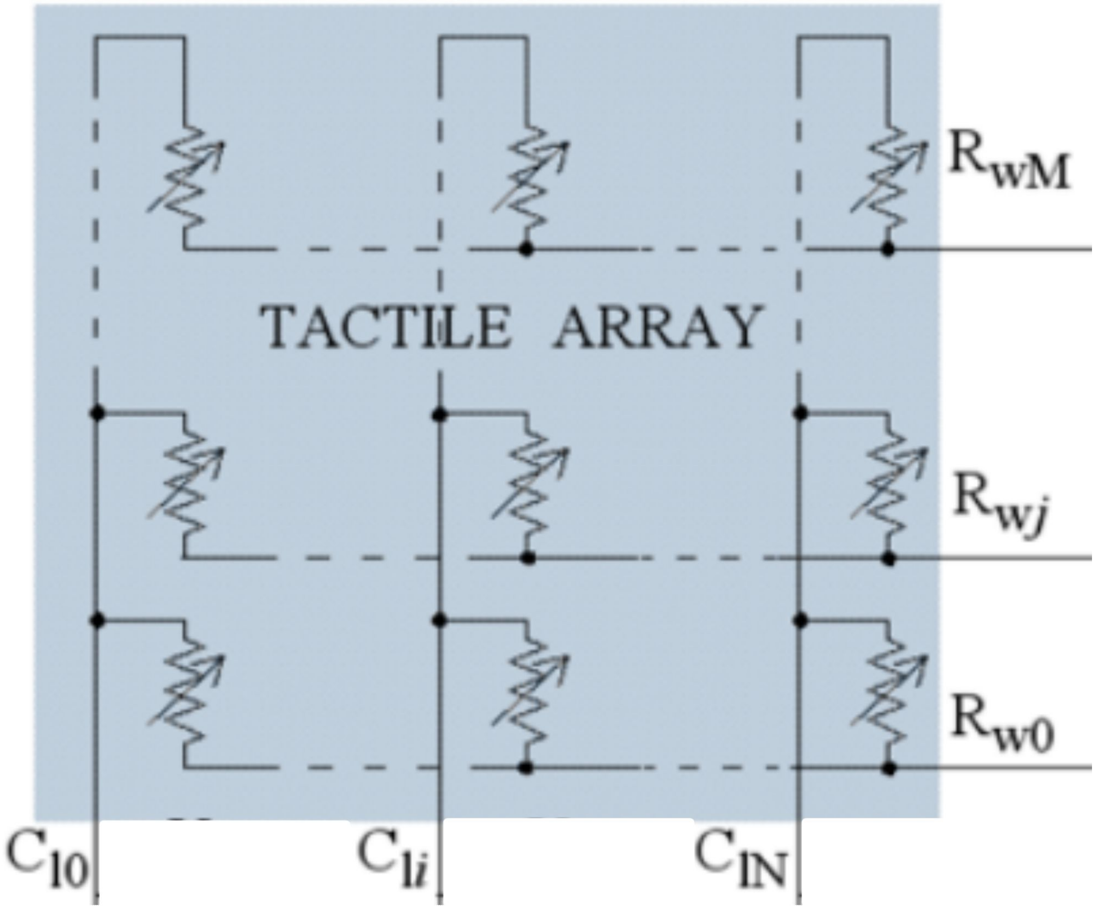


🟦 ~~Textile (cotton)~~ plastic foil sheet
⬛ Piezoresistive rubber (Velostat™)
🟨 Conductive sheet (Shieldex® Balingen)
Custom readout PCB secured on PLA holder, powered by 160 mAh LiPo battery
D0
D1
D2
D3
...
A2
A1
A0

Image illustrative, taken from literature

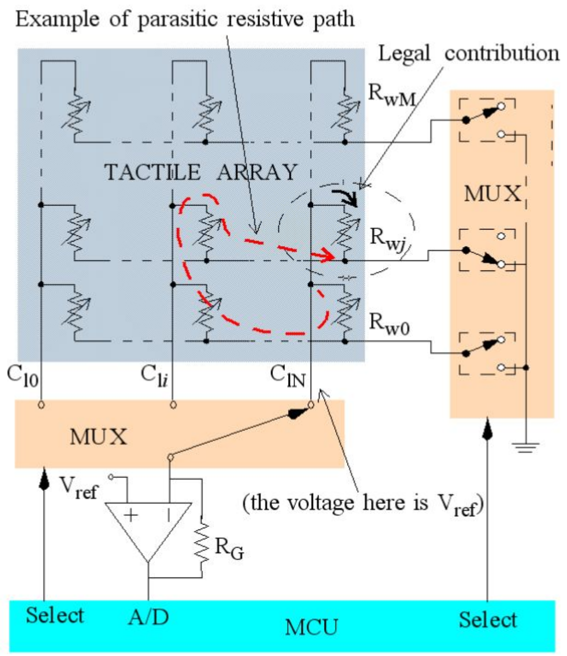
Equivalent schema

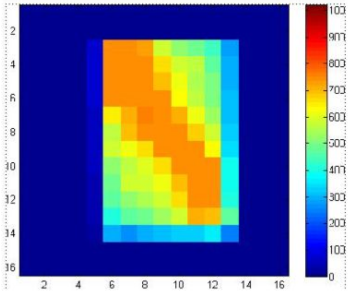
- Array of row and column lines
- Similar to keyboard or memories
- Special electronics to measure individual taxels (later in presentation)



Naive measurement - Crosstalk current

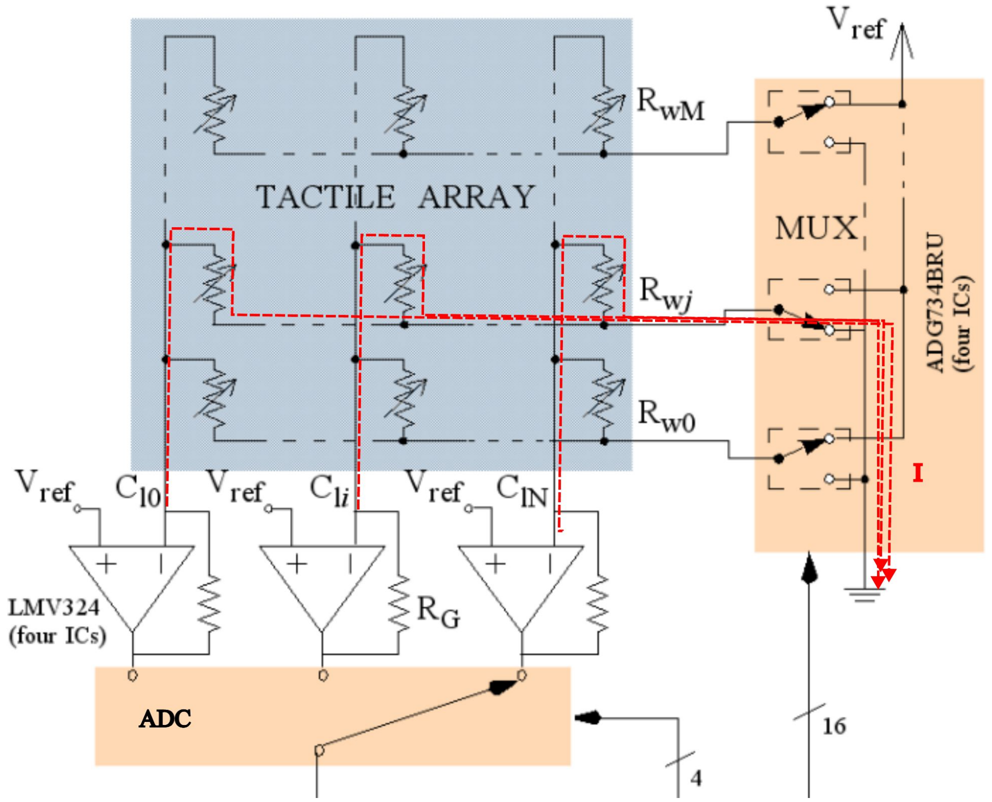
- Row and columns selecting multiplexers
- Pass current through circled resistor (black dashed)
- Current however can flow also through all the other resistors (red dashed line)
- Usable but we get distorted result





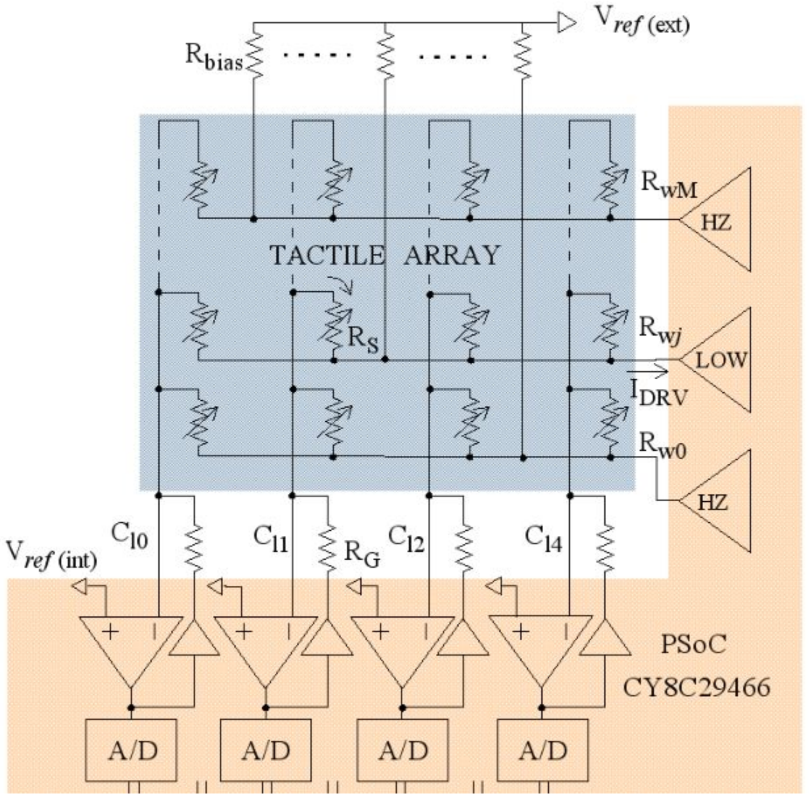
Crosstalk current compensation

- Unwanted resistive paths suppressed using operational amplifiers
- Row mux switches between Vref and GND (select by GND)
- Signal for each taxel is measured on output of given amplifier
- Similar to in-circuit testing from diagnostics course



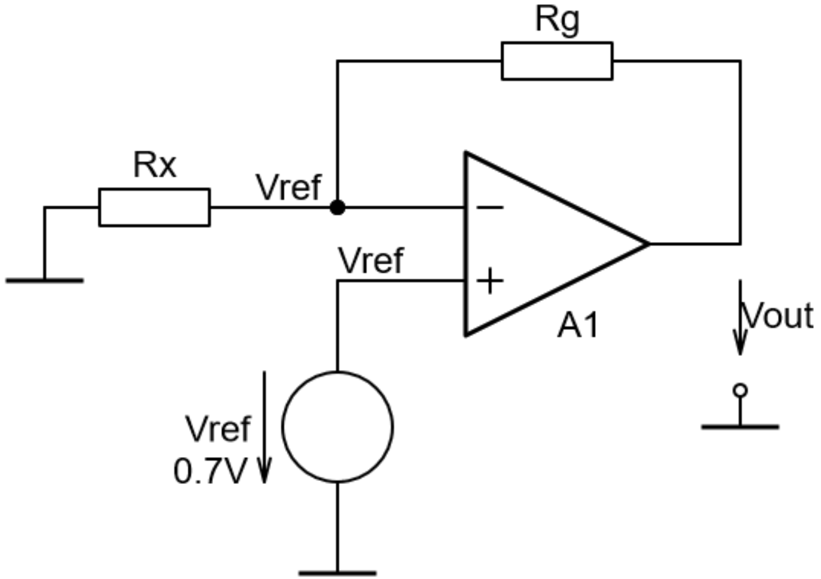
Real Implementation (for those who are interested)

- Pull-up resistors to Vref
- Mux switches between GND and High Impedance
- Each op amp sampled by analog to digital converter



What you really need to know

- We switch between rows using multiplexer
- To select row in MicroPython use function `set_row`
- Columns are sampled by ADC
- Thanks to operational amplifiers (assuming ideal) we can simplify to single resistor measurement

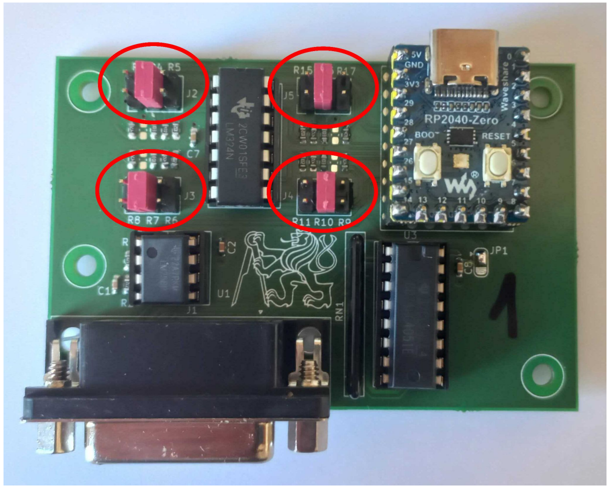


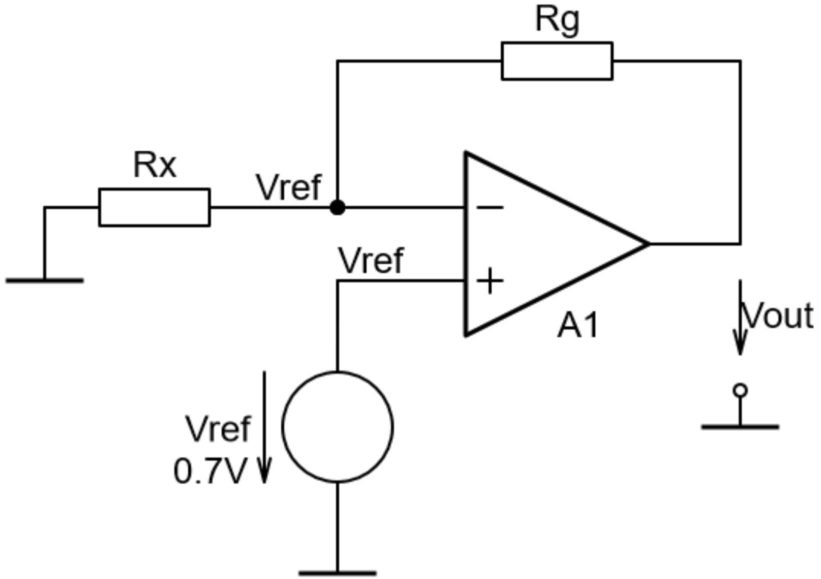
$$Vout = \left(\frac{Rg}{Rx} + 1\right)Vref$$

Rx → Measured resistor
Rg → Known (gain) resistor
Vref → Voltage reference **(0.7V)**

What you really need to know

- Selection of Rn can is done using jumper on board
- Values (from center → out):
  - 1 kΩ
  - 4.7 kΩ
  - 10 kΩ





$$Vout = \left(\frac{Rg}{Rx} + 1\right)Vref$$

Rx → Measured resistor
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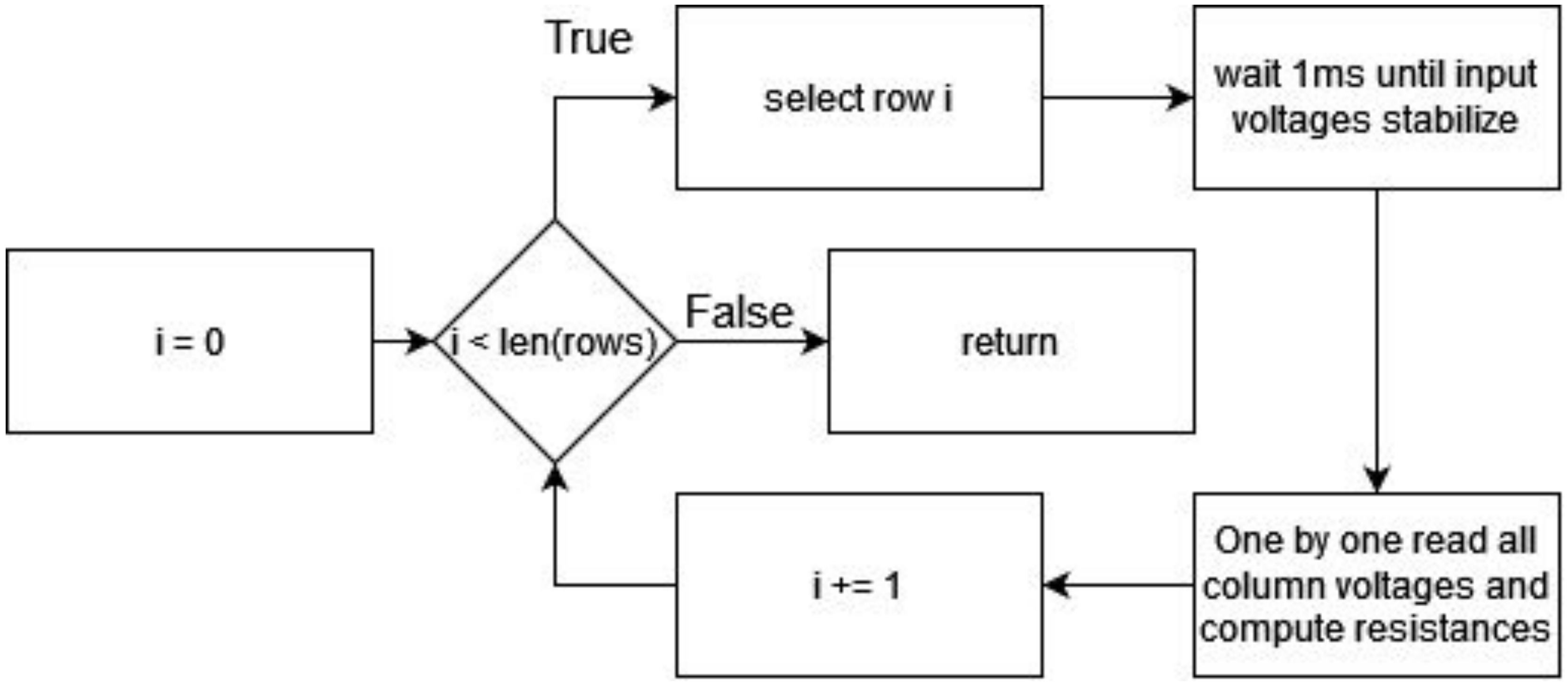
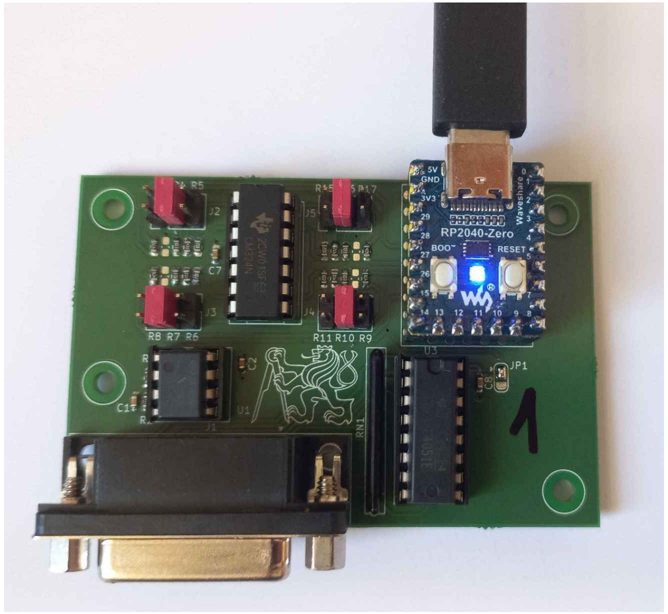
Read out algorithm and timing

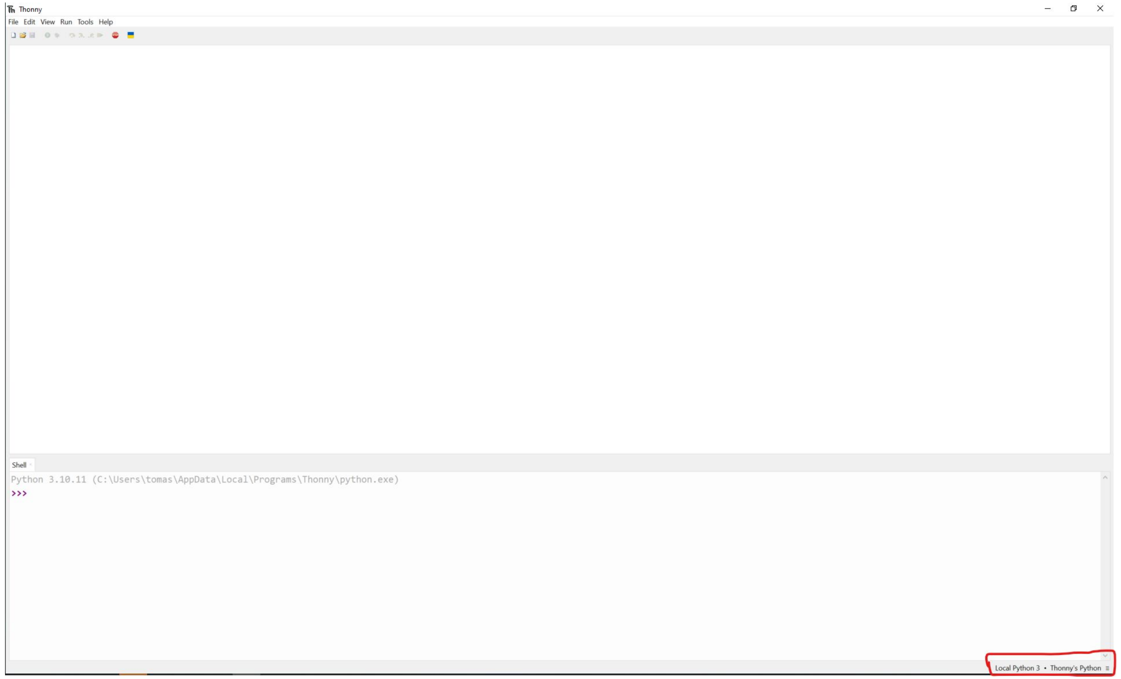

i = 0
i < len(rows)
True
False
select row i
wait 1ms until input voltages stabilize
return
One by one read all column voltages and compute resistances
i += 1

Crash Course to MicroPython (MP)

- MP = simple Python compiled for embed HW
- All hardware peripherals are objects with certain methods from `machine` module
- **Sadly no standard objects (things differ between platforms)**
- For your script to run automatically, it must be named **main.py**
- To edit script loaded in chip's memory we use Thonny IDE

How to edit MP script on HW using Thonny

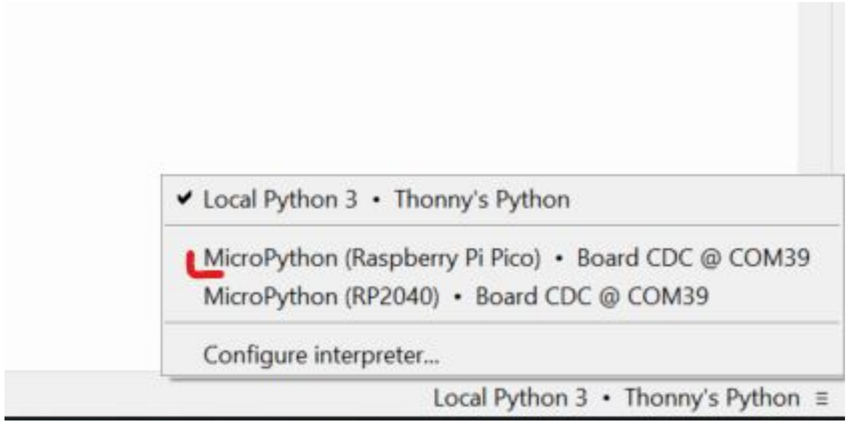



Thonny
File Edit View Run Tools Help
Shell
Local Python 3 • Thonny's Python

```
Python 3.10.11 (C:\Users\tomas\AppData\Local\Programs\Thonny\python.exe)
>>>
```

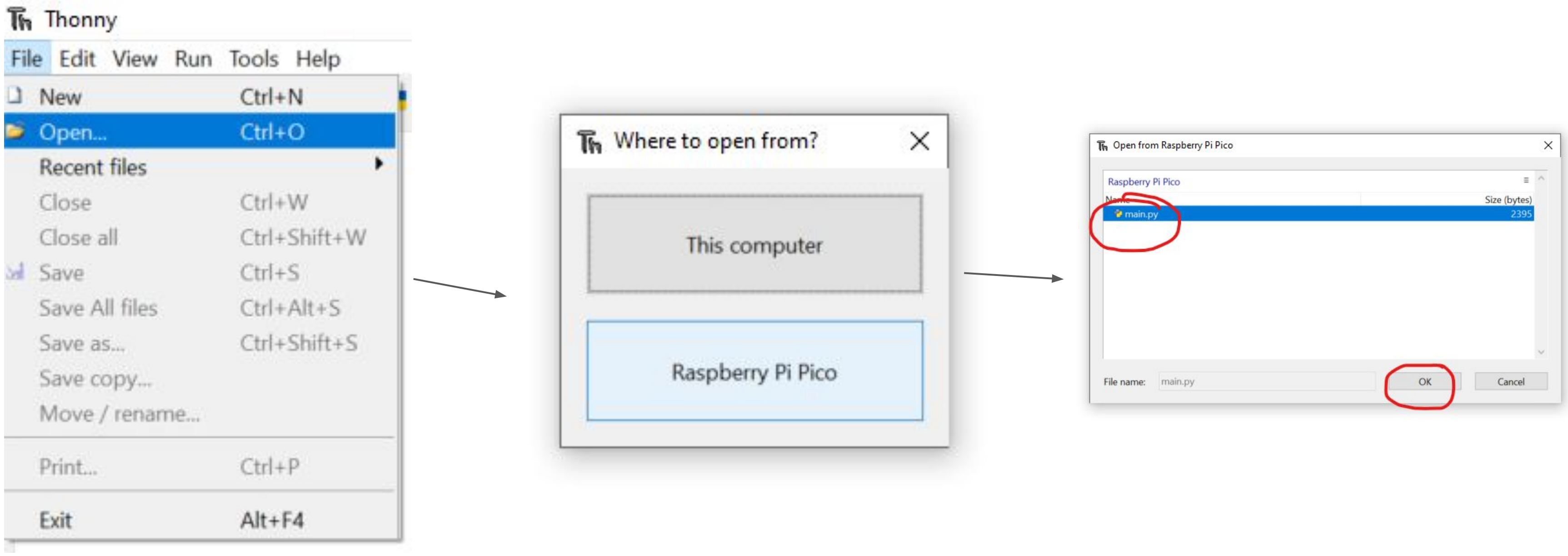
How to edit MP script on HW using Thonny

Select marked interpreter and note what is RP2040 listed as (COM39 in example), you will need this for Python scripting in your homework



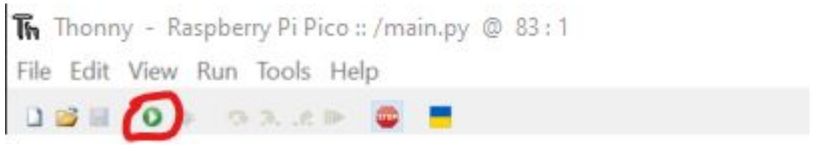
✔ Local Python 3 • Thonny's Python
MicroPython (Raspberry Pi Pico) • Board CDC @ COM39
MicroPython (RP2040) • Board CDC @ COM39
Configure interpreter...
Local Python 3 • Thonny's Python ≡

How to edit MP script on HW using Thonny



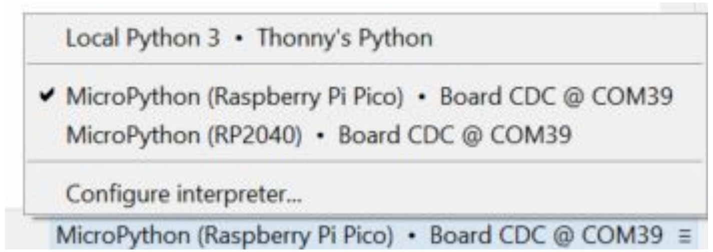
To store your progress, just hit Ctrl+s, it will store to RP2040 memory

How to run MicroPython script

- 
  Thonny - Raspberry Pi Pico :: /main.py @ 83 : 1
File Edit View Run Tools Help

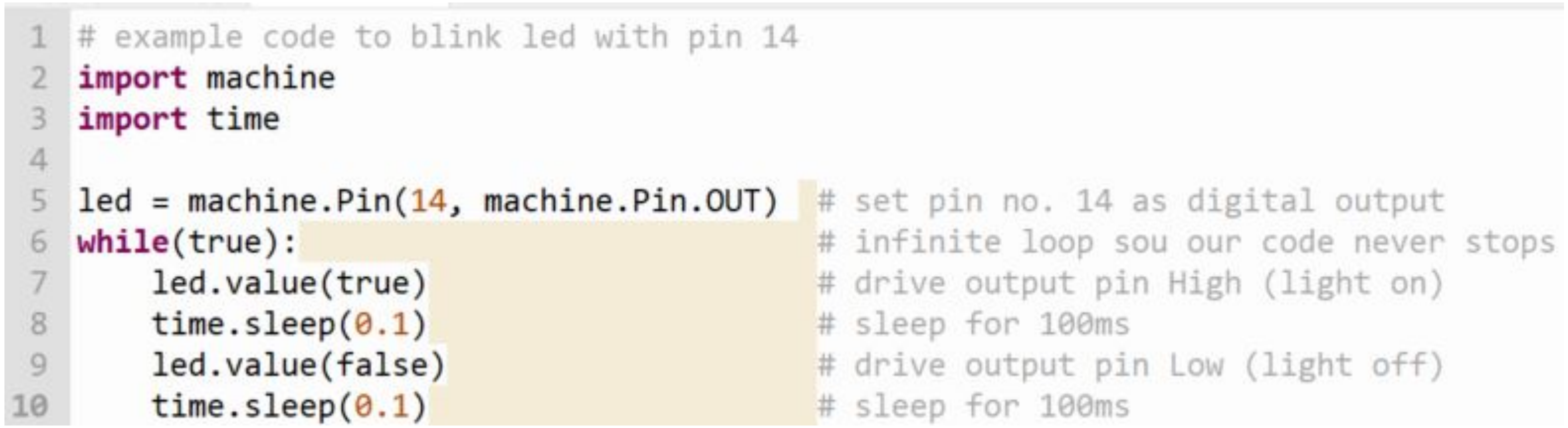
- Press reset button on board (this restarts board and main.py is automatically executed)
  - note resetting board causes it to disconnect from PC and must be manually reconnect even though Thonny shows board being connected

- While running Python script reading data from board (f.e.: example01_visualizaton.py) either close Thonny or set it to local interpreter to free serial port


Local Python 3 • Thonny's Python
✔ MicroPython (Raspberry Pi Pico) • Board CDC @ COM39
MicroPython (RP2040) • Board CDC @ COM39
Configure interpreter...
MicroPython (Raspberry Pi Pico) • Board CDC @ COM39

General Purpose Input Output (GPIO) in MP

- used for: buttons, digital communication, LEDs



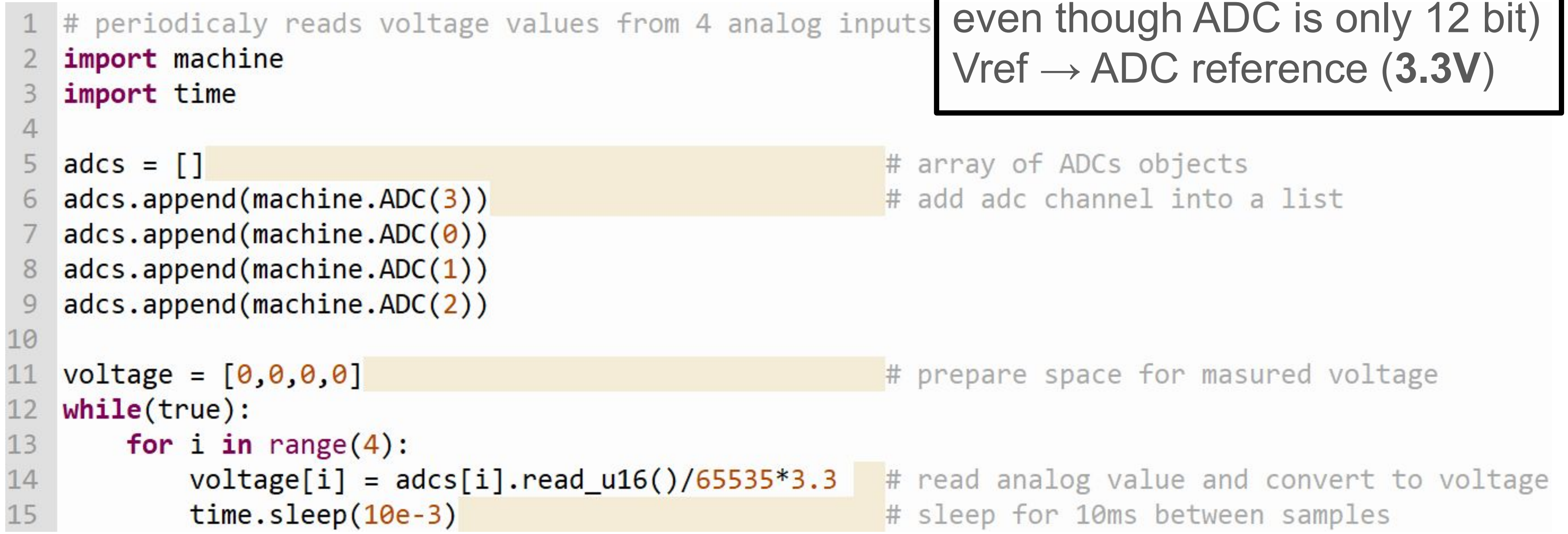
```
# example code to blink led with pin 14
import machine
import time

led = machine.Pin(14, machine.Pin.OUT)  # set pin no. 14 as digital output
while(true):                            # infinite loop sou our code never stops
    led.value(true)                     # drive output pin High (light on)
    time.sleep(0.1)                     # sleep for 100ms
    led.value(false)                    # drive output pin Low (light off)
    time.sleep(0.1)                     # sleep for 100ms
```

Read analog values in MP

$$V = \frac{n}{2^N - 1} Vref$$

- for some weird reason ADCs in MP return 16 bit numbers with maximum of 65535 even if given ADC is 12 bit

n → ADC output number
N → ADC bit resolution (**16 bit** even though ADC is only 12 bit)
Vref → ADC reference (**3.3V**)



```python
# periodicaly reads voltage values from 4 analog inputs
import machine
import time

adcs = []                                                 # array of ADCs objects
adcs.append(machine.ADC(3))                               # add adc channel into a list
adcs.append(machine.ADC(0))
adcs.append(machine.ADC(1))
adcs.append(machine.ADC(2))

voltage = [0,0,0,0]                                       # prepare space for masured voltage
while(true):
    for i in range(4):
        voltage[i] = adcs[i].read_u16()/65535*3.3         # read analog value and convert to voltage
        time.sleep(10e-3)                                 # sleep for 10ms between samples
```

Bibliography

- M. Hopkins, R. Vaidyanathan and A. H. Mcgregor, "Examination of the Performance Characteristics of Velostat as an In-Socket Pressure Sensor," in *IEEE Sensors Journal*, vol. 20, no. 13, pp. 6992-7000, 1 July1, 2020, doi: 10.1109/JSEN.2020.2978431. keywords: {Loading;Sensor phenomena and characterization;Sockets;Prosthetics;Temperature sensors;Mechanical sensors;Piezoresistive measurement;pressure sensing;prosthetics;prosthetic fitting;Velostat;wearable sensors}
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