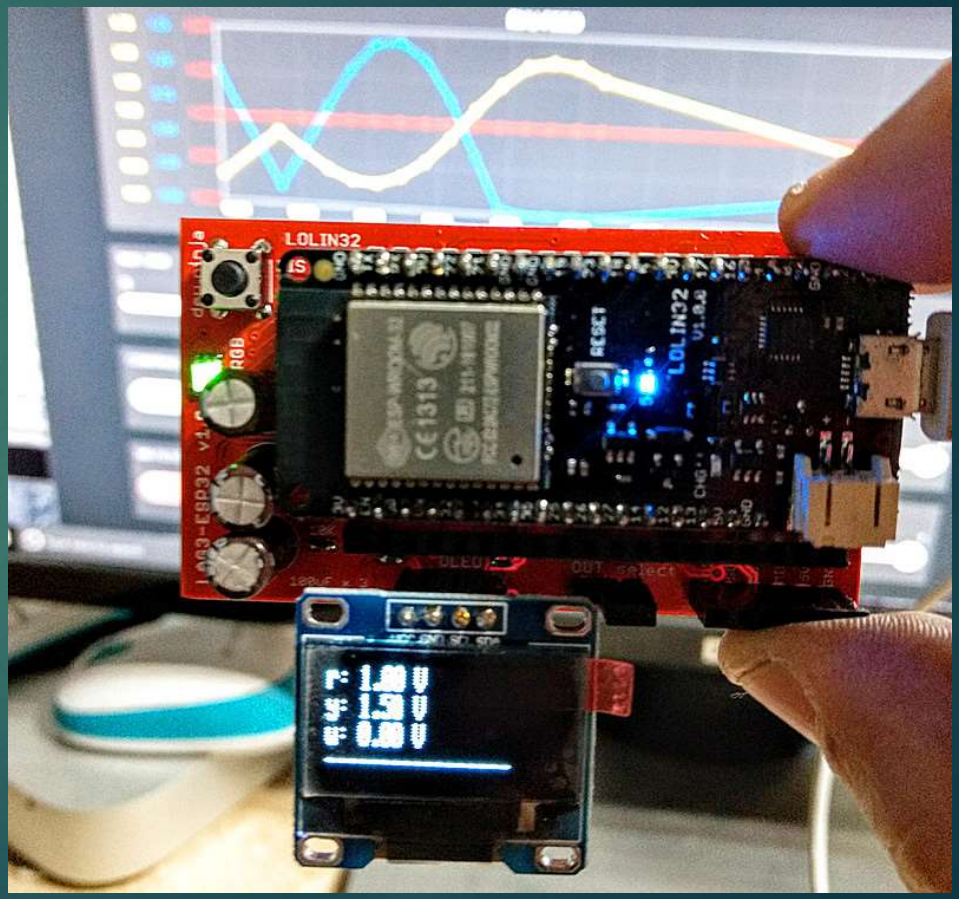
Session 1 : ESP32 Basics

IoT for Industrial Control workshop
Dept. of Physics, Faculty of Sciences
Naresuan University
June 26 – 27, 2021



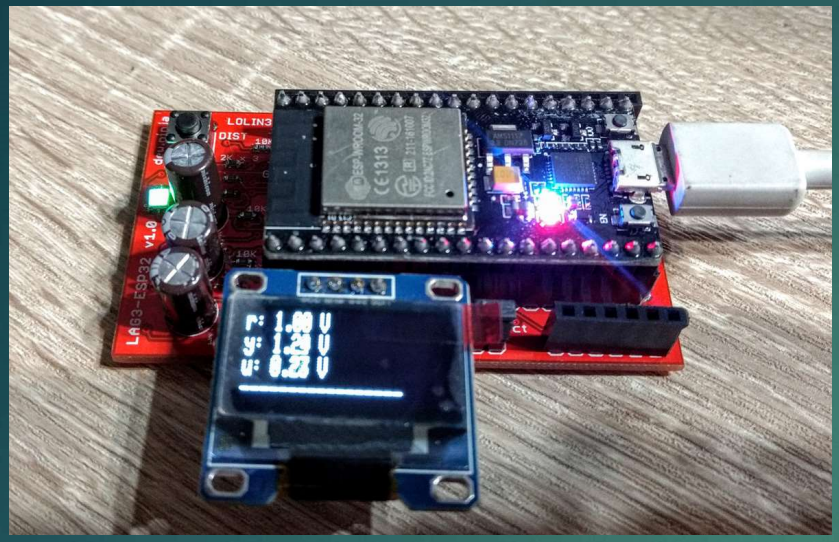
Dr.Varodom Toochinda
Dept. of Mechanical Engineering
Kasetsart University

Outline

- ESP32 Arduino core and libraries installation
- Learn to program ESP32 using Arduino IDE and C language for ESP32 main components such as ADC, PWM
- Learn basics of external interrupt and timer
- Learn how to construct a command interpreter function
- Plotting experimental data
- Connect ESP32 to NETPIE 2020

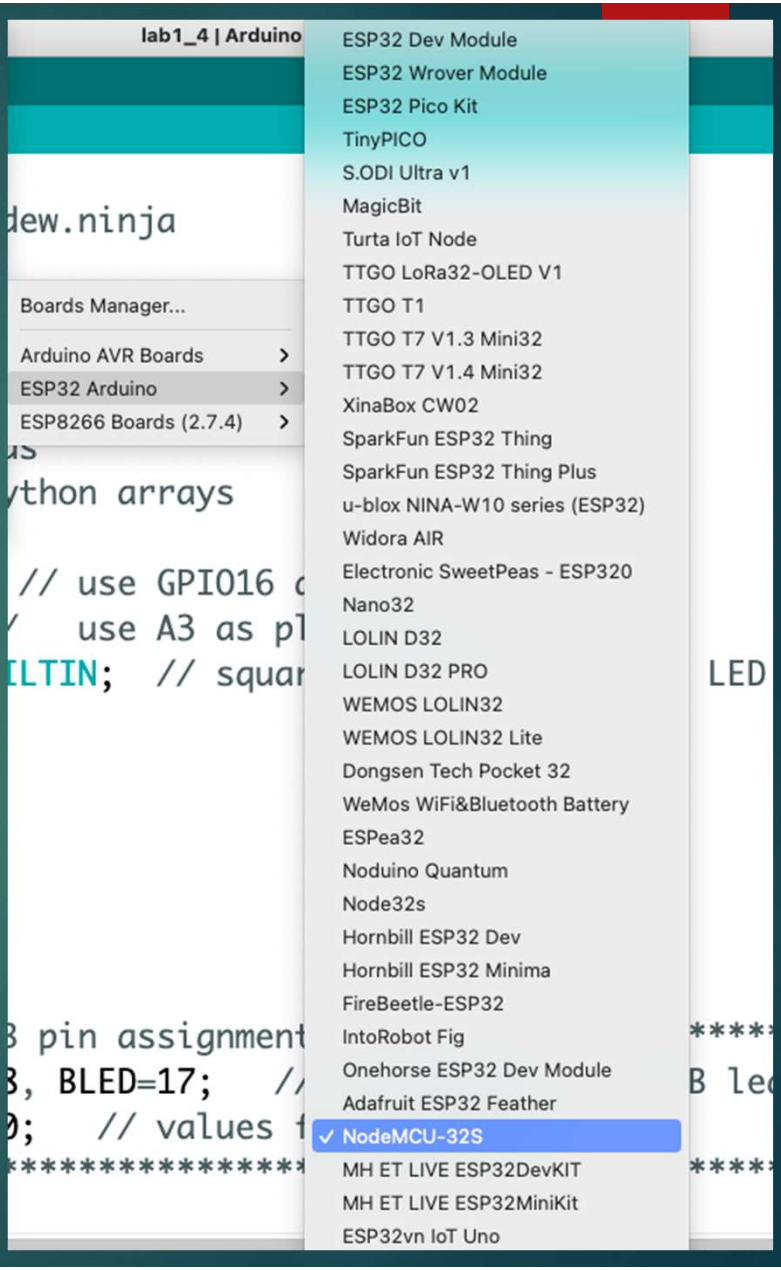
Hardware and Software

- Hardware
  - NodeMCU-32S
  - LAG3-ESP32 by dew.ninja
- Software
  - Arduino IDE ver 1.8.13 + ESP32 core + libraries
  - CP2104 USB to serial driver
- Cloud platform
  - NETPIE 2020
- Notebook computer
  - Windows preferred. Setup might be problematic with some version of MAC-OSX



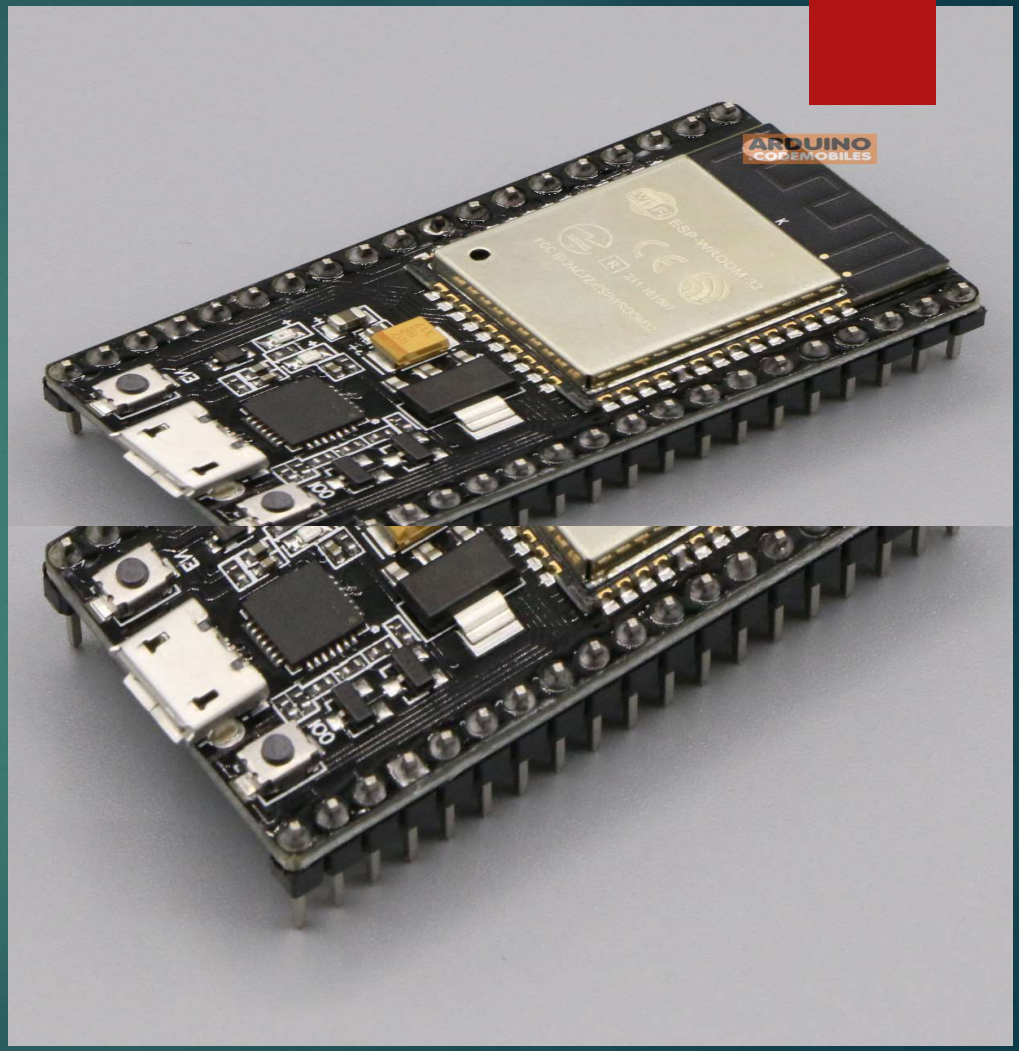
Hardware/Software

SETUP



NodeMCU-32S

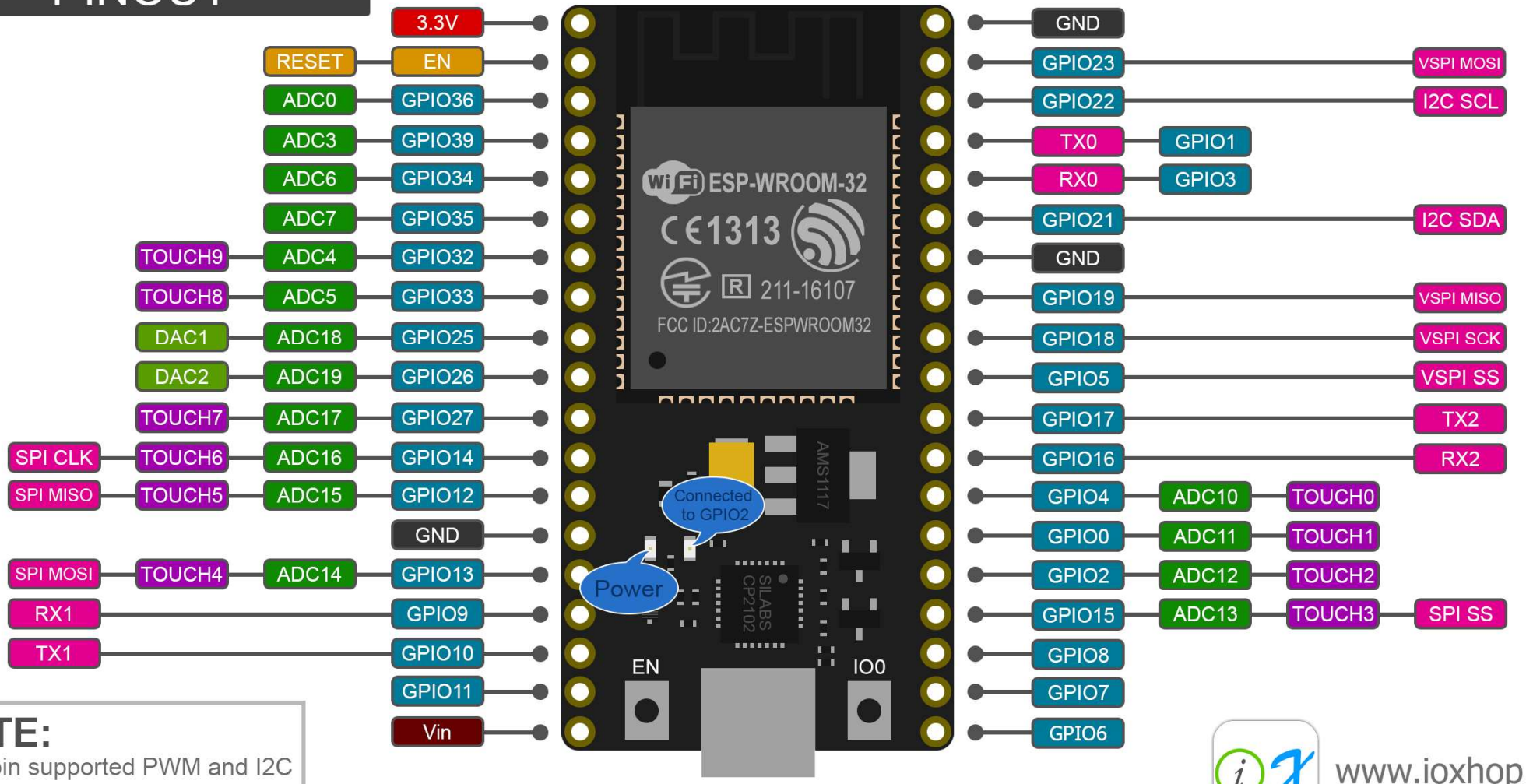
- ESP32 SoC with integrated WiFi/Bluetooth (dual-core Tensillica Xtensa LX6 microprocessor)
- Clock speed 240 MHz
- 4 MB Flash
- Digital I/O pins : 26
- Analog input pins: 12
- 8-bit analog outputs (DAC) : 2
- SPI, I2C, UART and sensors (see datasheet)



NodeMCU-32S

PINOUT

CC BY 4.0



NOTE:

All pin supported PWM and I2C

Pin current 6mA (Max. 12mA)

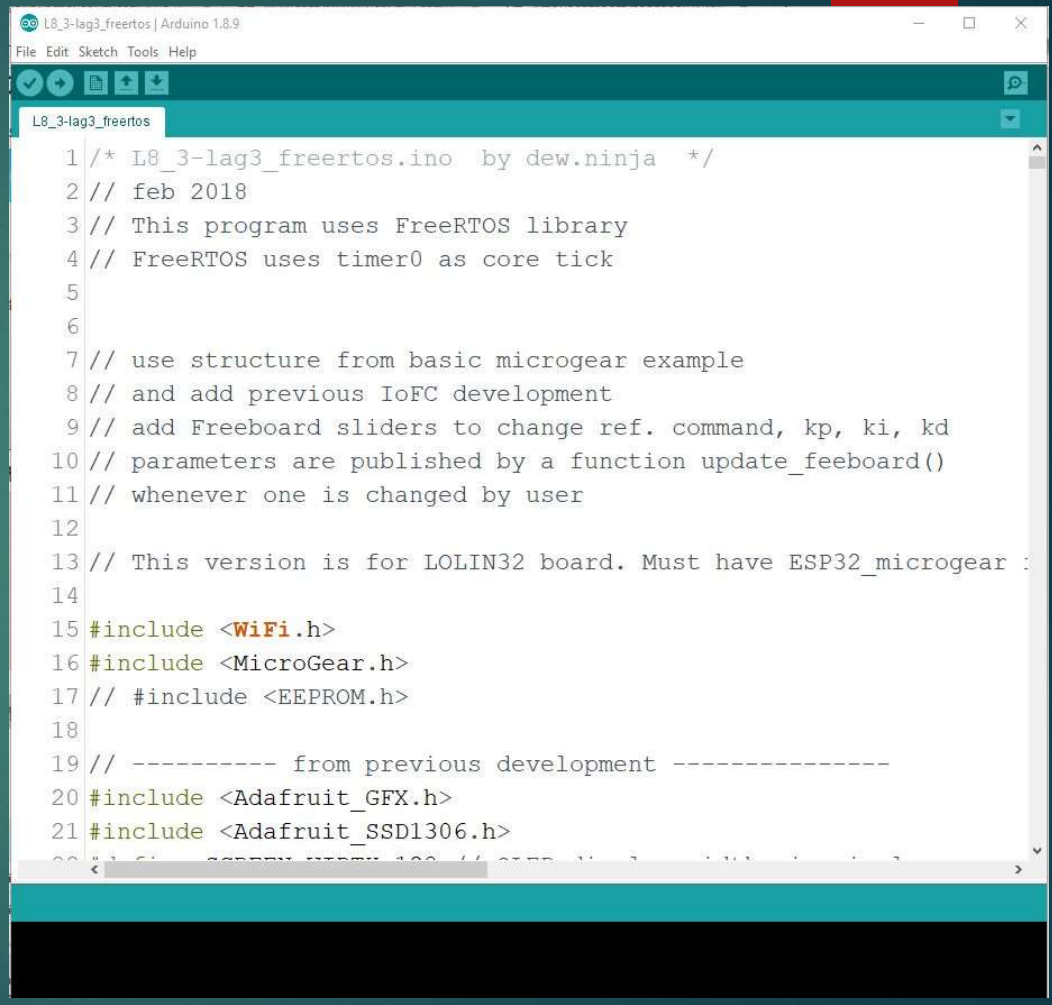
www.ioxhop.com

Use NodeMCU-32S with Arduino IDE

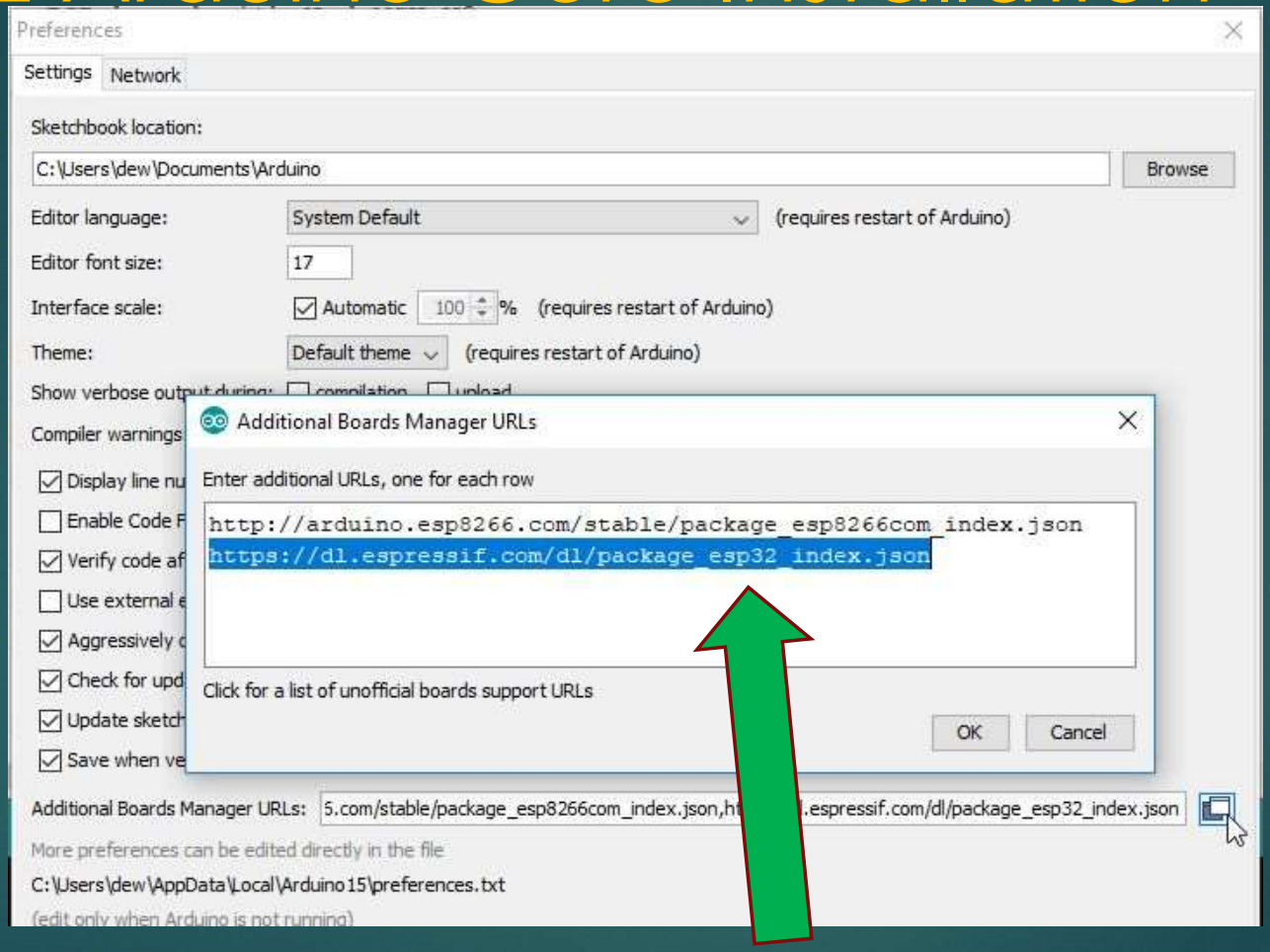
- Install Arduino IDE https://www.arduino.cc/en/Main/Software
- Install CP210x USB-to-serial driver
- Install ESP32 Arduino Core

Install Arduino IDE

- Latest version (March 21) 1.8.13
- Download and run installer (or download zip file and extract to the desired directory)
- Install CP210x USB driver
- Check Tools->Board . There is no support for ESP32. We need to install Arduino Core for ESP32



ESP32 Arduino Core Installation



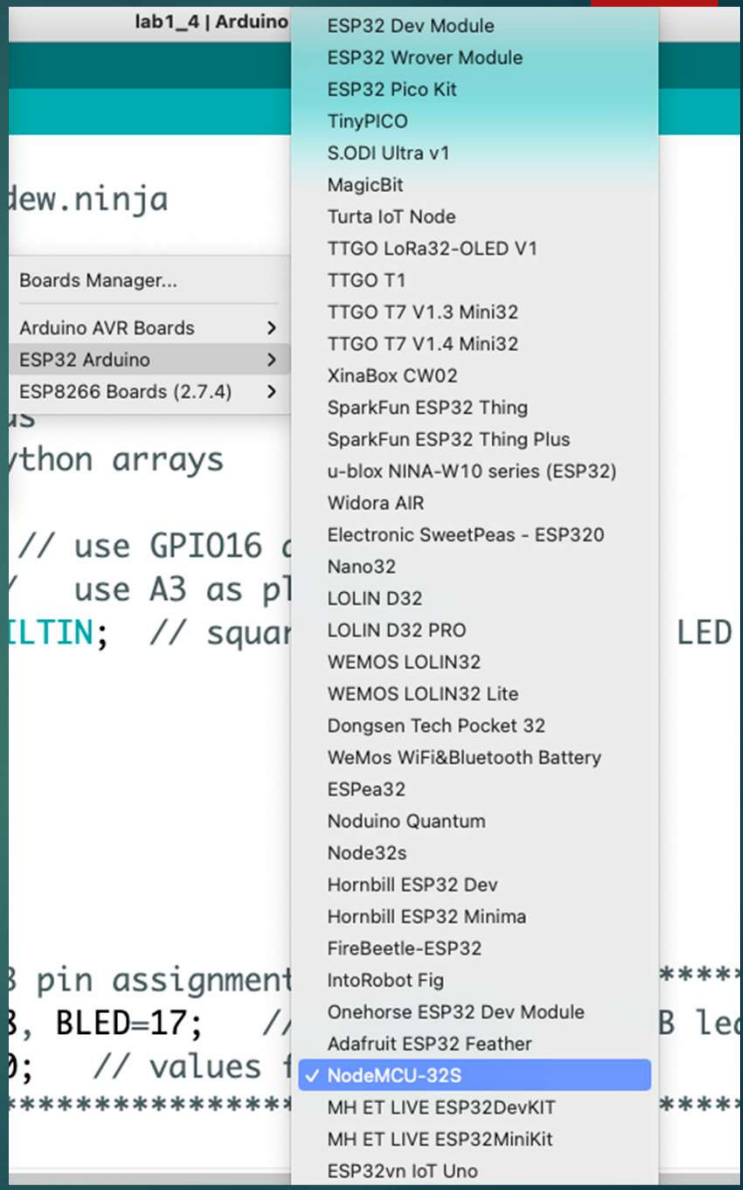
https://dl.espressif.com/dl/package_esp32_index.json

ESP32 Arduino Core Installation

ติดตั้งสำเร็จ

After ESP32 Arduino Core is installed

Select Tools -> Board ->ESP32 Arduino -> NodeMCU-32S

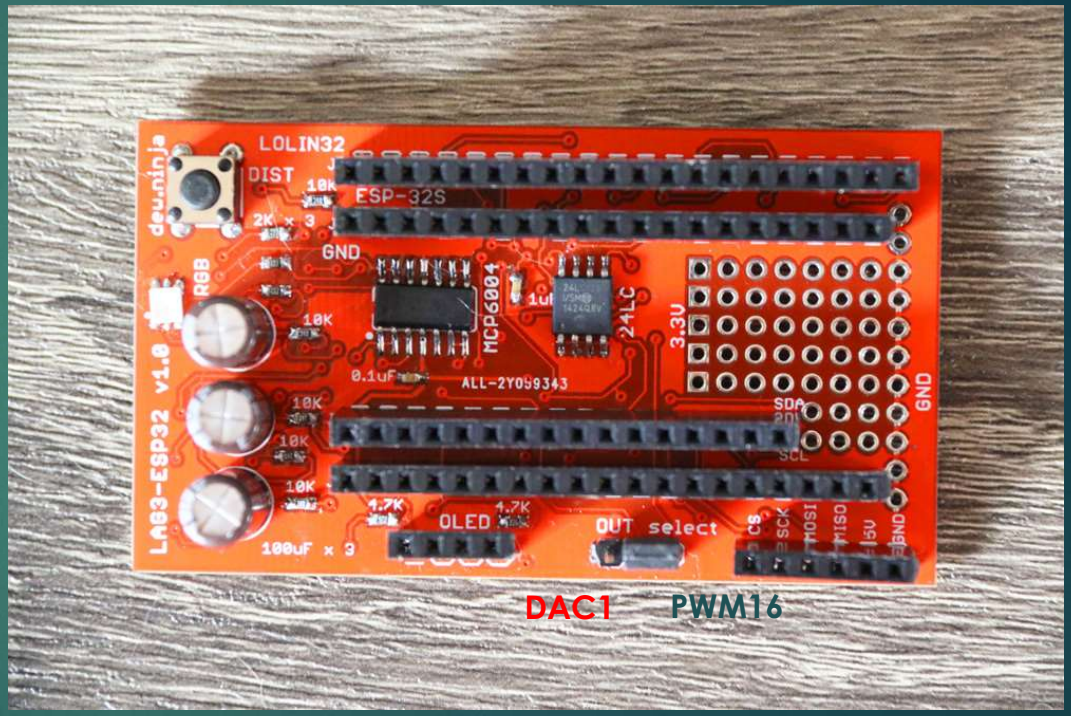


Install Library (use library manager)

- Pubsubclient for NETPIE 2020

LAG3-ESP32 board

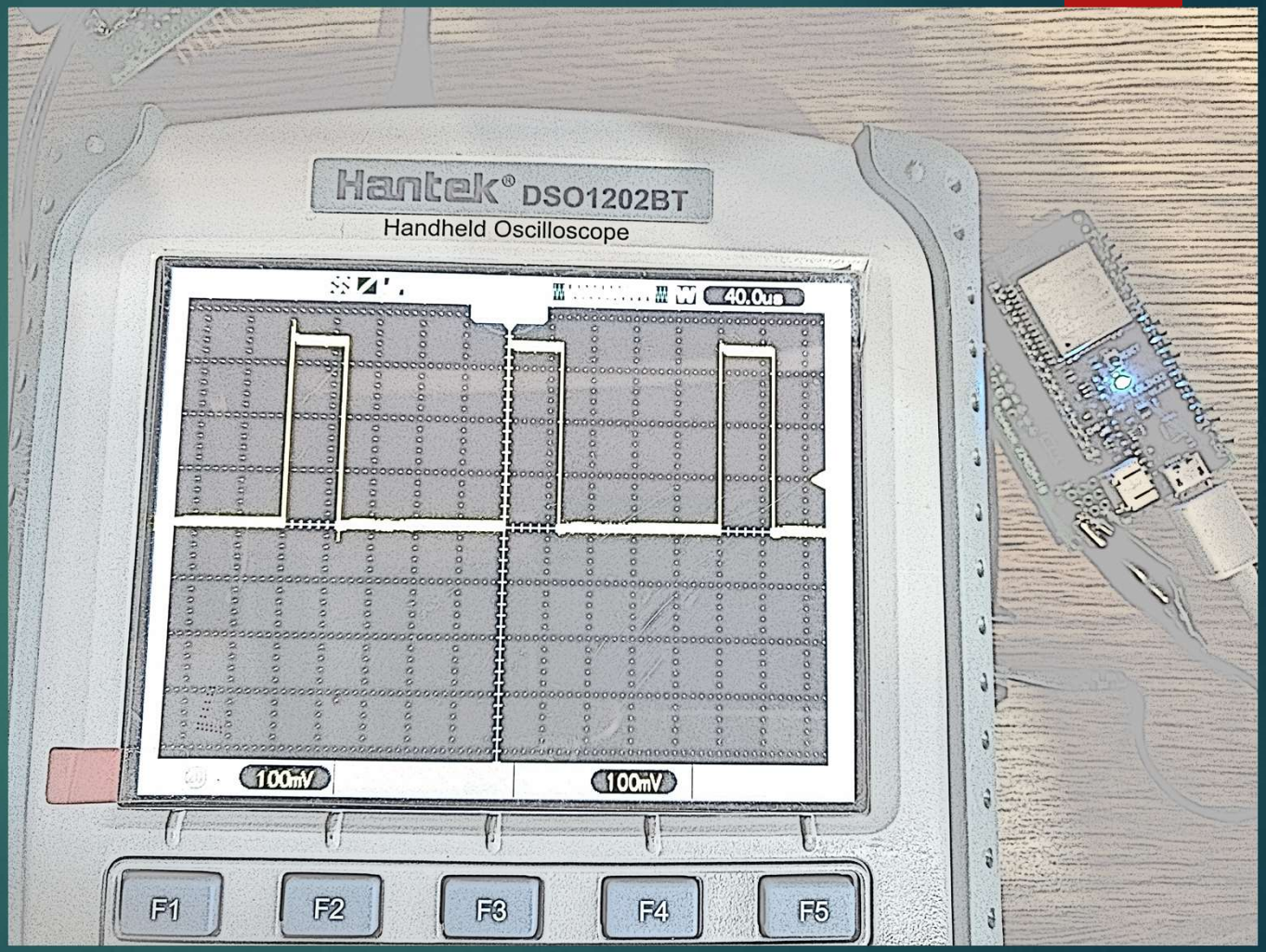
- 3-level cascade tank using RC circuit and op-amp
- Connector for OLED display
- RGB LED and EEPROM (optional)
- Can be used with WEMOS LOLIN32 or NODEMCU-32S (commercial ESP32 modules)
- DAC1/PWM16 outputs (selectable via jumper)



NodeMCU-32S pins used

GPIO	Name	Type	Function
39	ADC3	Analog IN	Plant output (Y)
32	ADC4	Analog IN	State variable (X2)
33	ADC5	Analog IN	State variable (X1)
25	DAC1	Analog OUT	Controller output (Analog)
16	PWM	OUT	Controller output (PWM)
22	SCL	OUT	I2C
21	SDA	OUT	I2C
19	PWMR	OUT	PWM for red LED
18	PWMG	OUT	PWM for green LED
17	PWMB	OUT	PWM for blue LED
5	LED	Digital OUT	On-board LED

ESP32 basic module programming



Arduino program structure

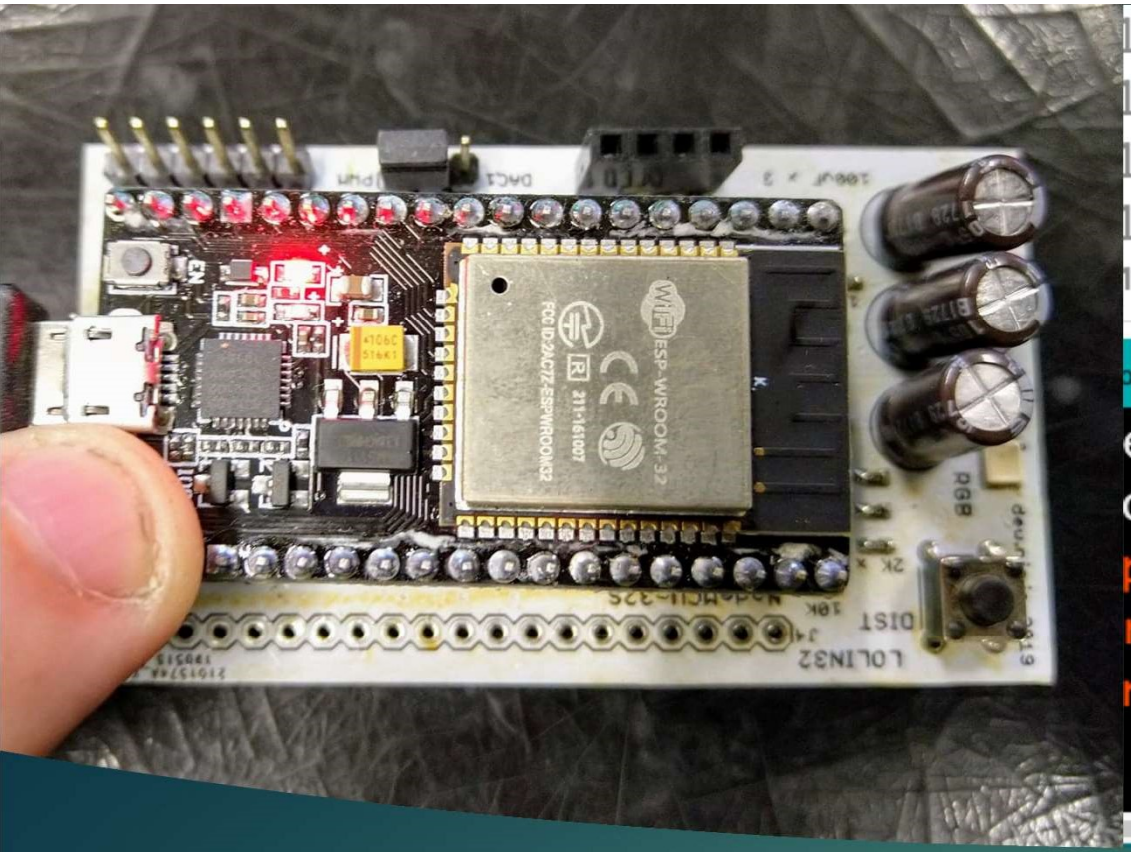
```
setup()   {
    // Module initialization.
    // run only once at
    // beginning
}

loop()   {
    // run iteratively
    user_func();
}

user_func()   { // optional
}
```

```
external_interrupt_function()  {
    // respond to external
    //interrupt
    //optional
}

timer_callback()   {
    //respond to timer interrupt
    // optional
}
```




```
12          r = parmvalfloat;
13          rold = r;   // save previous com
14      }
15      Serial.println("datamat = [");
16      datacnt = 1;    // set the flag t
```

```
oading...
etch uses 229844 bytes (17%) of program st
obal variables use 13580 bytes (4%) of dyn
ptool.py v3.0-dev
rial port /dev/cu.usbserial-0001
nnecting.....____.....____.....____.
```

Press button to upload code

Serial port communication

- Initialized by Serial.begin(), such as
  - Serial.begin(115200);
  - Other side must use same baudrate.
- Output string with Serial.print() or Serial.println()
- Read data with Serial.readString()
- Check data in buffer with Serial.available()
- Can use Serial Monitor/ Serial Plotter from Tools menu of Arduino IDE to monitor or send commands

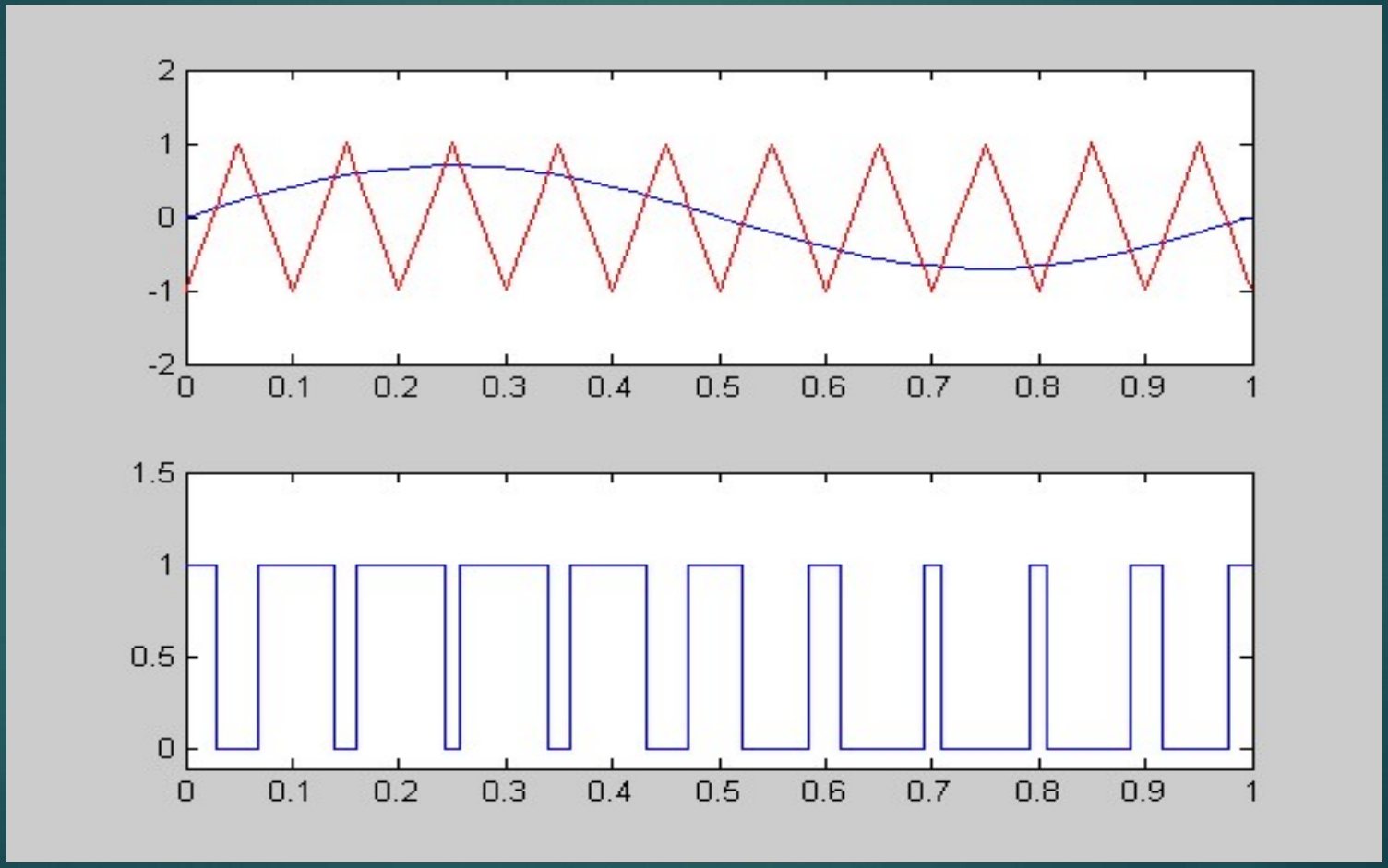
Analog inputs

- Maximum 16 channels
- Maximum voltage equals Vcc (3.3 V)
- 12-bit resolution (0 – 4095)
- Read data using analogRead();
- Can specify GPIO number or analog channel
  - int adcval = analogRead(A0);
  - int adcval = analogRead(36);

Analog outputs

- 8-bit DAC modules
- 2 channels : GPIO25 (DAC1) and GPIO26 (DAC2)
- Write function : dacWrite();
- Can specify GPIO or DAC channels. For example, to send 1.65 volts out at pin DAC1
  - dacWrite(25, 127);
  - dacWrite(DAC1, 127);
- Limited output current. In practice, an op-amp buffer may be needed to supply more current.

PWM generation



PWM outputs

- Native ESP32 core does not have analogWrite() function (additional library is needed)
- Use ledc() , which must be setup with ledcSetup() ; ex.,
  - ledcSetup(1, 5000, 12); use timer 1 PWM frequency 5 KHz and 12-bit resolution
- Attach timer to GPIO using ledcAttachPin(timer, pin)
  - ledcAttachPin(2,1); attach timer 1 to GPIO2
- After setup, use ledcWrite() to write to PWM module (the first argument is timer number, not GPIO pin!)
  - ledcWrite(1, 1023); generate PWM with duty cycle 25%

Using analogWrite library

- Must install ESP32 analogWrite library
- #include <analogWrite.h>
- Set resolution in setup()
  - analogWriteResolution(LED_BUILTIN, 12);
- Output some value
  - analogWrite(LED_BUILTIN, brightness);

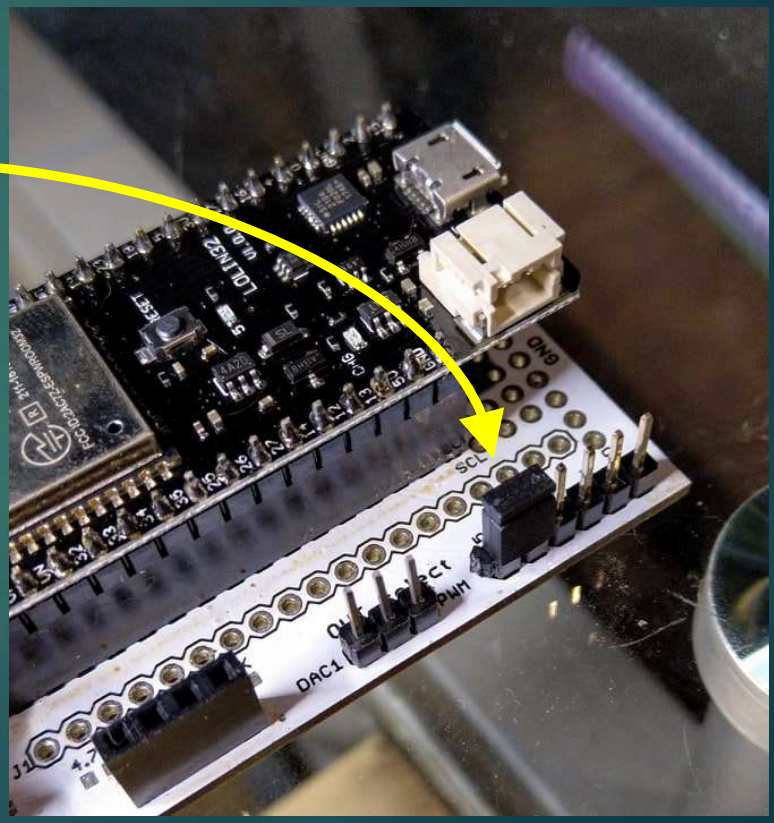
From my experiment on pin 15, the PWM waveform does not give expected result ?

External interrupt

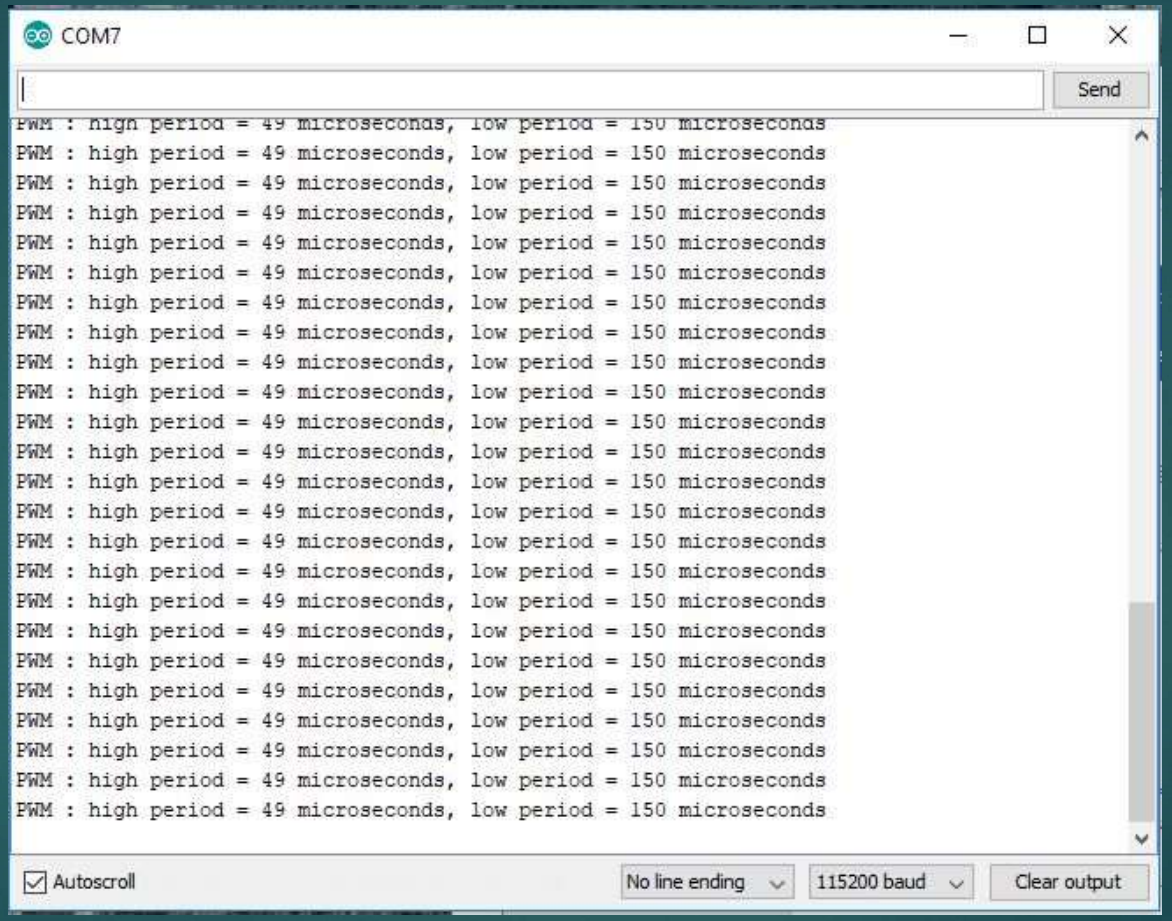
- Use attachinterrupt()
  - attachinterrupt(34, funcA, RISING); setup GPIO34 such that when the logic level changes from 0 to 1 (rising edge), execute funcA()
  - Choice of external interrupt events
    - LOW – when input has logic 0
    - HIGH – when input has logic 1
    - CHANGE – when input changes logic level
    - RISING – at rising edge of input
    - FALLING – at falling edge of input

Lab 1.1 : measure PWM periods without using an oscilloscope

- Assign PWM output to GPIO15
- Use timer 1 PWM frequency 5 KHz
- Connect GPIO15 to GPIO14
- Setup GPIO14 to interrupt every logic change
- Create PWM with duty cycle 25%
- Use micros() to measure high and low periods



Lab 1.1 : Serial Monitor Output



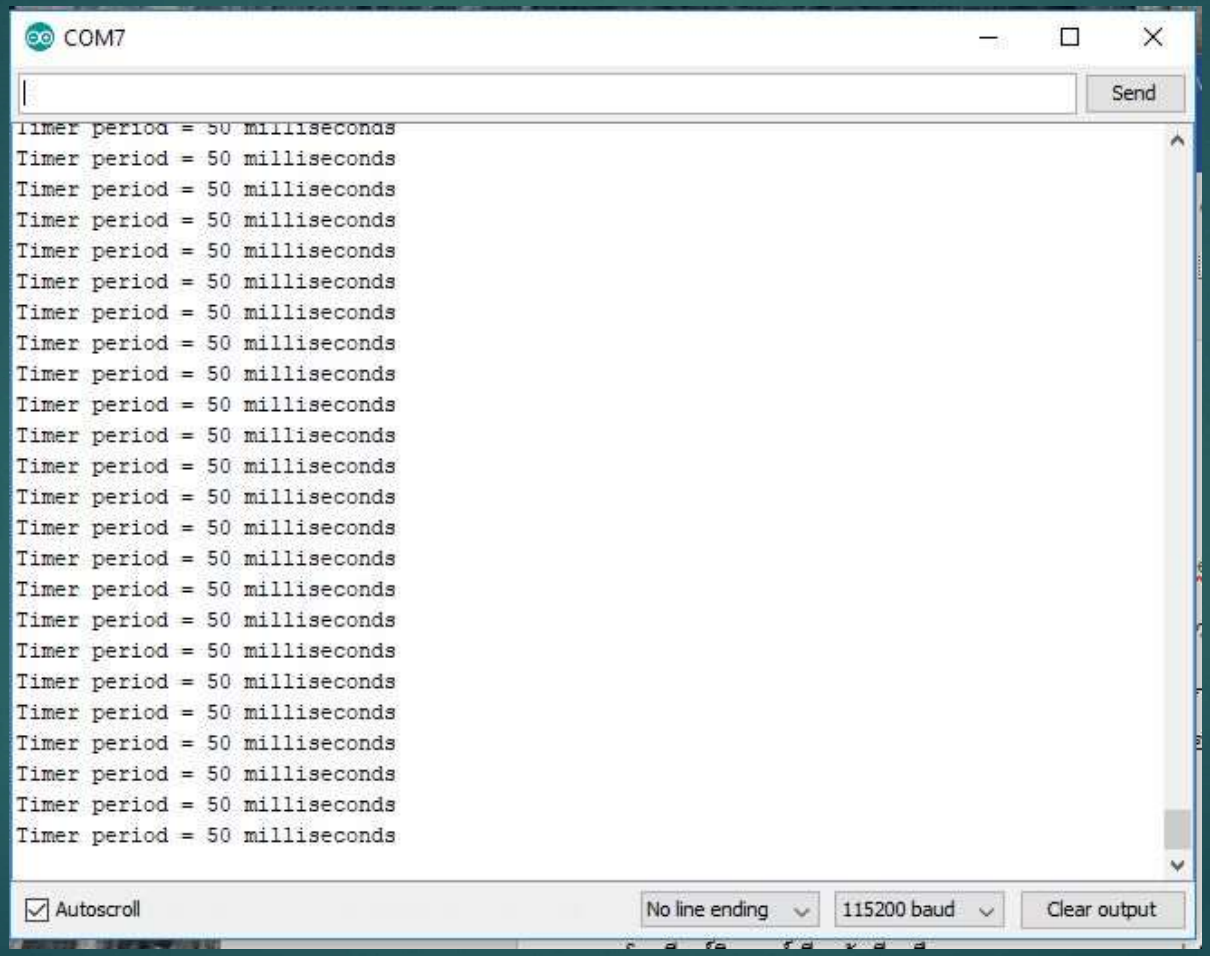
Using timer on ESP32

- Use hardware timer (can cause watchdog reset for long interrupt period)
- Setup using timerBegin()
- Write a callback and attach to timer using timerAttachinterrupt()
- Set interrupt period with timerAlarmWrite()
- Enable interrupt with timerAlarmEnabled()

Lab 1.2 : using a timer on ESP32

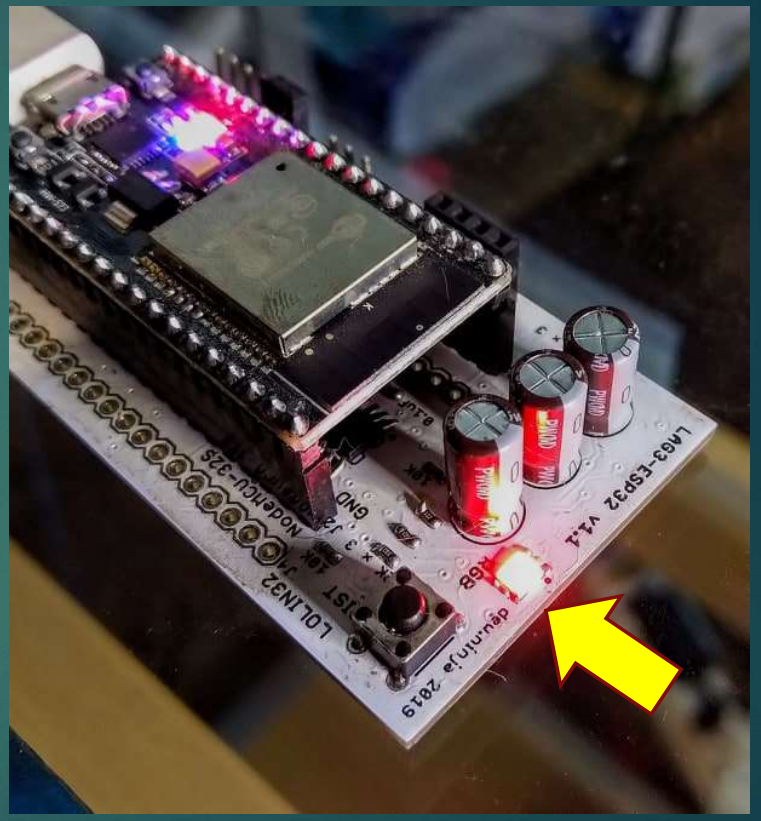
- Setup timer 0 to interrupt every 50 milliseconds
- Blink onboard LED on NodeMCU-32S
- Measure period with millis()
- Output result on Serial Monitor

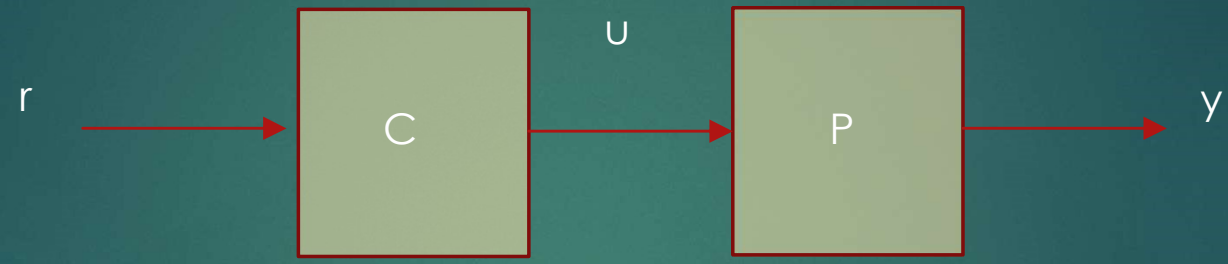
Lab 1.2 Serial Monitor Output



Exercise 1:

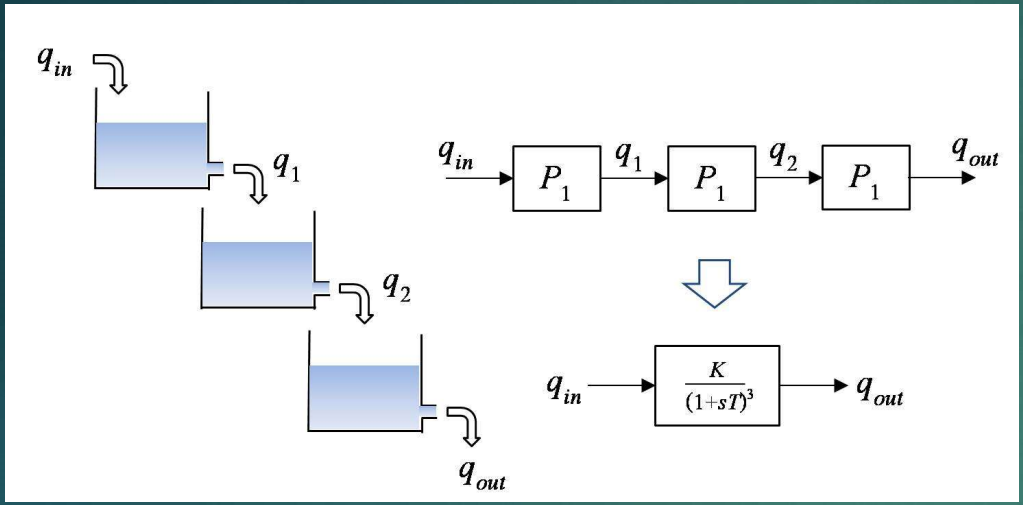
modify LAB1_2.ino to blink red LED independently from on-board LED





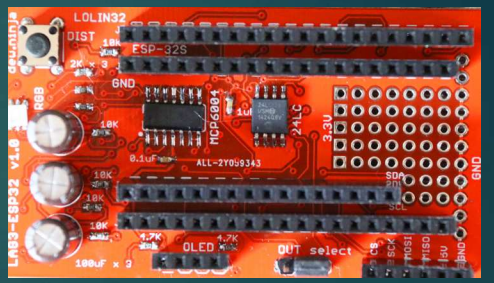
OPEN-LOOP SYSTEM

3 cascade tank model(LAG3)

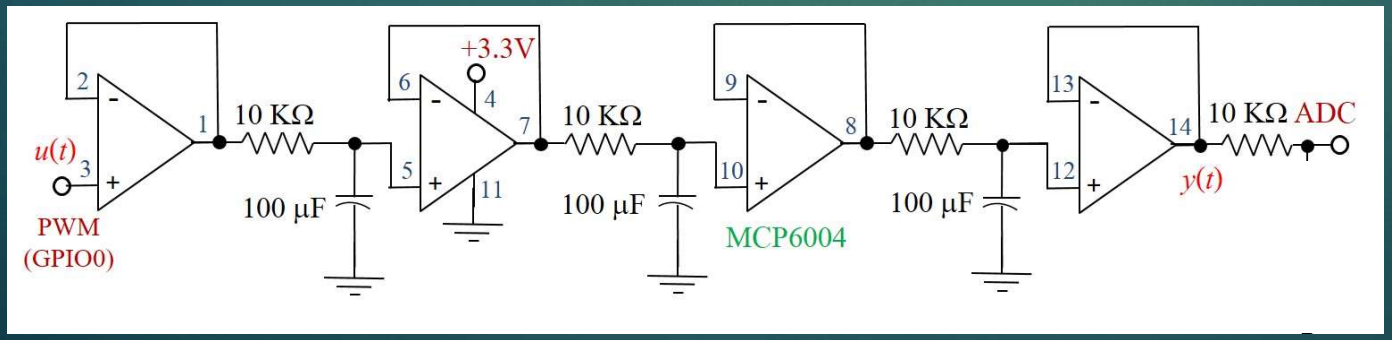


normalized transfer function

$$\frac{1}{(s+1)^3}$$



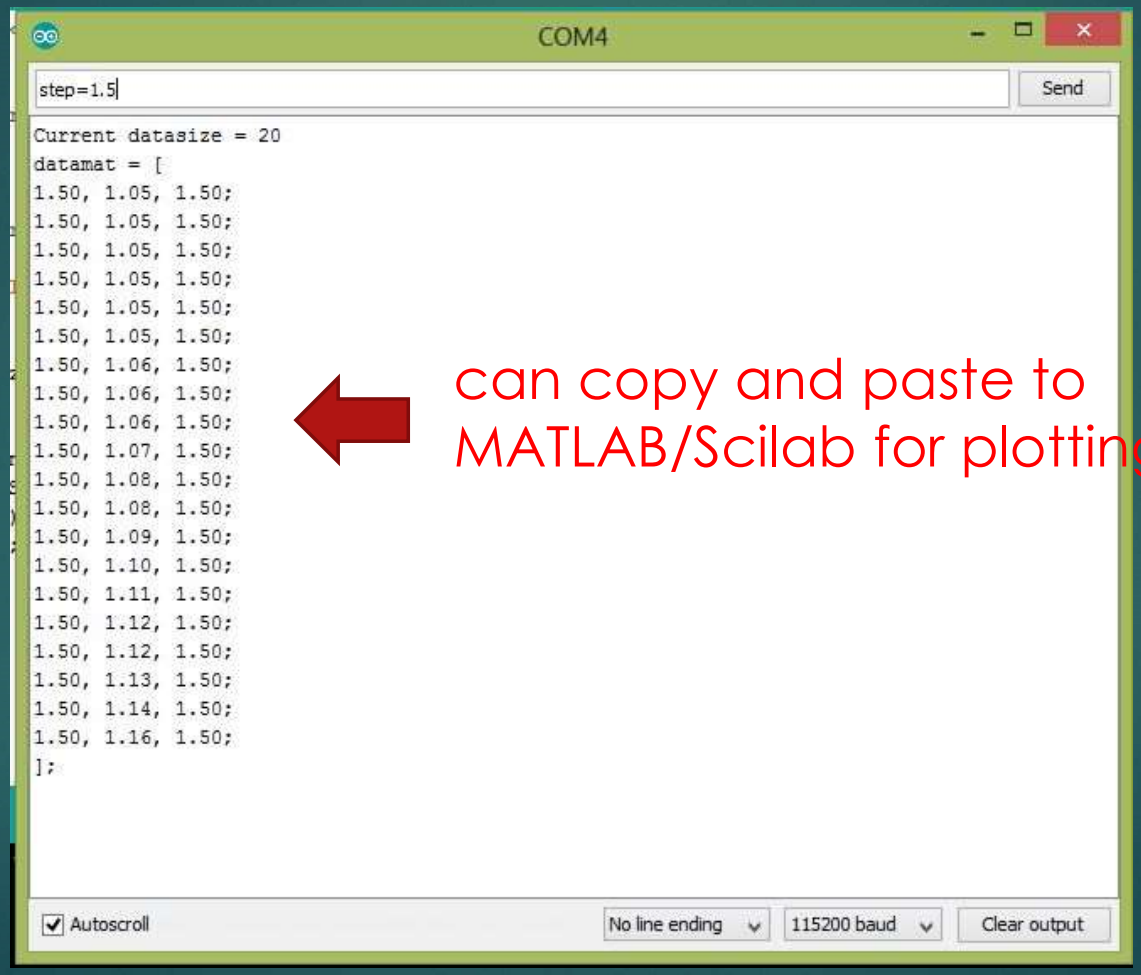
Simulaton by electronic circuit



Lab 1.4 Command interpreter function

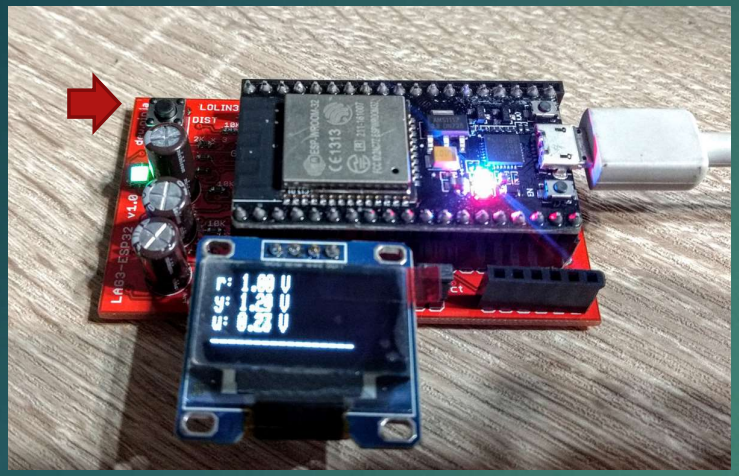
- Construct cmdInt() for the following commands
  - step=<value> : adjust reference input
  - datasize=<num> : specify number of data points
  - Other commands you may want to add, using format command=<parameter>

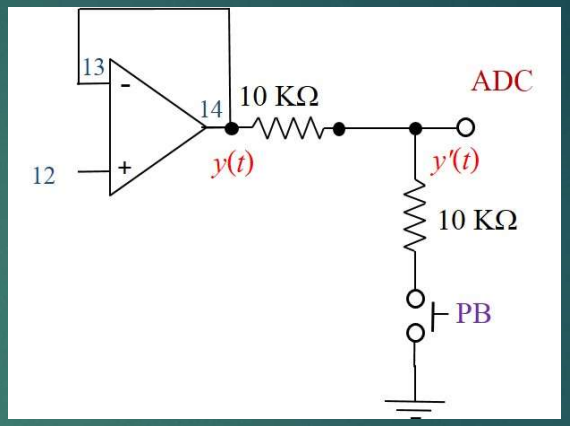
Test command via serial monitor

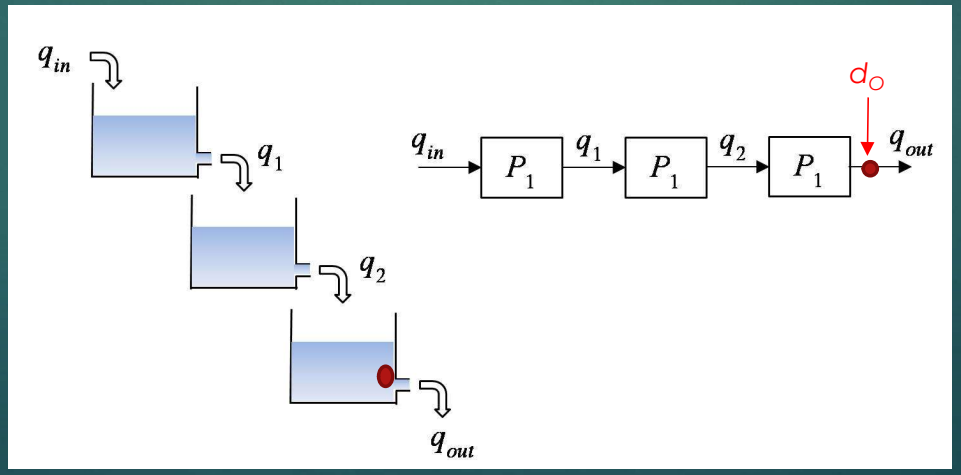


can copy and paste to MATLAB/Scilab for plotting

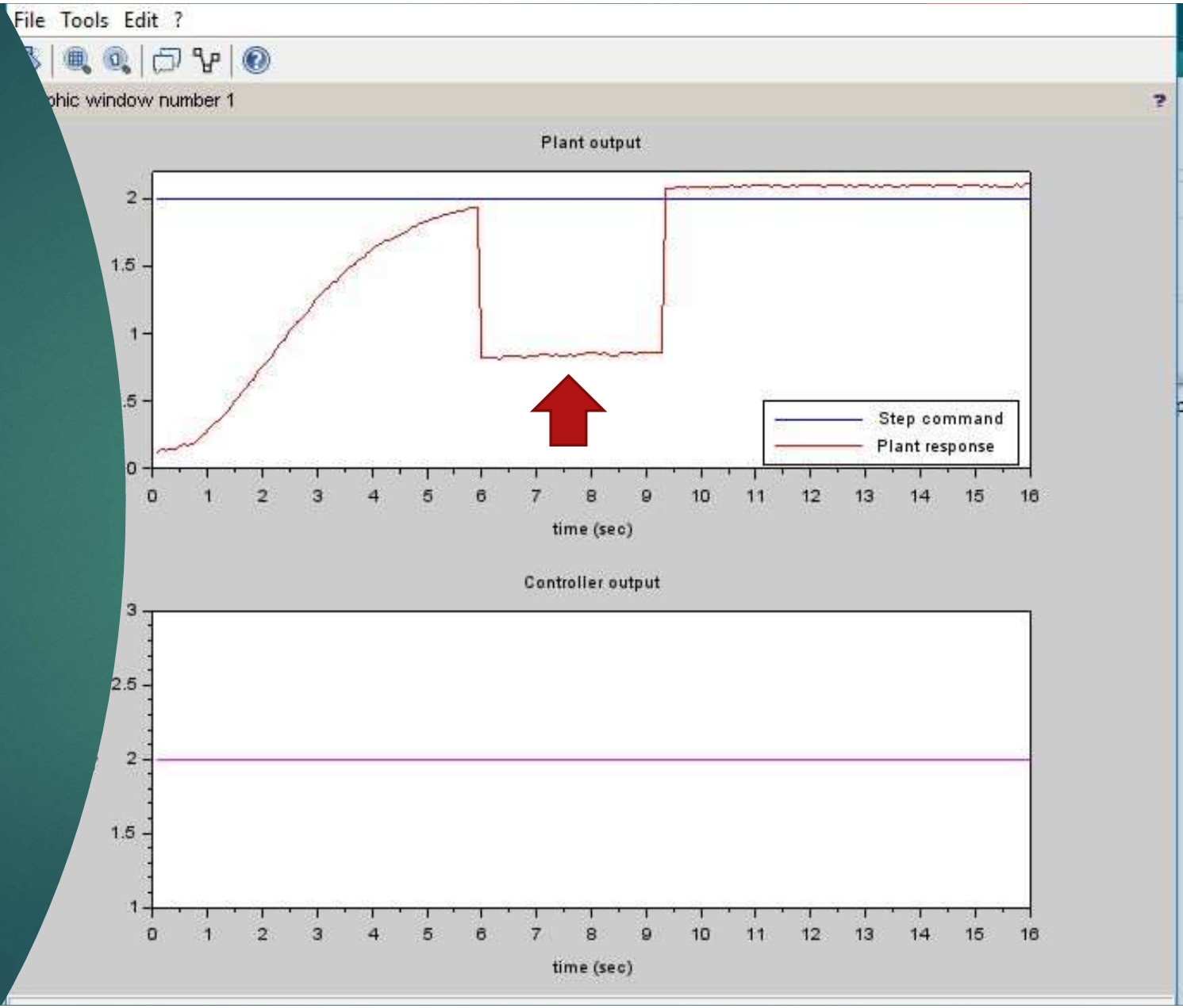
Output disturbance switch

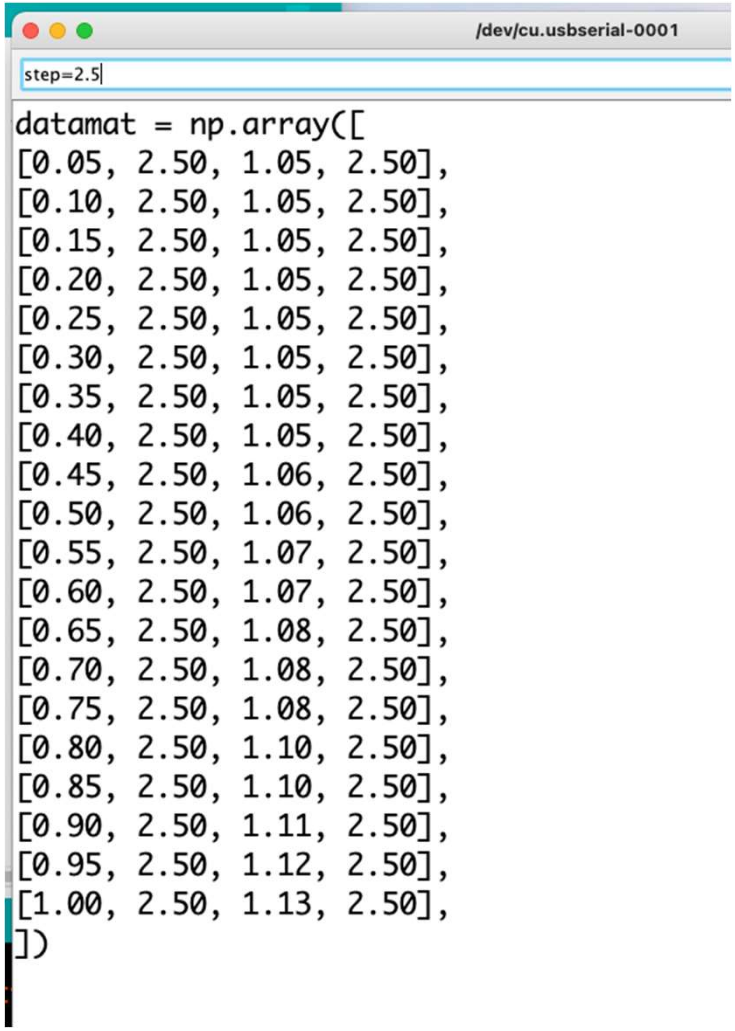






When disturbance switch is pressed





Output as numpy array

jupyter plotresp Last Checkpoint: 2 hours ago (autosaved)

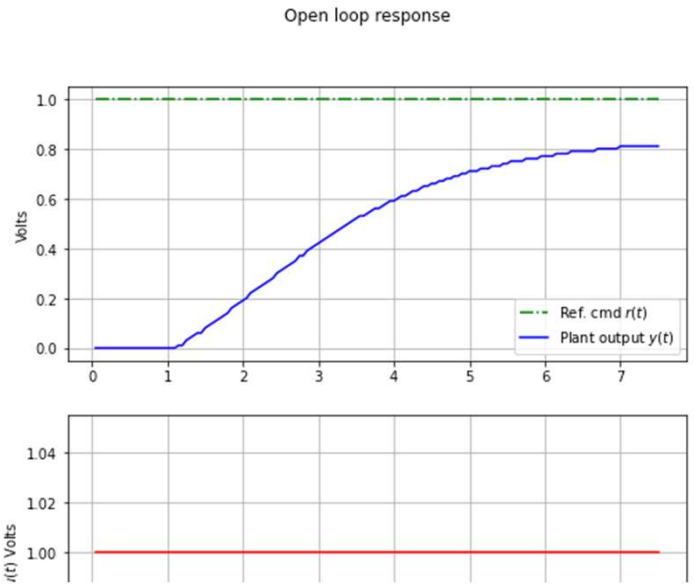
File Edit View Insert Cell Kernel Widgets Help

Run Code

In [13]:
```
tvec = datamat[:,0]
rvec = datamat[:,1]
yvec = datamat[:,2]
uvec = datamat[:,3]
```

In [15]:
```
fig, (ax1, ax2) = plt.subplots(2,figsize=(8,8))
fig.suptitle('Open loop response')
ax1.plot(tvec,rvec,'g-.',tvec,yvec,'b-')
ax1.grid(True)
ax1.set_ylabel('Volts')
ax1.legend(['Ref. cmd $r(t)$','Plant output $y(t)$'])

ax2.plot(tvec,uvec,'r-')
ax2.set_xlabel('time (s)')
ax2.set_ylabel('$u(t)$ Volts')
ax2.grid(True)
```



Plot on Jupyter Notebook

What we have learnt from Lab 1

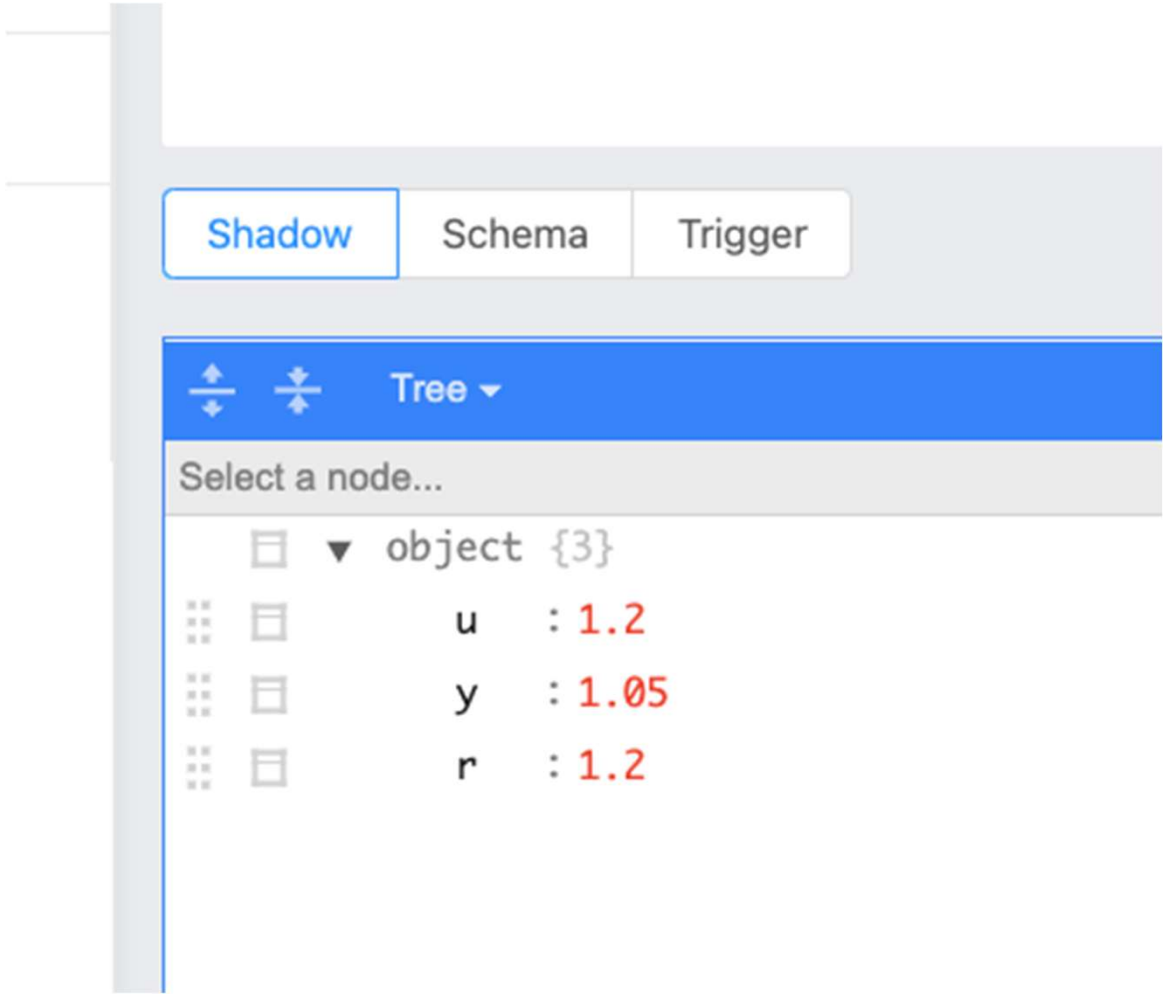
- Generate PWM output
- How to use external interrupt and timer
- Serial communication and command intepreter
- Drawback of open-loop control

Monitoring and control via NETPIE 2020›

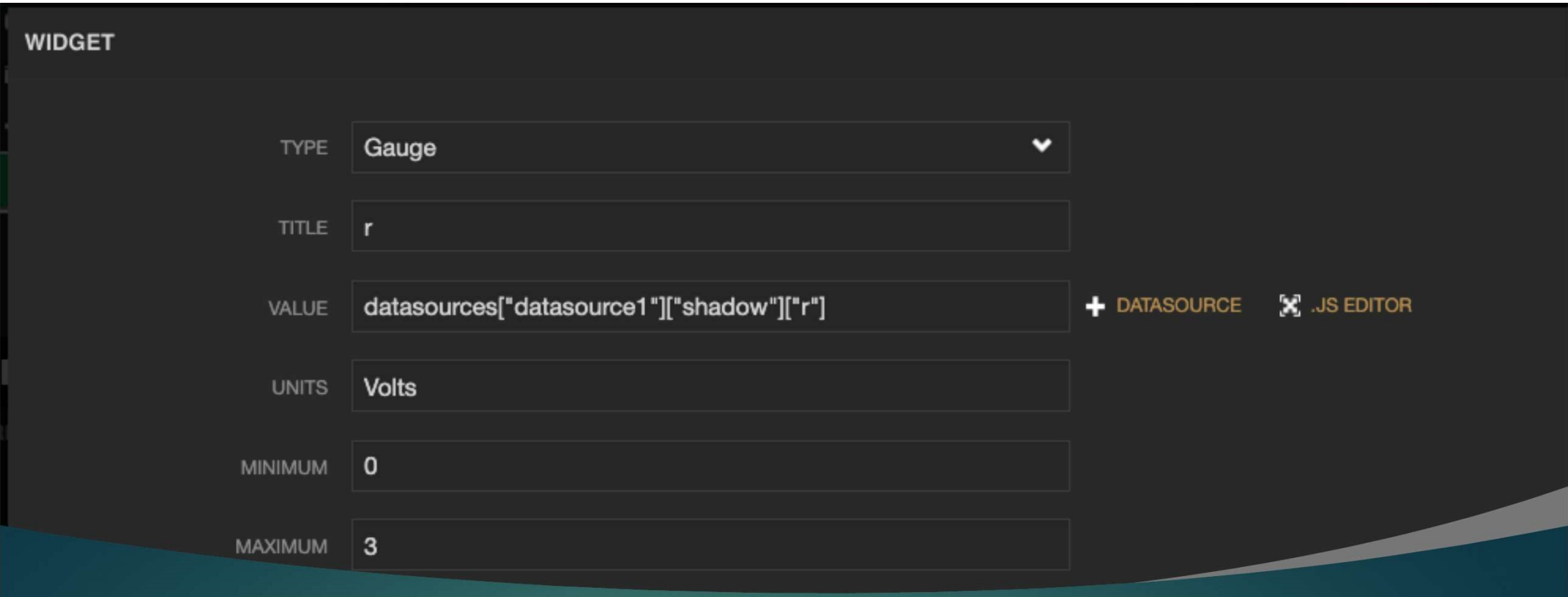
- Cloud platform developed by NECTEC
- Can use with various hardware such as ESP8266, ESP32, Raspberry PI, Android
- Latest version is NETPIE 2020
- Details can be read from https://netpie.io

Lab1_4_NETPIE.ino

- Add WiFi and internet connection code to Lab 1.4
- On NETPIE account, create a project and device
- Copy Client-ID, Username, Token information to Lab1_4_NETPIE.ino
- Publish r,y,u data to NETPIE shadow
- Create Freeboard and datasource
- Add 3 gauge widgets for r, y, u data
- Add a slider for ref. command adjustment



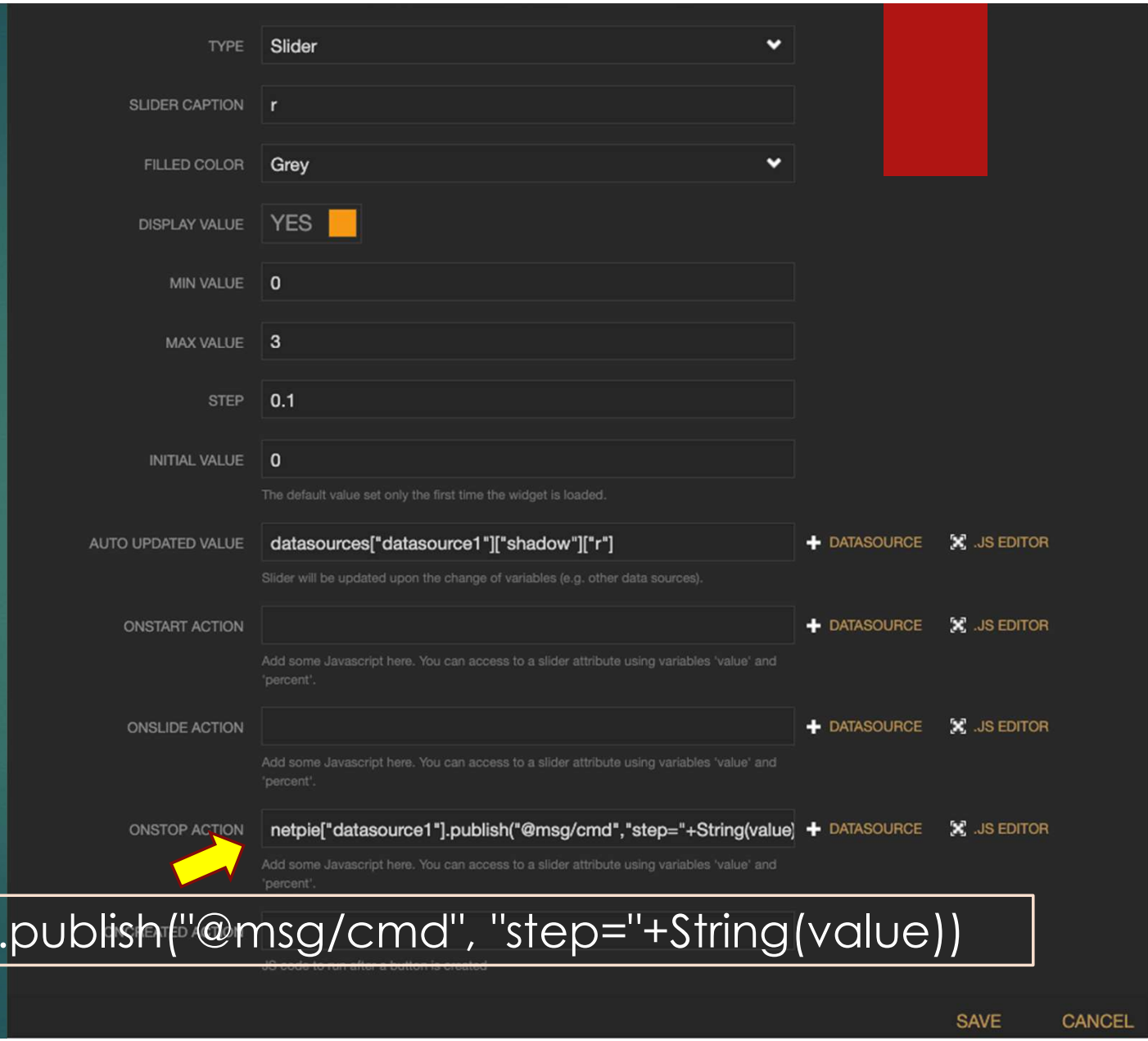
r,y,u data on NETPIE Shadow



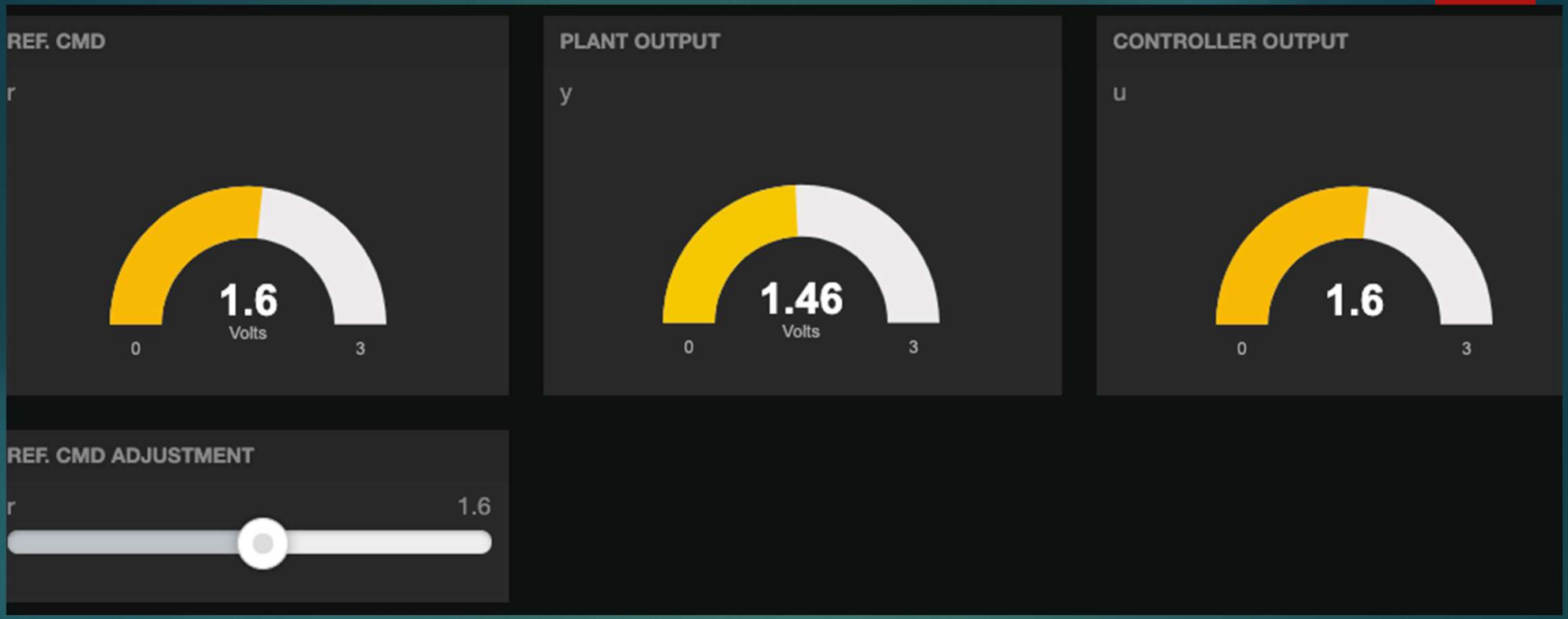
Gauge widget settings

Click on [+DATASOUCRE] on the right and make selection

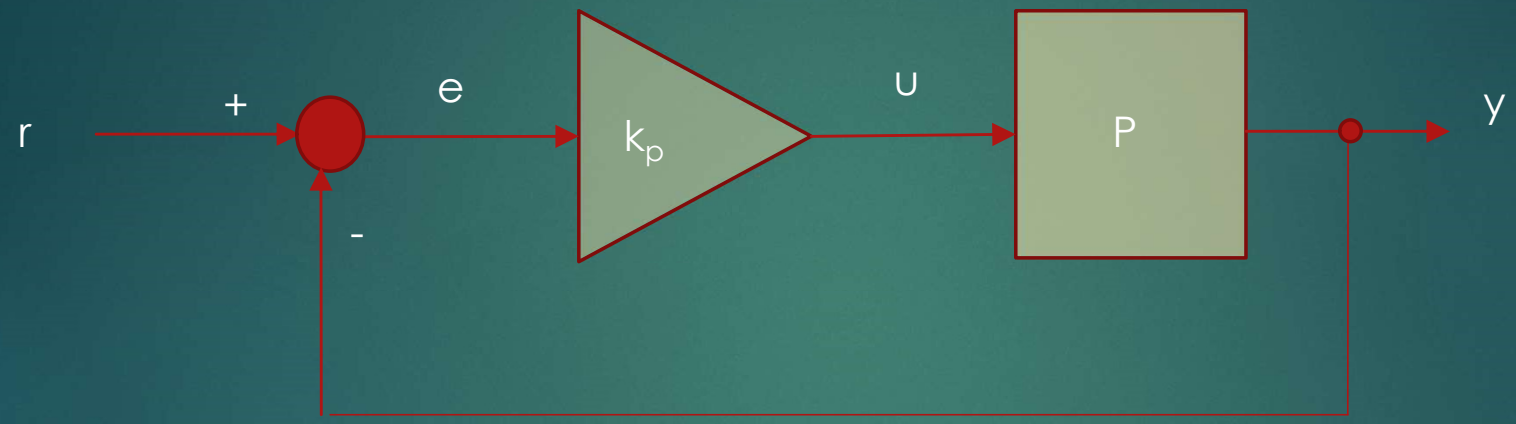
Slider settings



netpie["datasourcename"].publish("@msg/cmd", "step="+String(value))

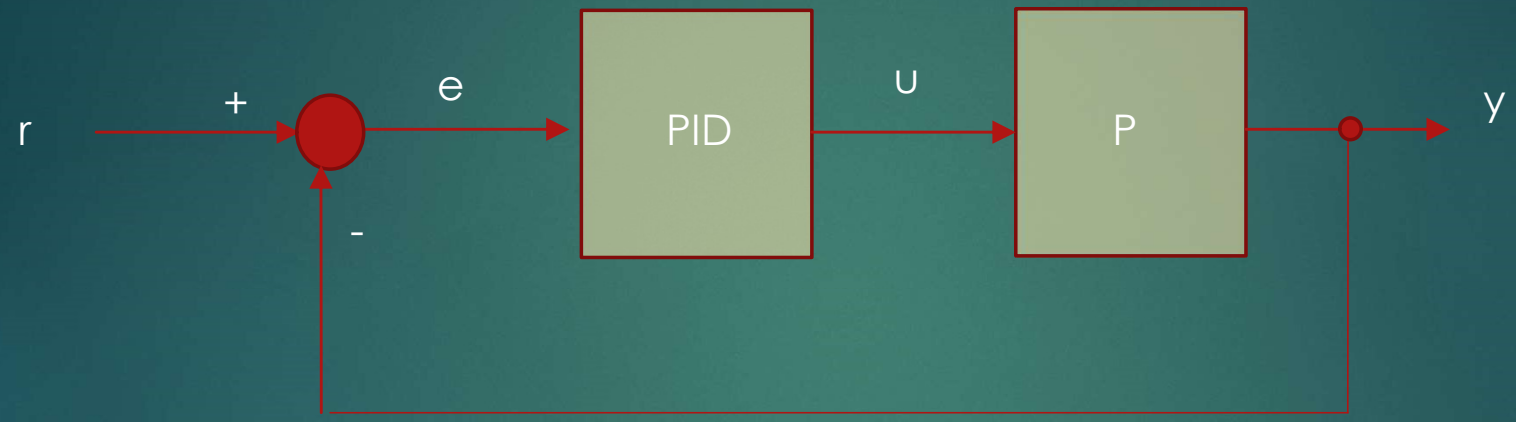


Freeboard Layout

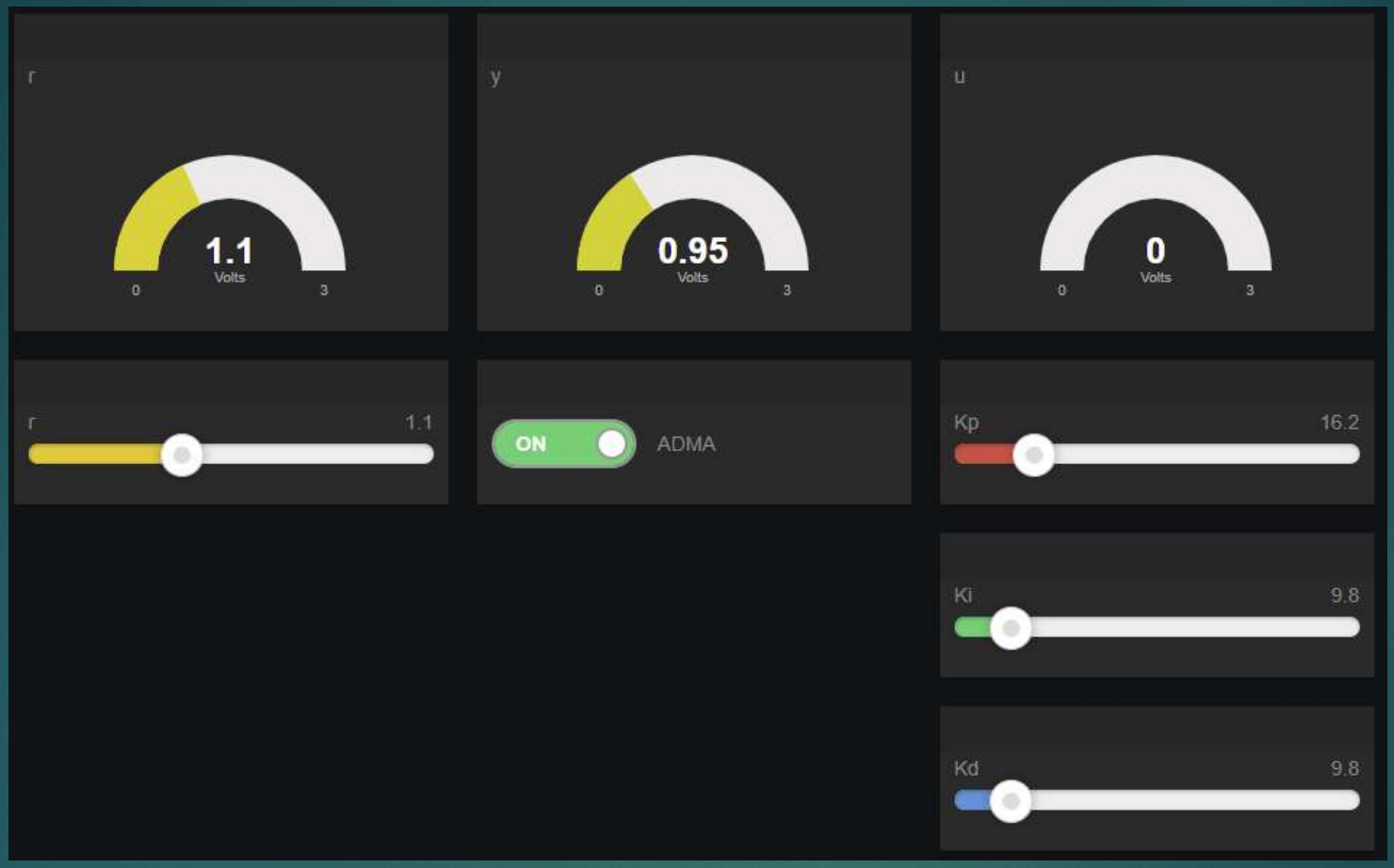


Exercise 2 : modify Lab1_4_NETPIE.ino to implement a proportional feedback. The gain k_p can be adjusted by a command and a slider in NETPIE 2020

Lab1_5_pid_NETPIE.ino

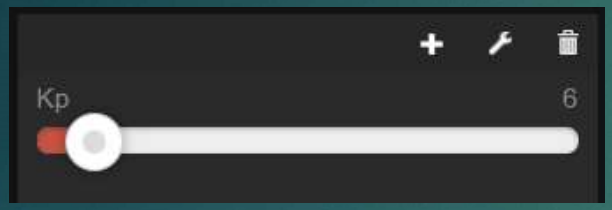


- PID controller is implemented in timer function
- Can adjust controller parameters via serial port and NETPIE 2020



Freeboard Layout

Kp slider setup example



WIDGET

A slider widget that can perform Javascript action.

TYPE: Slider

SLIDER CAPTION: Kp

FILLED COLOR: Red

DISPLAY VALUE: YES

MIN VALUE: 0

MAX VALUE: 100

STEP: 0.1

INITIAL VALUE: 0

The default value set only the first time the widget is loaded.

AUTO UPDATED VALUE: datasources["piddatasource"]["shadow"]["kp"] + DATASOURCE JS EDITOR

Slider will be updated upon the change of variables (e.g. other data sources).

ONSTART ACTION: + DATASOURCE JS EDITOR

Add some Javascript here. You can access to a slider attribute using variables 'value' and 'percent'.

ONSLIDE ACTION: + DATASOURCE JS EDITOR

Add some Javascript here. You can access to a slider attribute using variables 'value' and 'percent'.

ONSTOP ACTION: netpie["piddatasource"].publish("@msg/cmd", "kp="+String(value + DATASOURCE JS EDITOR

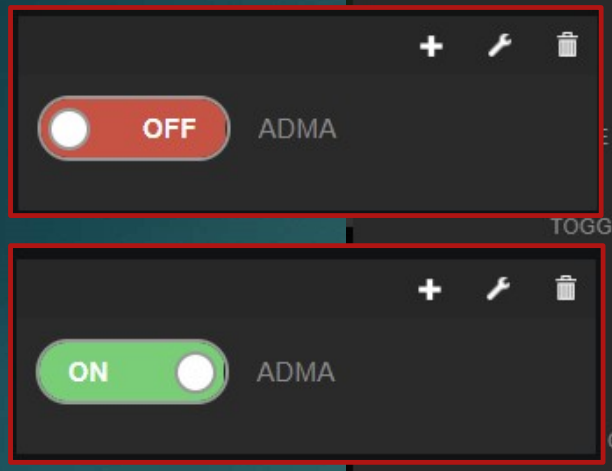
Add some Javascript here. You can access to a slider attribute using variables 'value' and 'percent'.

ONCREATED ACTION

SAVE CANCEL

```
netpie["datasourcename"].publish("@msg/cmd", "kp="+String(value))
```

ADMA toggle button setup



TYPE: Toggle

CAPTION: ADMA

TOGGLE STATE: datasources["piddatasource"]["shadow"]["adma"]==1 + DATASOURCE .JS EDITOR

Add a condition to switch a toggle state here. Otherwise it just toggle by click.

ON TEXT: ON

OFF TEXT: OFF

ONTOGGLEON ACTION: netpie["piddatasource"].publish("@msg/cmd", "adma=on")

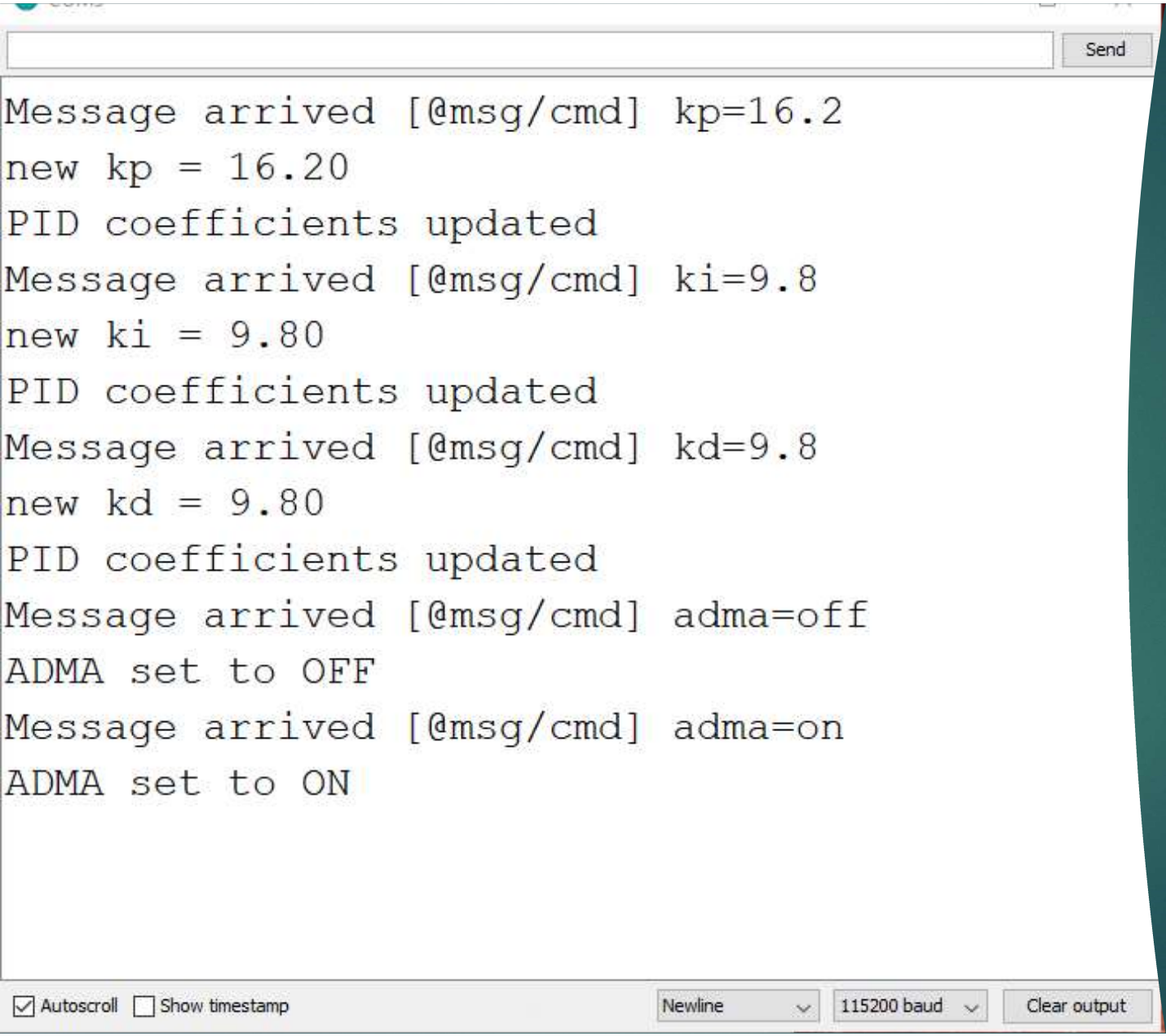
JS code to run when a toggle is switched to ON

ONTOGGLEOFF ACTION: netpie["piddatasource"].publish("@msg/cmd", "adma=off")

JS code to run when a toggle is switched to OFF

SAVE CANCEL

```
netpie["datasourcename"].publish("@msg/cmd", "adma=on")
netpie["datasourcename"].publish("@msg/cmd", "adma=off")
```



Received commands shown on serial monitor

References

- Books
  - K.J. Astrom and T. Hagglund. Advanced PID Control. Instrumentation, Systems, and Automation Society, 2006.
  - Varodom Toochinda. Feedback Control with Scilab and Arduino. dew.ninja, 2017.
- Websites
  - http://dewninjathai.blogspot.com
  - https://netpie.io

Thank You