La stabilisation de caméra

Dans quelles mesures l’analyse d’un système de stabilisation mécanique asservie permet-elle d’améliorer la stabilité du système ?

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II. Stabilisation

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3. Expérience et prévision en référentiel non galiléen

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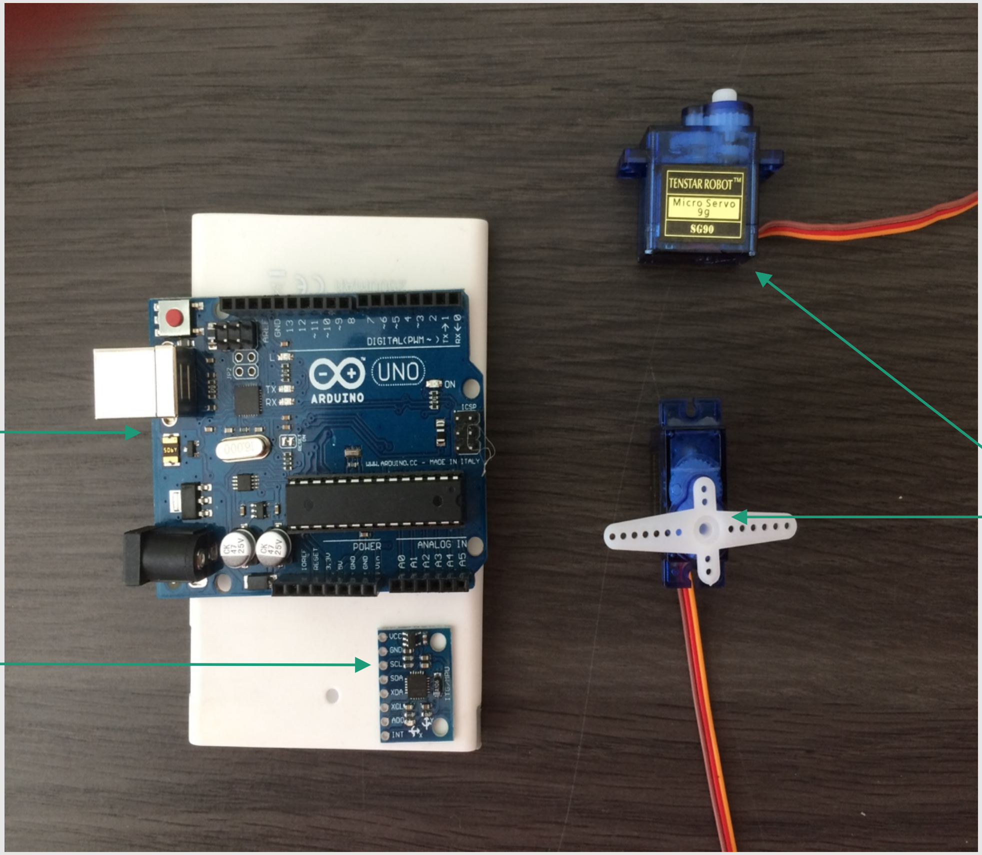
1. Atténuation du bruit
2. Amélioration en référentiel non galiléen

I. Présentation et modélisation

1. Le système d’étude

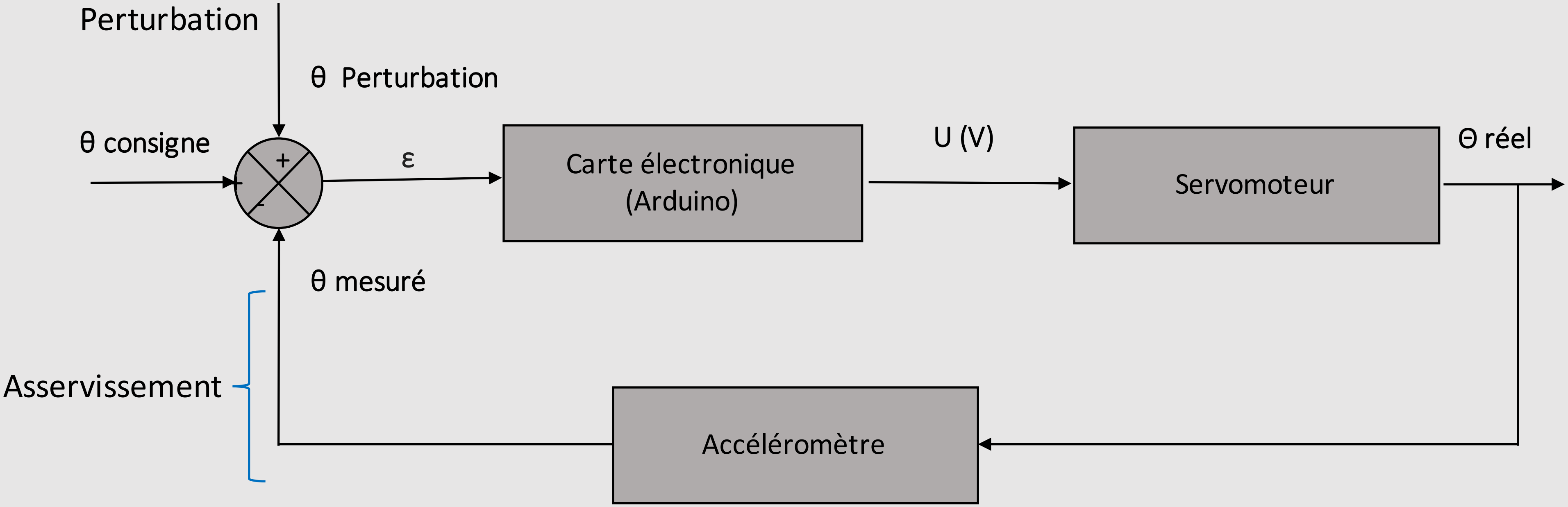

UNO
ARDUINO
TENSTAR ROBOT™
Micro Servo 9g
SG90

Carte Arduino Uno

Accéléromètre
MPU6050

Servomoteur SG90

2. Modélisation du stabilisateur



Perturbation

θ Perturbation

θ consigne

ε

Carte électronique (Arduino)

U (V)

Servomoteur

Θ réel

θ mesuré

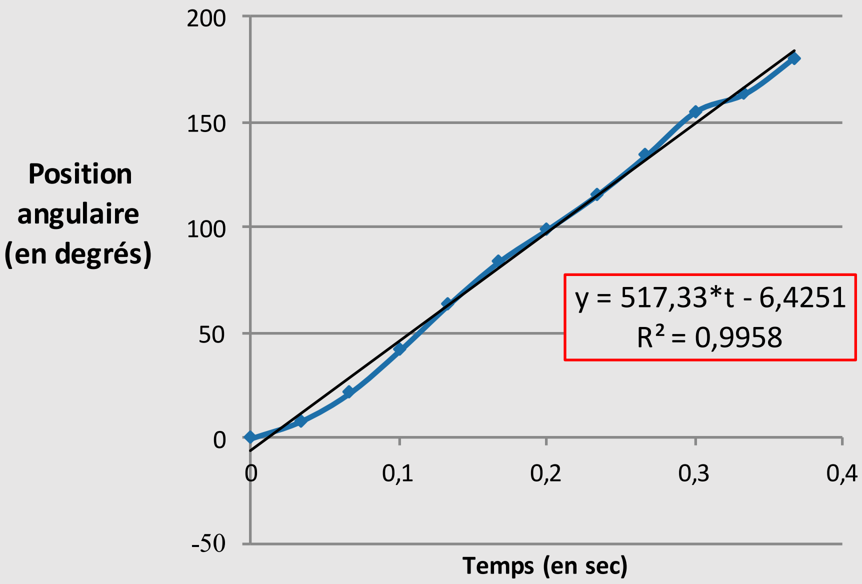
Asservissement

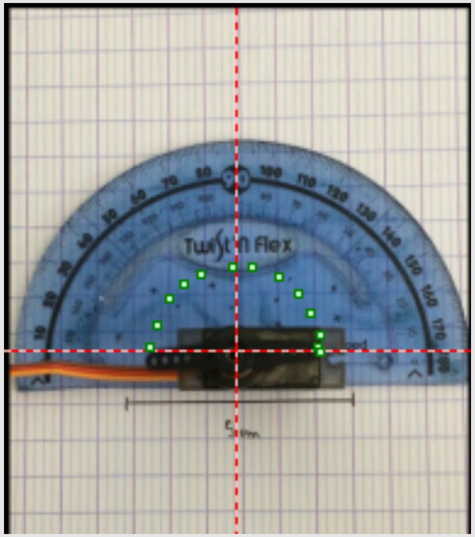
Accéléromètre

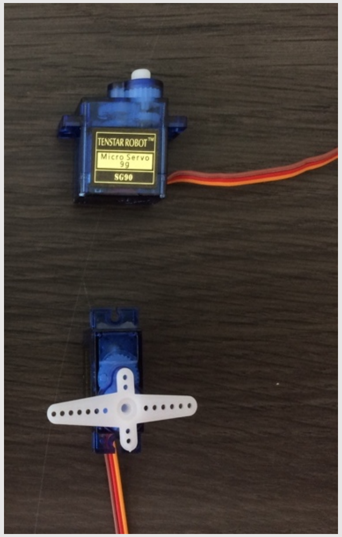
But: θ mesuré = θ perturbation → ε = θ consigne

3. Etude du servomoteur

Réponse du servomoteur à un échelon de 180 degrés




Twist'n Flex
5cm

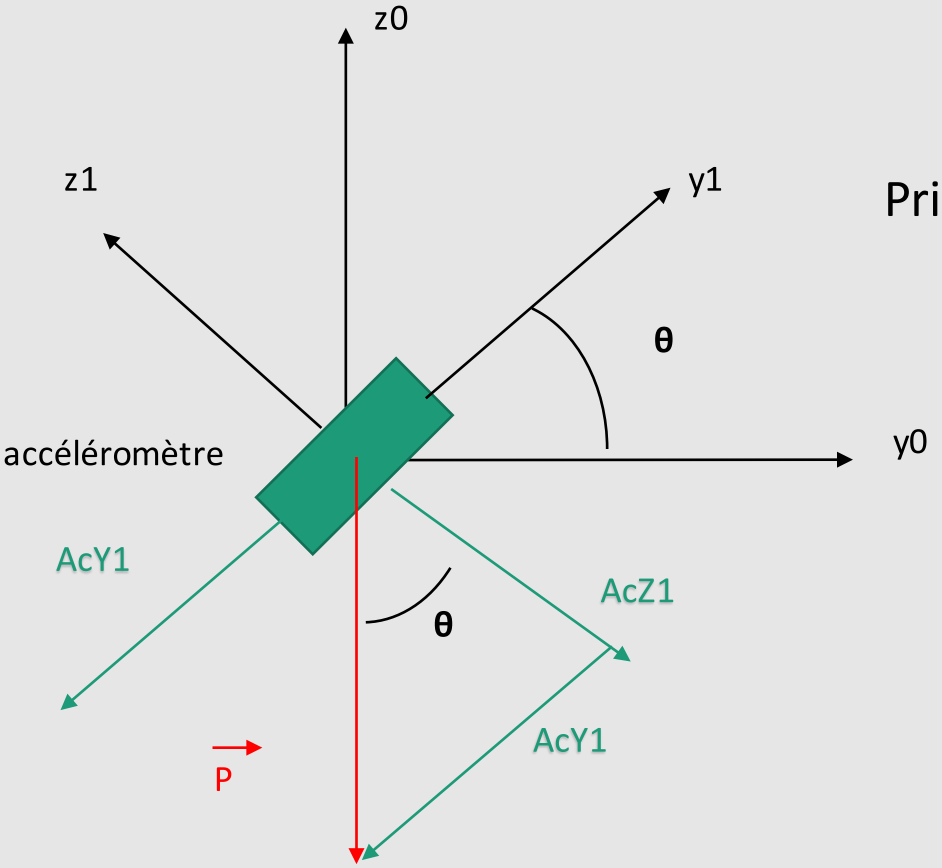

TENSTAR ROBOT
Micro Servo 9g
SG90

Temps de réponse à 5% =(0,33 ± 0,01) s

Vitesse de rotation moyenne = (8,8 ± 0,8) rad.s^{-1}

II. Stabilisation

1. Le référentiel galiléen


z0
z1
y1
θ
y0
accéléromètre
AcY1
AcZ1
θ
AcY1
$\vec{P}$

Principe fondamental de la dynamique :

$$\boxed{\theta = \tan^{-1}\frac{-AcY1}{AcZ1}}$$

2. Mise en œuvre algorithmique et analyse des données

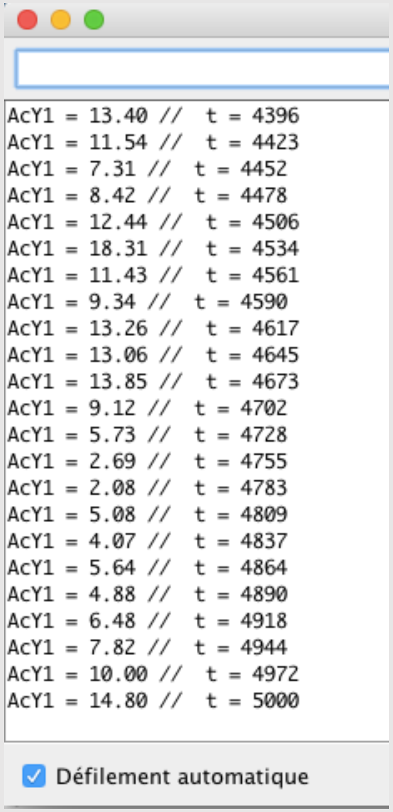
1
- Lien avec l'accéléromètre

2
- Lecture des accélérations
- Transformation en angle

3
- Demande de mouvement du servomoteur

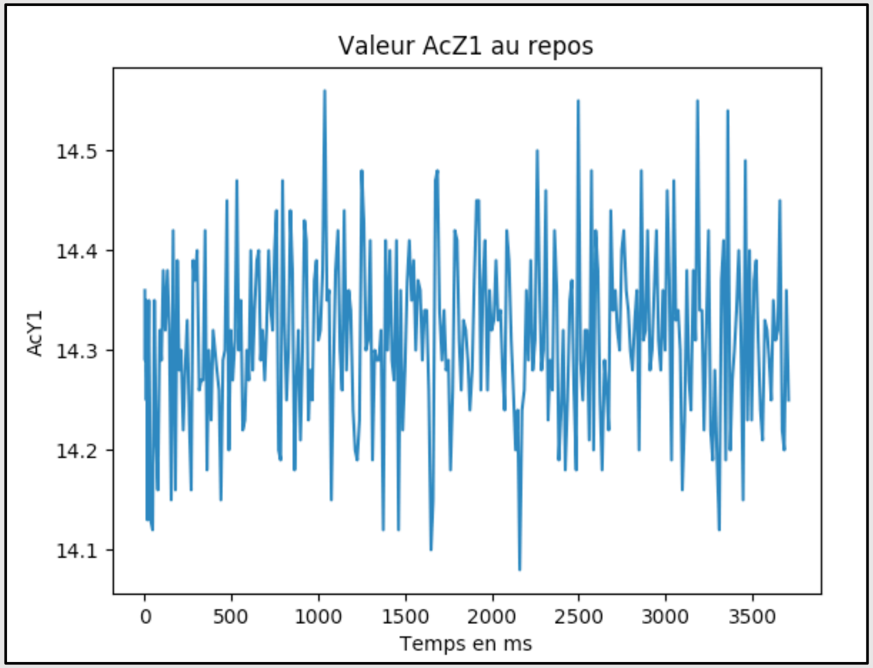
4
- Lien Arduino-Python

5
- Analyse des données



```
AcY1 = 13.40 //  t = 4396
AcY1 = 11.54 //  t = 4423
AcY1 = 7.31 //  t = 4452
AcY1 = 8.42 //  t = 4478
AcY1 = 12.44 //  t = 4506
AcY1 = 18.31 //  t = 4534
AcY1 = 11.43 //  t = 4561
AcY1 = 9.34 //  t = 4590
AcY1 = 13.26 //  t = 4617
AcY1 = 13.06 //  t = 4645
AcY1 = 13.85 //  t = 4673
AcY1 = 9.12 //  t = 4702
AcY1 = 5.73 //  t = 4728
AcY1 = 2.69 //  t = 4755
AcY1 = 2.08 //  t = 4783
AcY1 = 5.08 //  t = 4809
AcY1 = 4.07 //  t = 4837
AcY1 = 5.64 //  t = 4864
AcY1 = 4.88 //  t = 4890
AcY1 = 6.48 //  t = 4918
AcY1 = 7.82 //  t = 4944
AcY1 = 10.00 //  t = 4972
AcY1 = 14.80 //  t = 5000
```

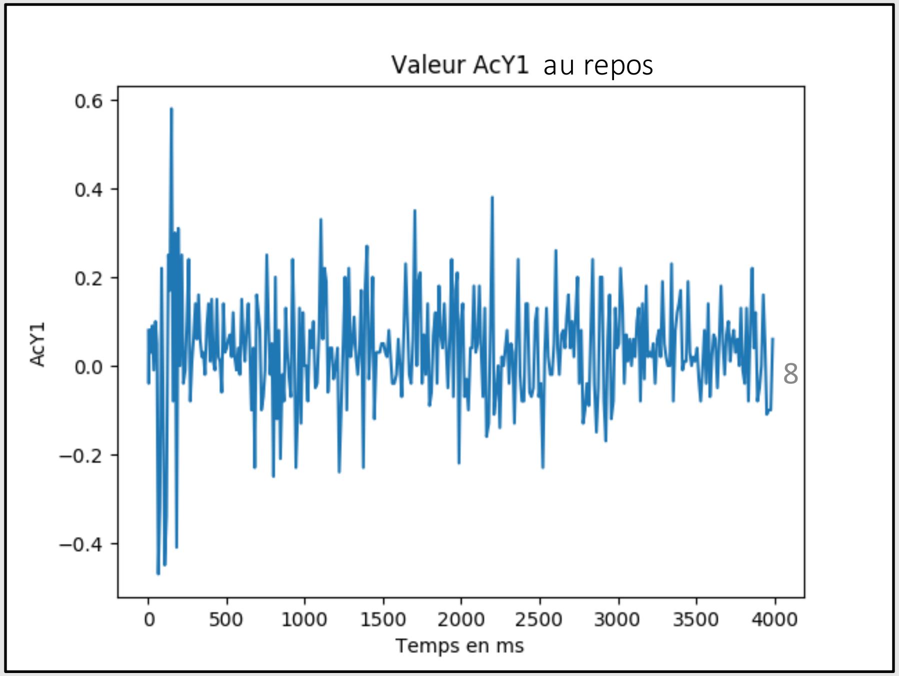
☑ Défilement automatique



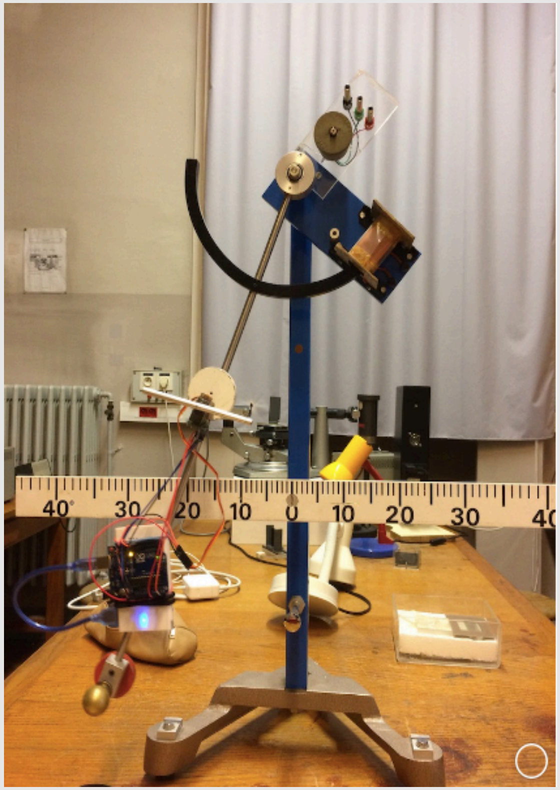
Accélération au repos

AcZ1 ≠ g au repos

Période d’échantillonnage: 10 ms

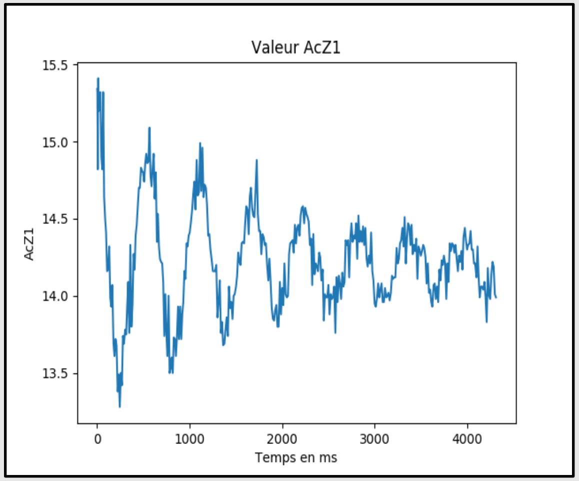


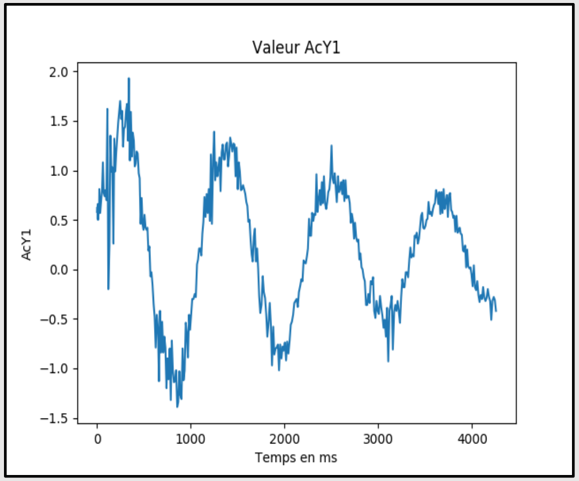
Bruit



Conditions initiales :

$$\begin{cases} \theta\ (t=0) = 24.5\ \pm 0.5\, deg \\ \dot{\theta}(t=0) = 0\ \mathrm{deg.}\, s^{-1} \\ l = 21\ cm \end{cases}$$





Analogie Période:

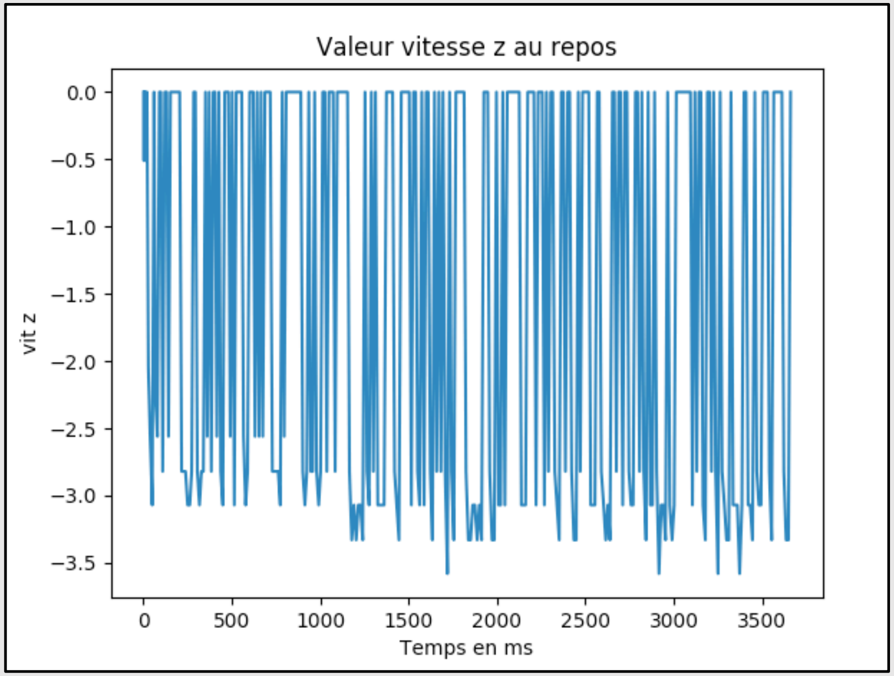
$$T_{exp} = 1200 \pm 50\ ms$$

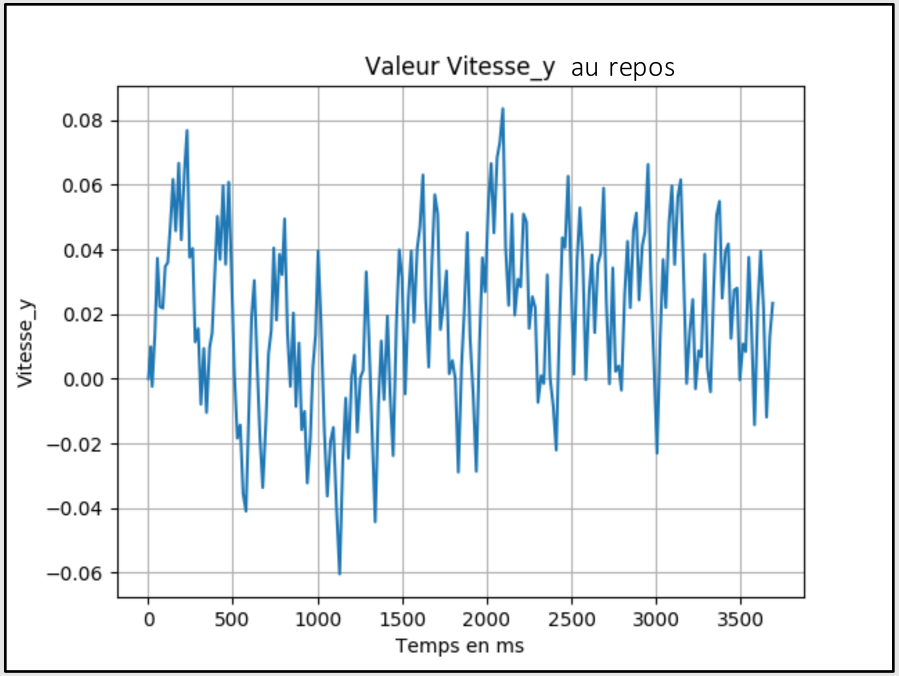
$$T_{\ theorique} = \frac{2\pi}{\omega_0} = 2\pi\sqrt{\frac{l}{g}} = 910\ ms$$

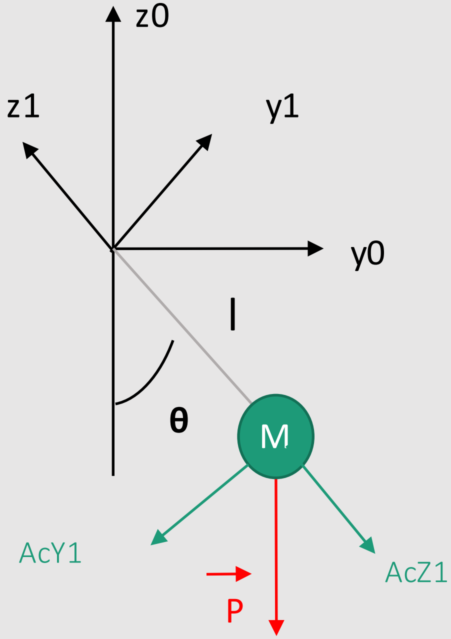
$$\frac{T_{\ théorique}}{T_{exp}} = 76\ \pm 2\ \ \%$$

Intégration par la méthode des rectangles:

$$vitesse(t) = \sum_{ti \in [t, t+\Delta t]} acc(ti) * \Delta t$$ avec Δt la durée d'acquisition $\sim 10\ ms$

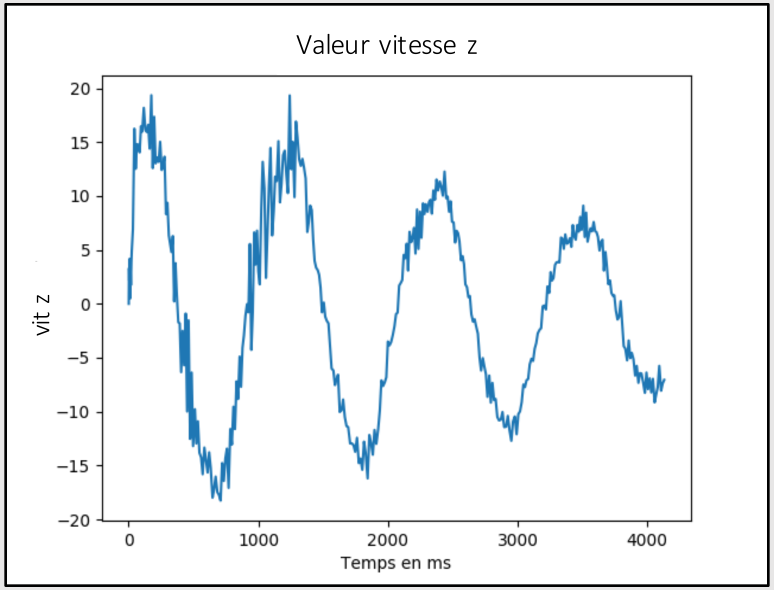


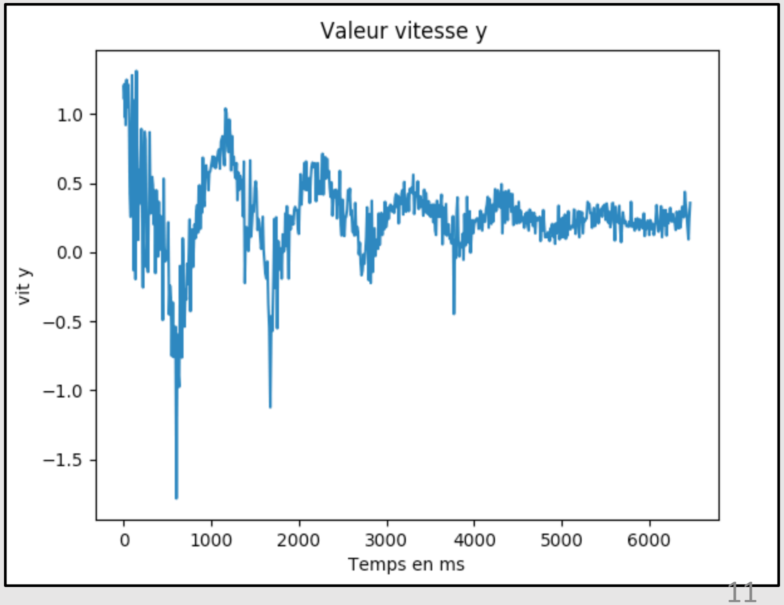



z0
z1
y1
y0
l
θ
M
AcY1
AcZ1
P

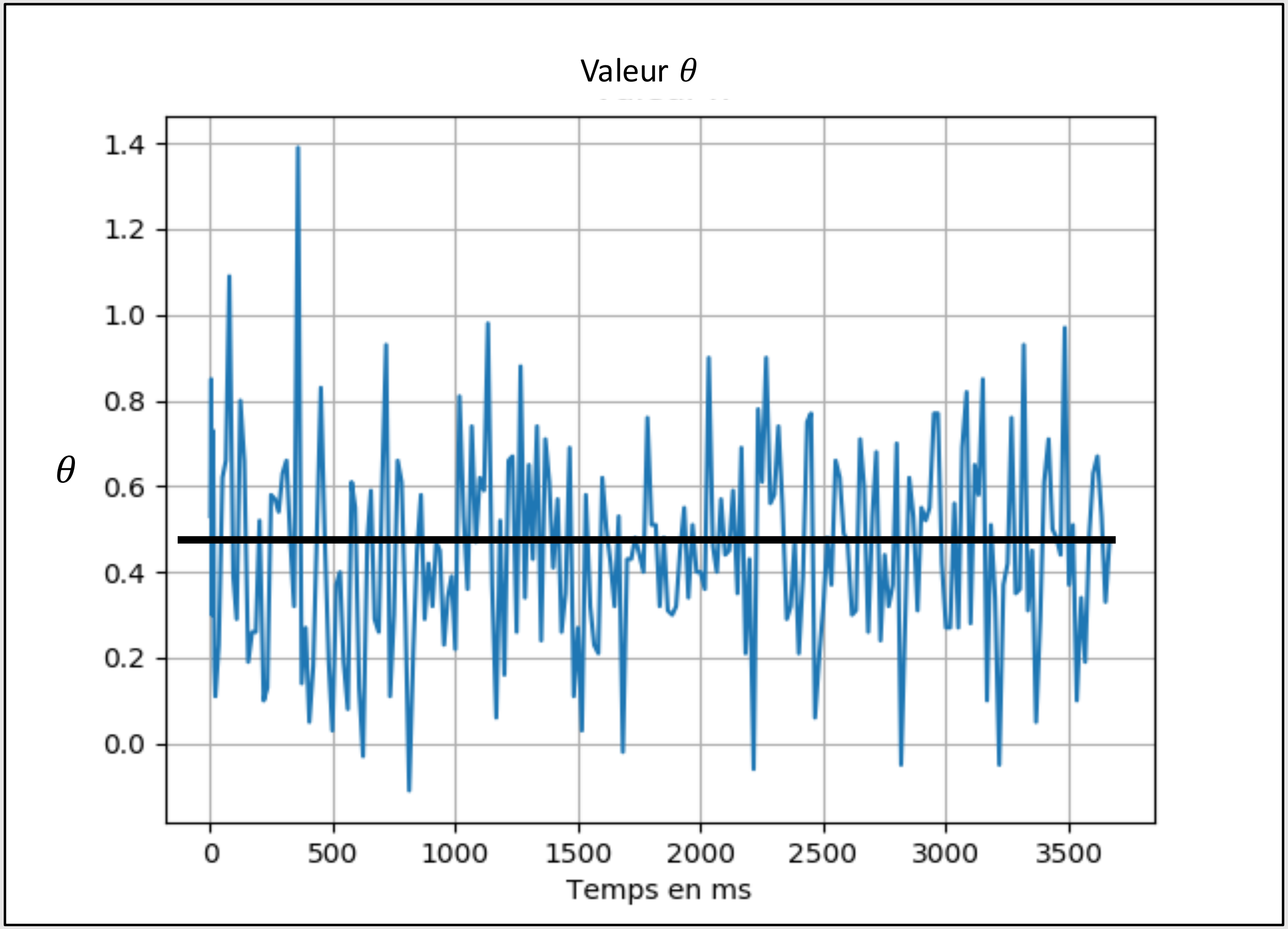
Conditions initiales :

$$\begin{cases} \theta\,(t=0) = 24.5 \pm 0.5\ deg \\ \dot{\theta}(t=0) = 0\ \text{deg}.\,s^{-1} \\ l = 21\ cm \end{cases}$$


Valeur vitesse z

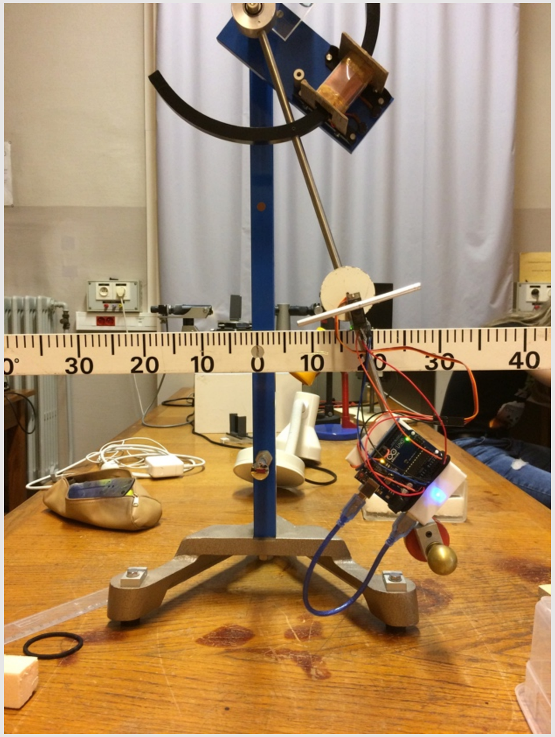

Valeur vitesse y

Angle au repos



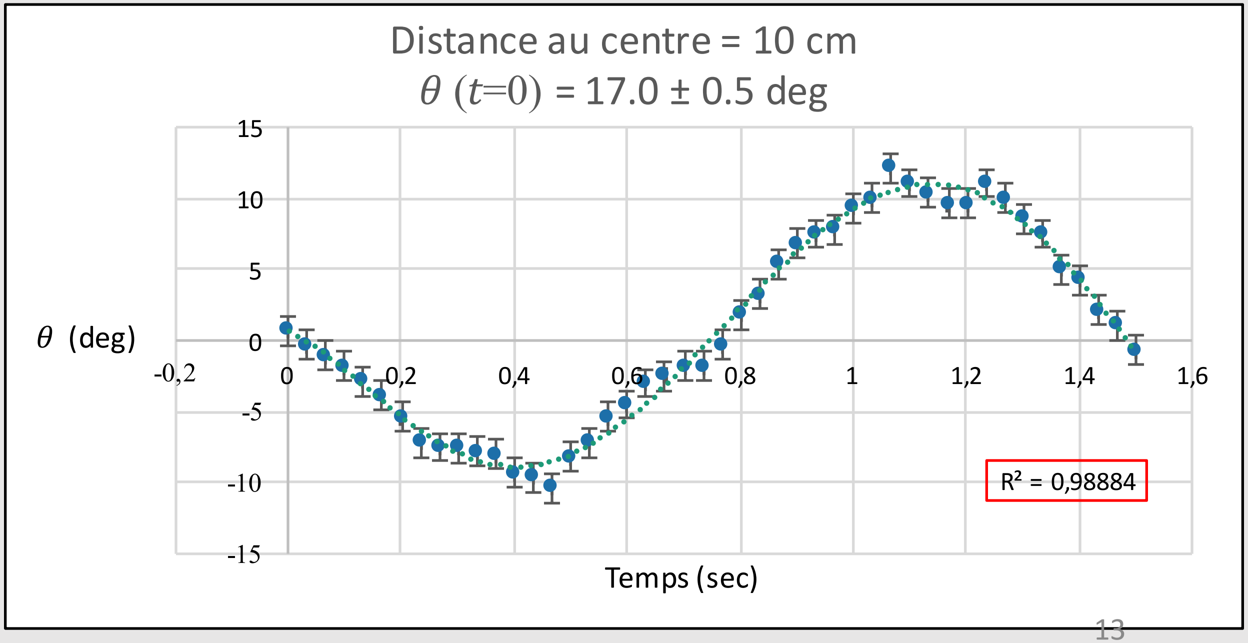
Valeur moyenne = 0.47 deg

3. Expérience et prévision en référentiel non galiléen



Conditions initiales :
$$\begin{cases} \theta\,(t=0) = 17.0 \pm 0.5\; deg \\ \dot{\theta}(t=0) = 0 \text{ deg}.\,s^{-1} \\ l = 10\; cm \end{cases}$$

θ < Perturbation = 17.0 ±0.5 deg



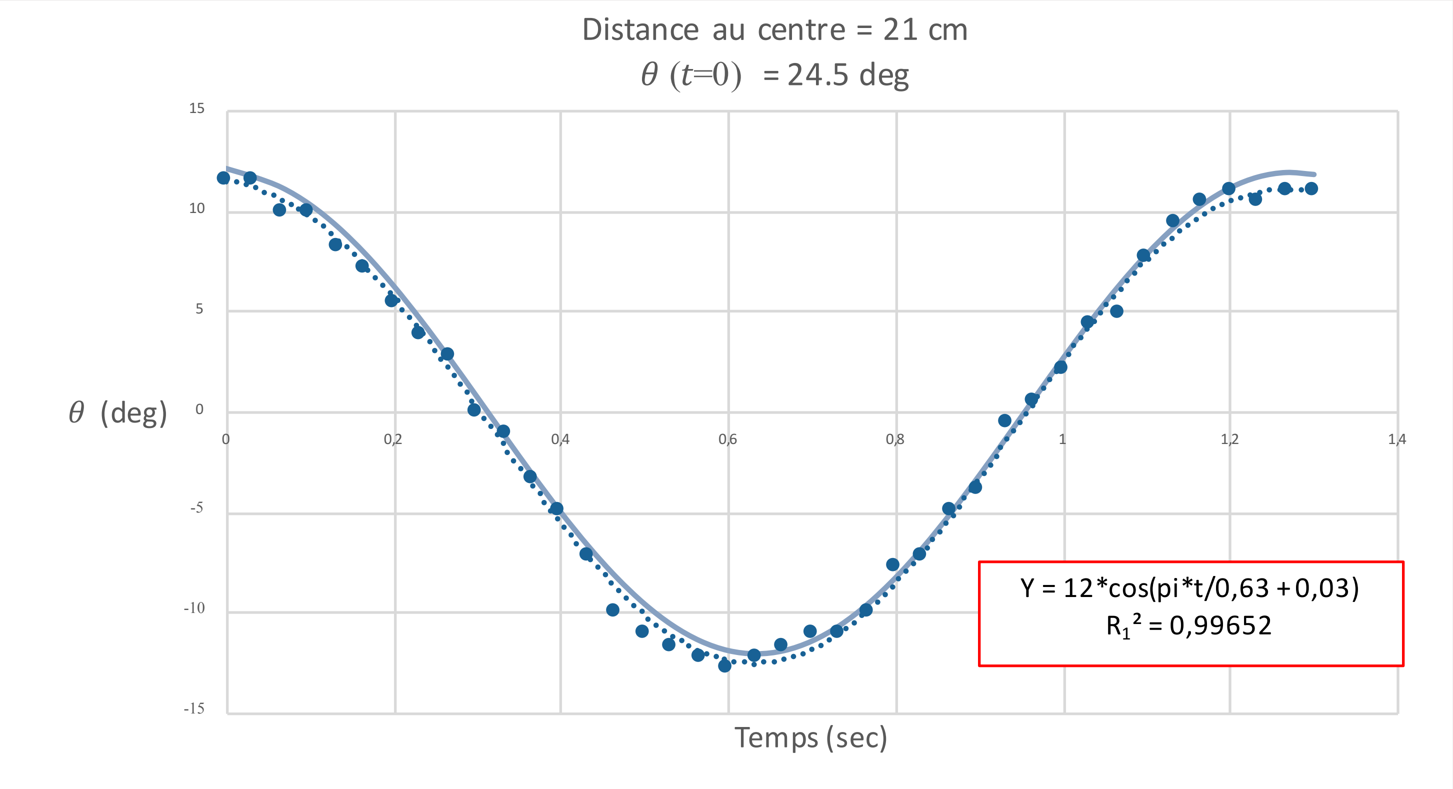
Distance au centre = 10 cm
$\theta\ (t{=}0)$ = 17.0 ± 0.5 deg

Autre pointage:

$$\begin{cases} \theta\ (t = 0) = 24.5 \pm 0.5\ deg \\ \dot{\theta}(t = 0) = 0\ \text{deg}.s^{-1} \\ l = 21\ cm \end{cases}$$

Mouvement sinusoïdal ⇒ Logique car perturbation de la forme $\theta(t) = \theta_0 \cos(\ \omega_0 t\ )$

⇒ Approximation des petits angles



Distance au centre = 21 cm

$\theta\ (t=0)$ = 24.5 deg

Y = 12*cos(pi*t/0,63 +0,03)

$R_1{}^2$ = 0,99652

Accélération considérée en référentiel non galiléen

$$-Ay = g\sin(\theta) - l\ddot{\theta}$$

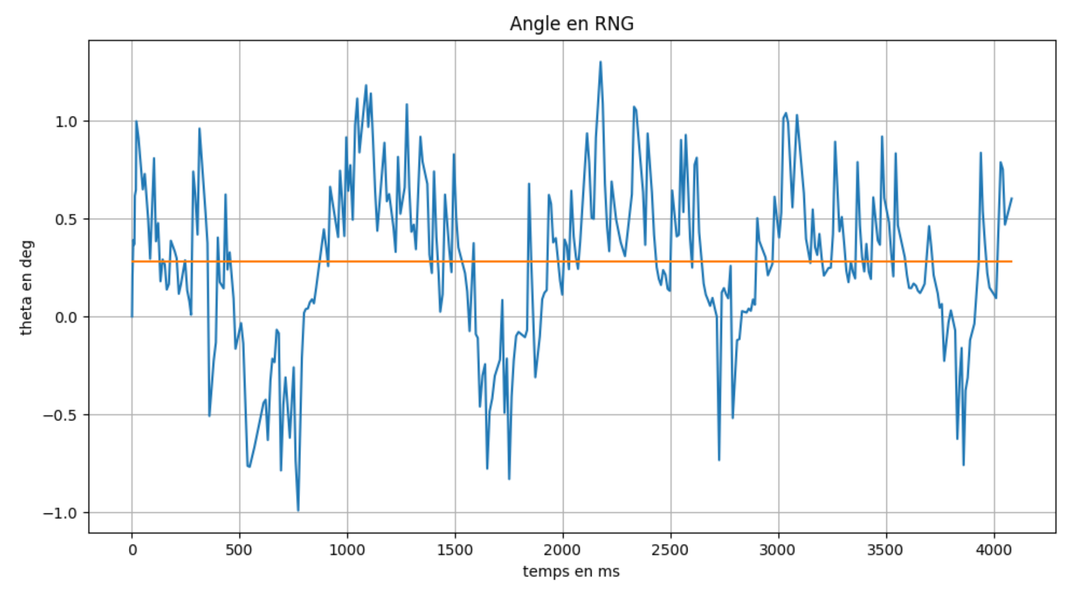
$$Az = g\cos(\theta) + l\dot{\theta}^2$$

$$\text{avec } \theta\ (t) = 12\cos(\frac{\pi}{0.63}t + 0.03)$$

$$\theta_{\text{ mesurée}} = \tan^{-1} \frac{-Ay + l\ddot{\theta}}{Az - l\dot{\theta}^2}$$

Amplitude beaucoup plus faible

Besoin de correction du bruit



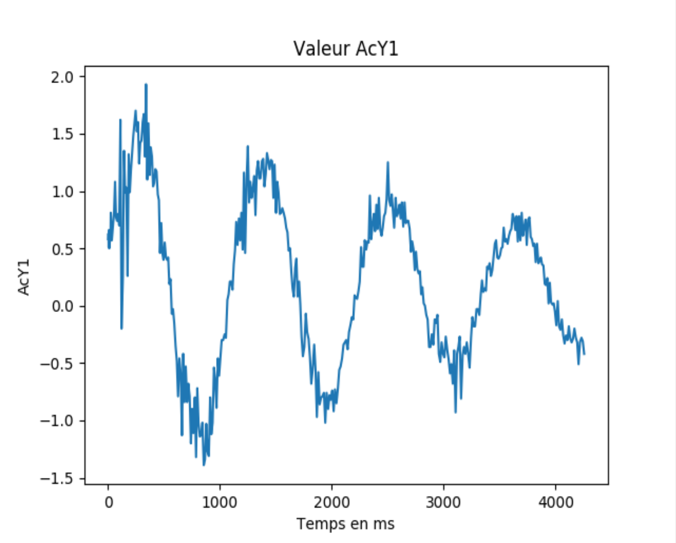
III. Améliorations

1. Considération du bruit

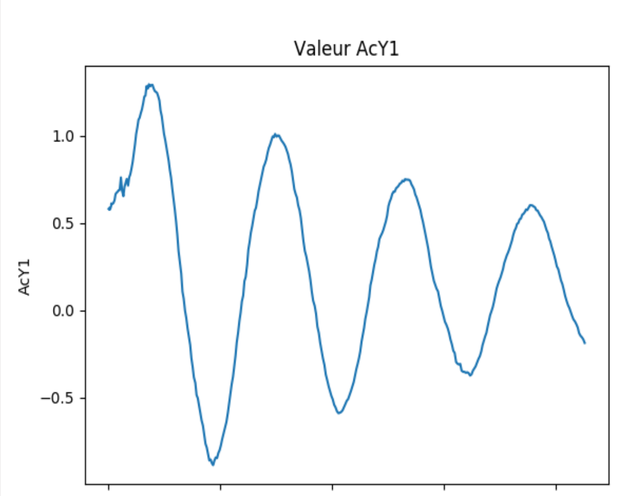
Equation filtre passe-bas: $\frac{ds}{dt} + \omega_0{}^2\, s = \omega_0{}^2\, e$

$$\Leftrightarrow \boxed{\frac{s[n] - s[n-1]}{dt} + \omega_0{}^2\, s[n] = e[n]\omega_0{}^2}$$

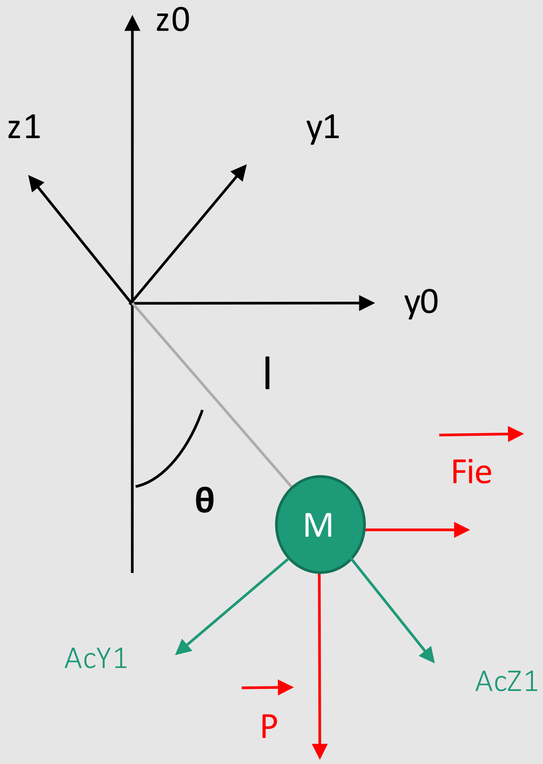
$\omega_0 = 2\pi f_{coup}$ avec $f_{coup} \sim 2Hz$: la fréquence de la marche de l'homme



Filtre P-B



2. Amélioration en référentiel non galiléen



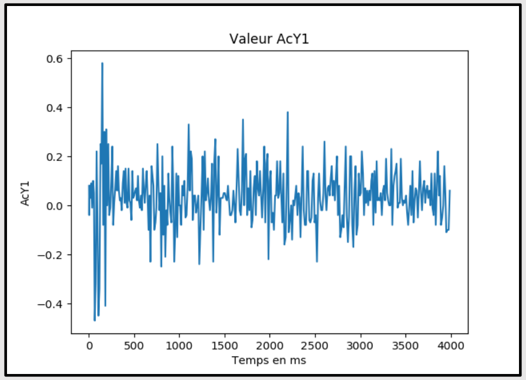
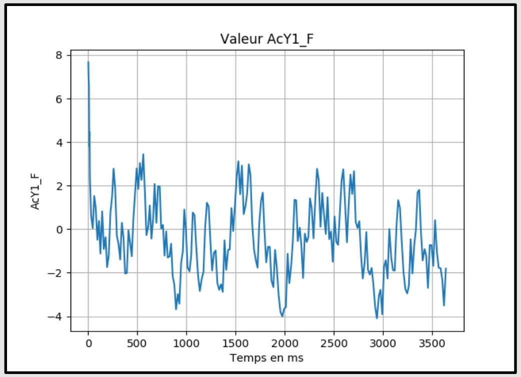
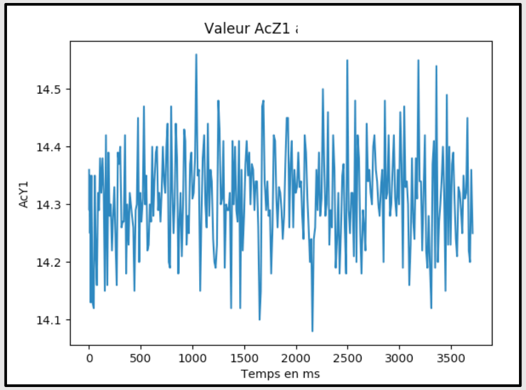
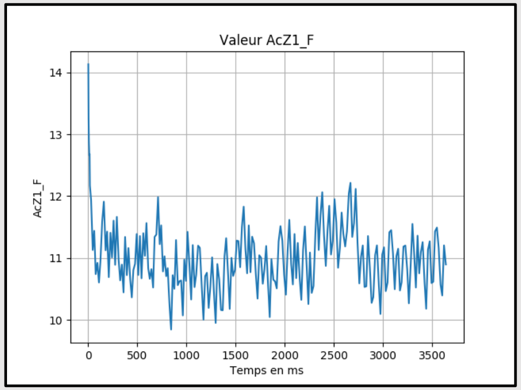
Accéléromètre en rotation sur le pendule

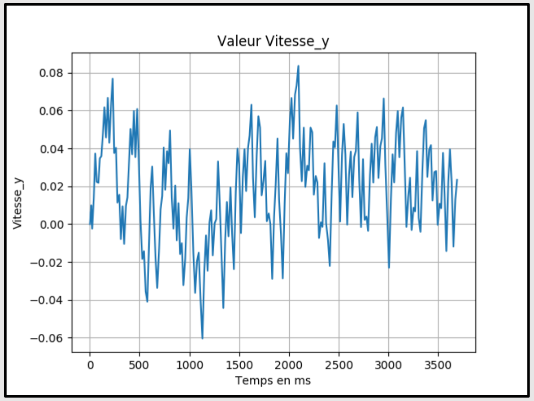
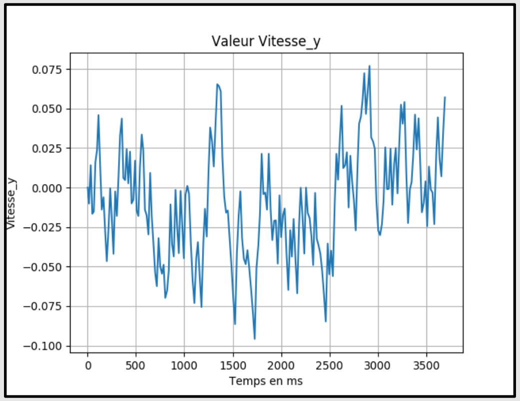
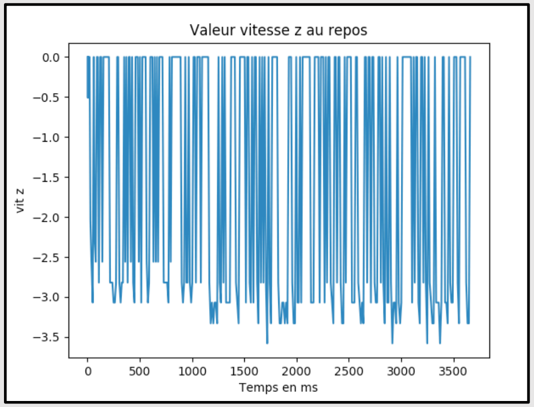
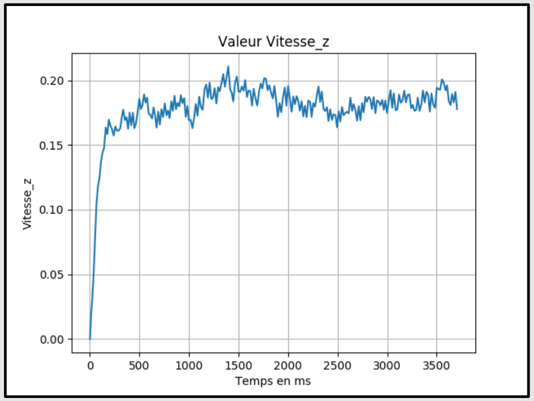
Principe fondamental de la dynamique sur M:

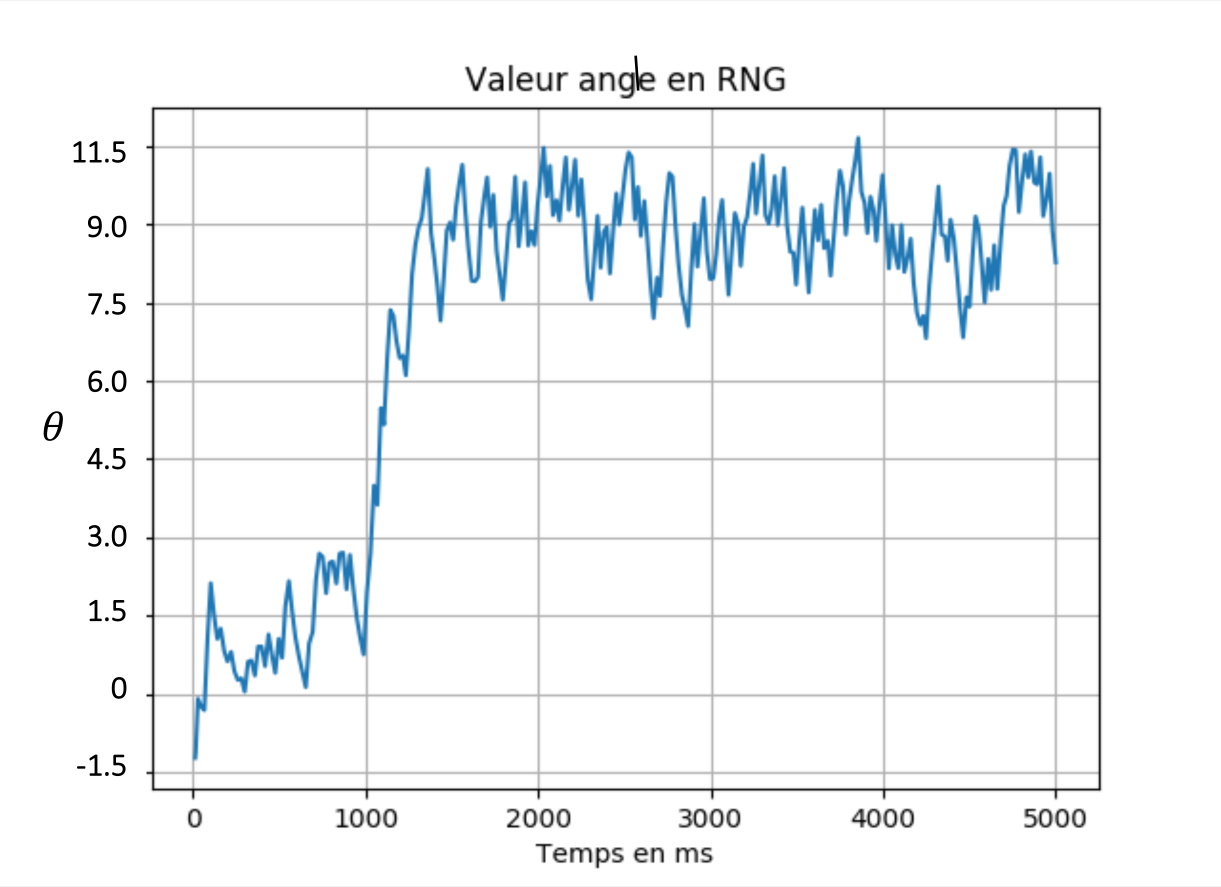
$$\boxed{\theta = \tanh^{-1} \frac{AcY1 + l\,\omega_0\,\theta_0 \sin(\omega_0 t)}{AcZ1 - l\,\omega_0^2\,\theta_0 \cos(\omega_0 t)}}$$

Avec $\theta(t) = \theta_0 \cos(\omega_0 t)$

Conditions initiales : $\begin{cases} \theta\ (t=0) = 24.5 \pm 0.5\ deg \\ l = 21.0 \pm 0.1 cm \end{cases}$

	Accélération en référentiel galiléen	Accélération en référentiel non-galiléen
Accélération selon Y1 ➡ Belle correction		
Accélération selon Z1 ➡ Plus proche de g		

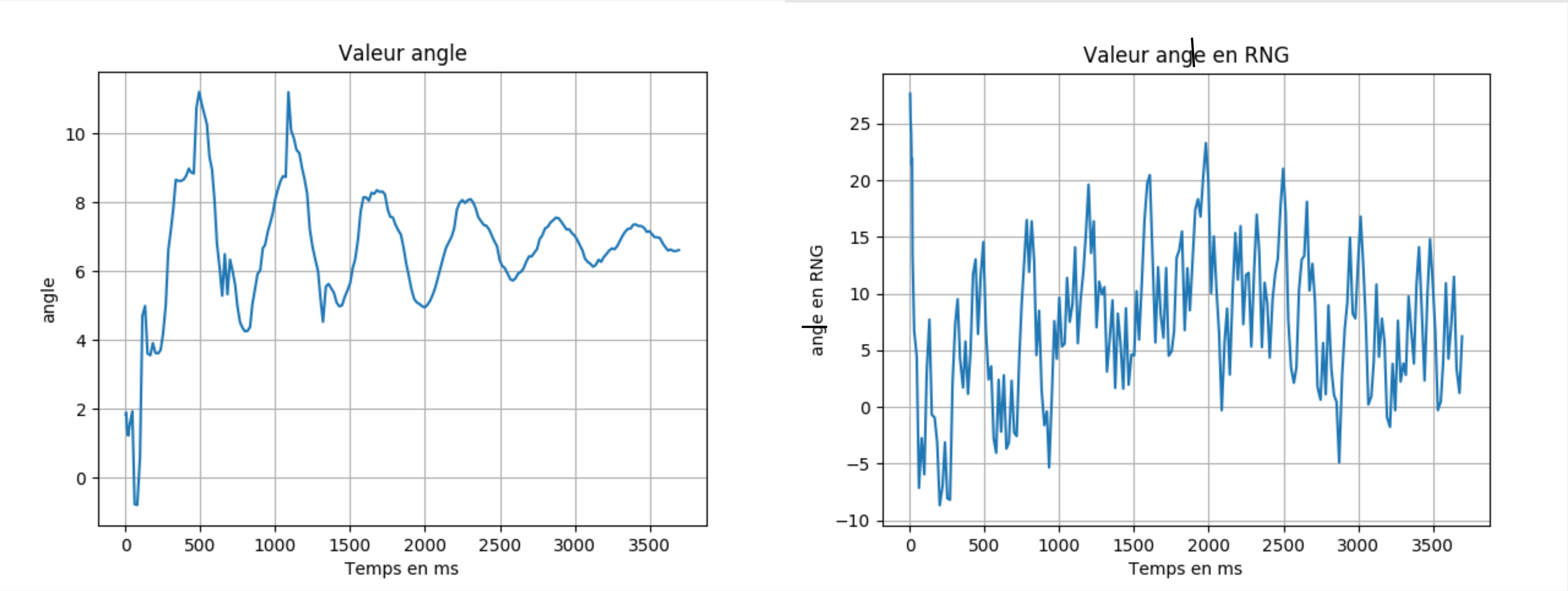
	Vitesse en référentiel galiléen	Vitesse en référentiel non galiléen
Vitesse selon Y1	 	
Vitesse selon Z1	 	



Stable au début
A t = 1000 ms : le système diverge

Désynchronisation à partir d'une seconde
Instabilité du système ➡ approximation des petits angles fausse

➡ En remplaçant l$\dot{\theta}^2$ par $\dfrac{(Vitesse\ z)^2}{l}$



Système en RNG instable

Conclusion

- Référentiel non galiléen → système plus instable

- Améliorations possibles:

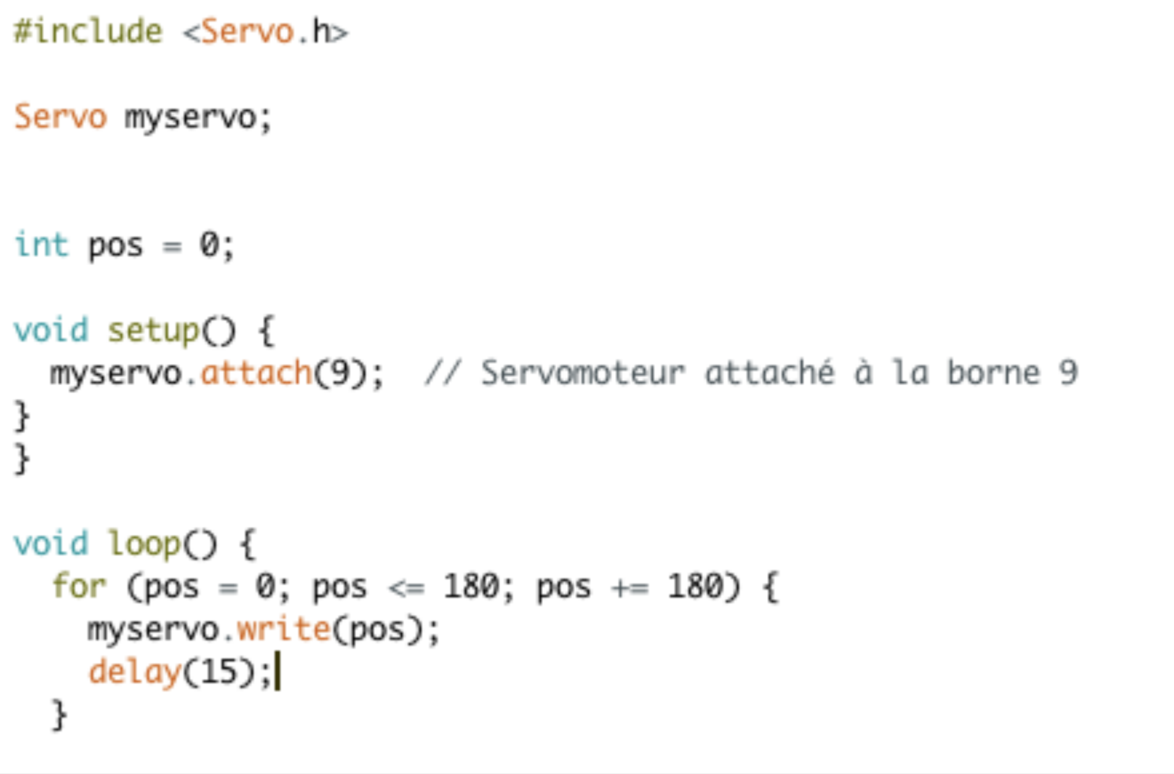
  - Se placer en étude quasi-statique

  - Augmenter la bande passante de stabilité en rajoutant un gyromètre pour la stabilité en HF et BF

Annexe

- Programmes sur Arduino

Réponse du moteur à un échelon de 180 degrés



```
#include <Servo.h>

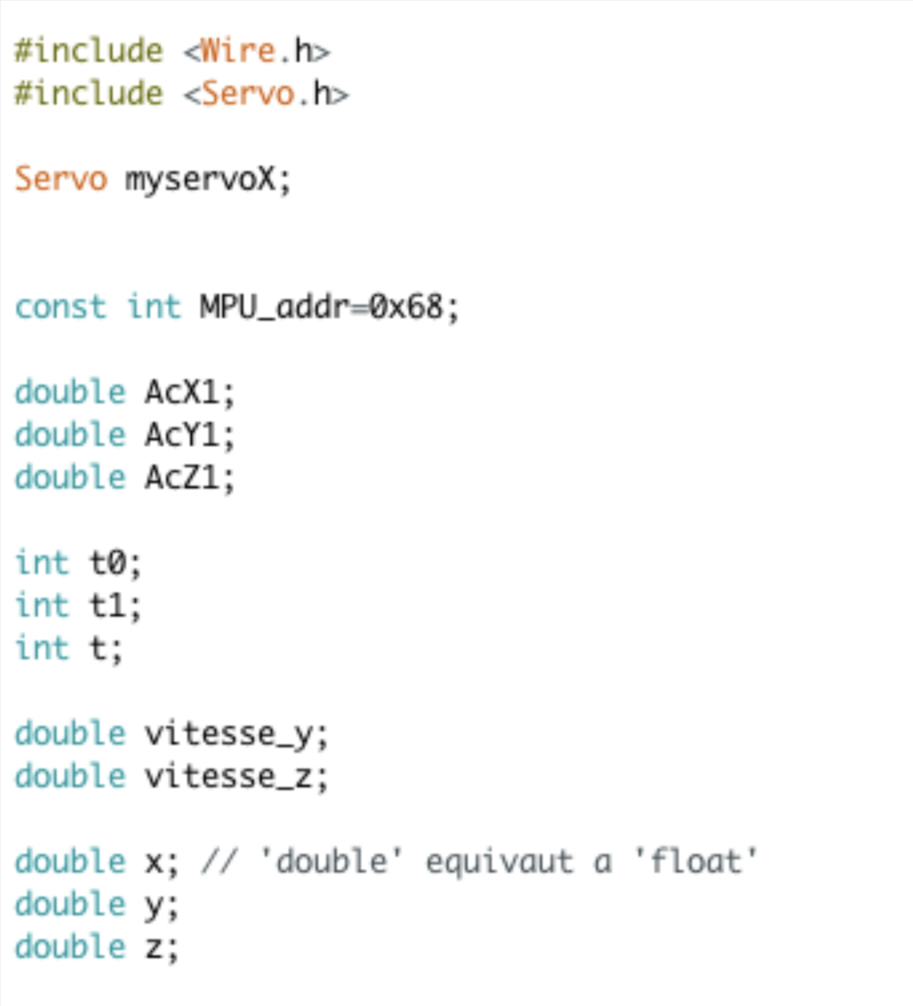
Servo myservo;


int pos = 0;

void setup() {
  myservo.attach(9);  // Servomoteur attaché à la borne 9
}
}

void loop() {
  for (pos = 0; pos <= 180; pos += 180) {
    myservo.write(pos);
    delay(15);
  }
```

- Programmes sur Arduino



```
#include <Wire.h>
#include <Servo.h>

Servo myservoX;


const int MPU_addr=0x68;

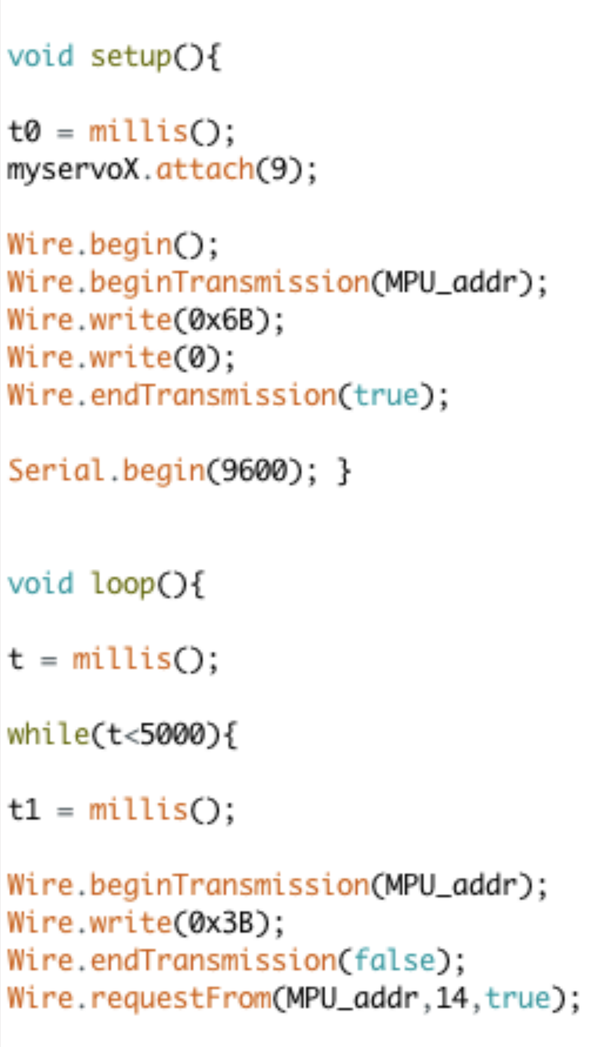
double AcX1;
double AcY1;
double AcZ1;

int t0;
int t1;
int t;

double vitesse_y;
double vitesse_z;

double x; // 'double' equivaut a 'float'
double y;
double z;
```

- Programmes sur Arduino



```
void setup(){

t0 = millis();
myservoX.attach(9);

Wire.begin();
Wire.beginTransmission(MPU_addr);
Wire.write(0x6B);
Wire.write(0);
Wire.endTransmission(true);

Serial.begin(9600); }


void loop(){

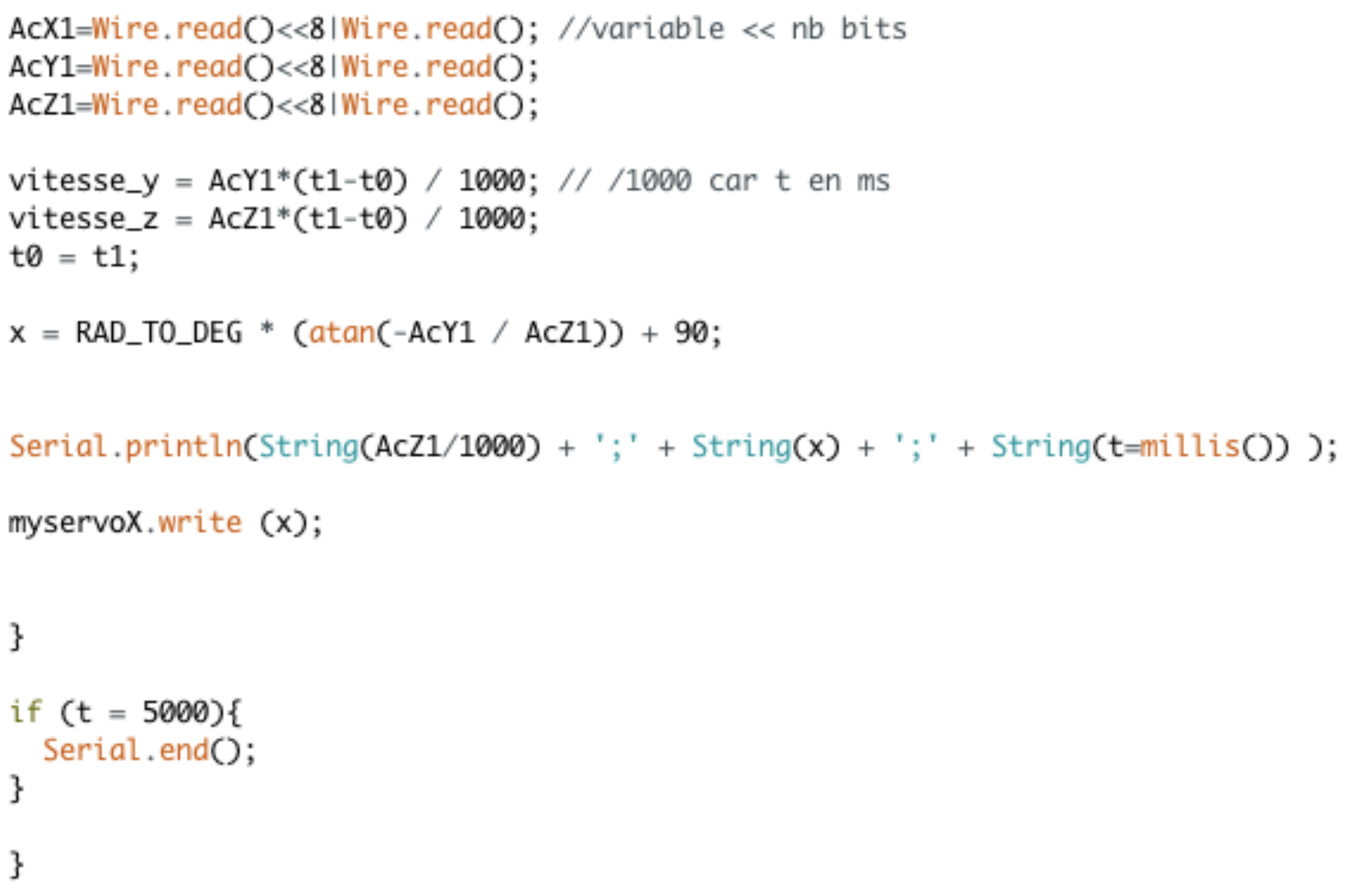
t = millis();

while(t<5000){

t1 = millis();

Wire.beginTransmission(MPU_addr);
Wire.write(0x3B);
Wire.endTransmission(false);
Wire.requestFrom(MPU_addr,14,true);
```

- Programmes sur Arduino



```
AcX1=Wire.read()<<8|Wire.read(); //variable << nb bits
AcY1=Wire.read()<<8|Wire.read();
AcZ1=Wire.read()<<8|Wire.read();

vitesse_y = AcY1*(t1-t0) / 1000; // /1000 car t en ms
vitesse_z = AcZ1*(t1-t0) / 1000;
t0 = t1;

x = RAD_TO_DEG * (atan(-AcY1 / AcZ1)) + 90;


Serial.println(String(AcZ1/1000) + ';' + String(x) + ';' + String(t=millis()) );

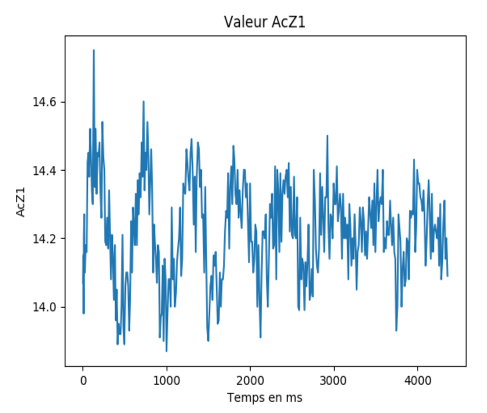
myservoX.write (x);

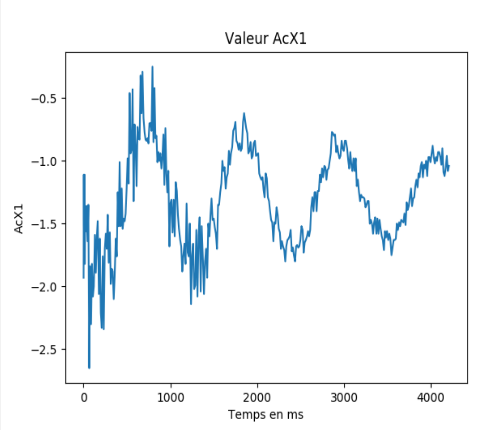

}

if (t = 5000){
  Serial.end();
}

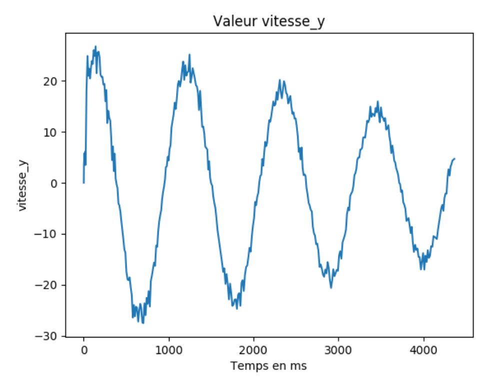
}
```

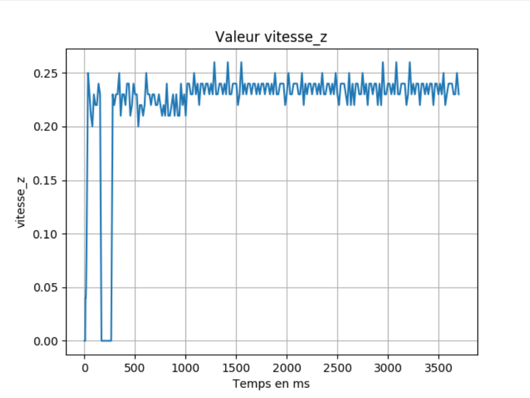
- Autres études





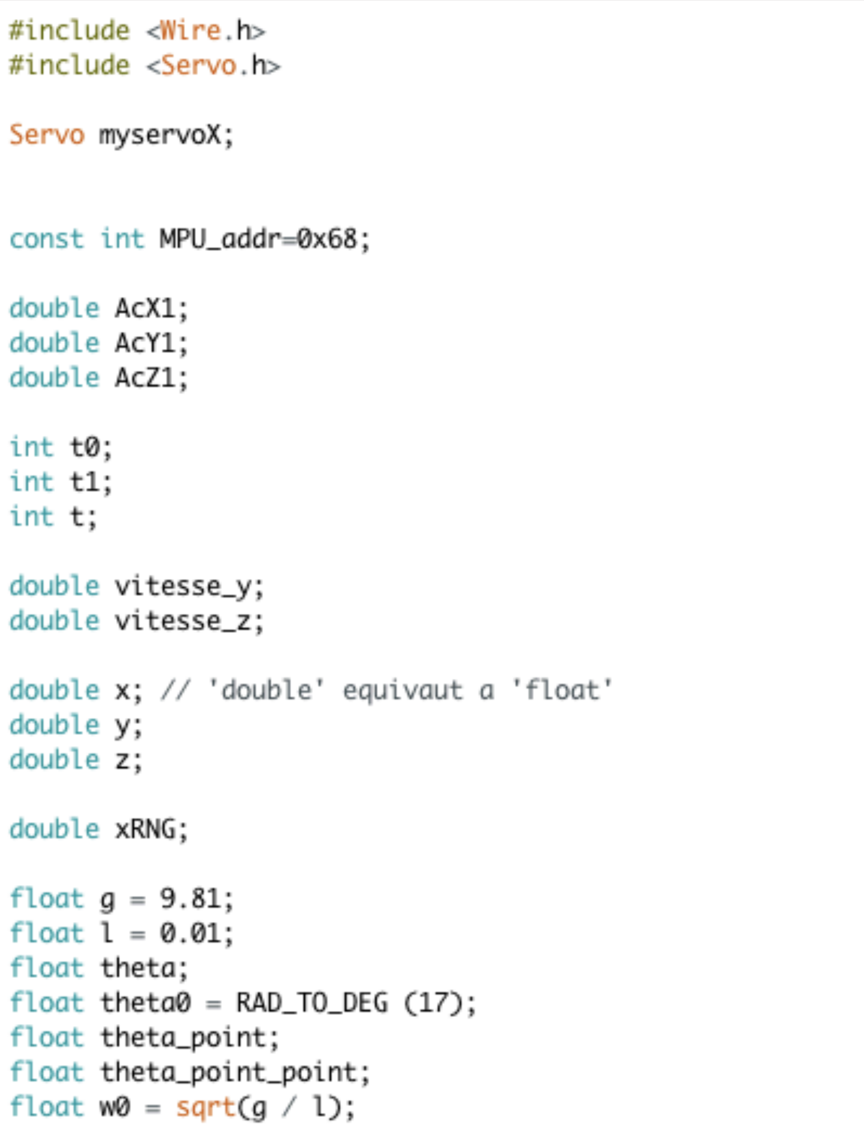
$$\begin{cases} \theta\ (t=0) = 17.0 \pm 0.5\, deg \\ \dot{\theta}(t=0) = 0\ \mathrm{deg}.s^{-1} \\ l = 10\ cm \end{cases}$$





$$\begin{cases} \theta\ (t=0) = 17.0 \pm 0.5\, deg \\ \dot{\theta}(t=0) = 0\ \mathrm{deg}.s^{-1} \\ l = 10\ cm \end{cases}$$

- Programmes sur Arduino



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Servo myservoX;


const int MPU_addr=0x68;

double AcX1;
double AcY1;
double AcZ1;

int t0;
int t1;
int t;

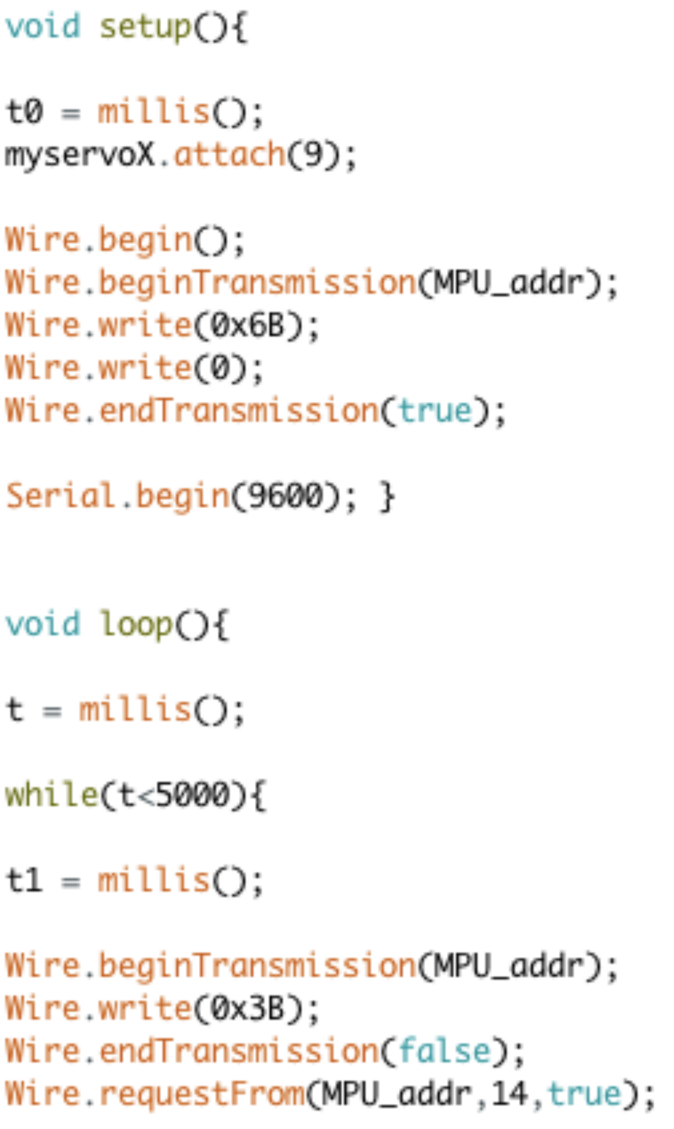
double vitesse_y;
double vitesse_z;

double x; // 'double' equivaut a 'float'
double y;
double z;

double xRNG;

float g = 9.81;
float l = 0.01;
float theta;
float theta0 = RAD_TO_DEG (17);
float theta_point;
float theta_point_point;
float w0 = sqrt(g / l);
```

- Programmes sur Arduino



```
void setup(){

t0 = millis();
myservoX.attach(9);

Wire.begin();
Wire.beginTransmission(MPU_addr);
Wire.write(0x6B);
Wire.write(0);
Wire.endTransmission(true);

Serial.begin(9600); }


void loop(){

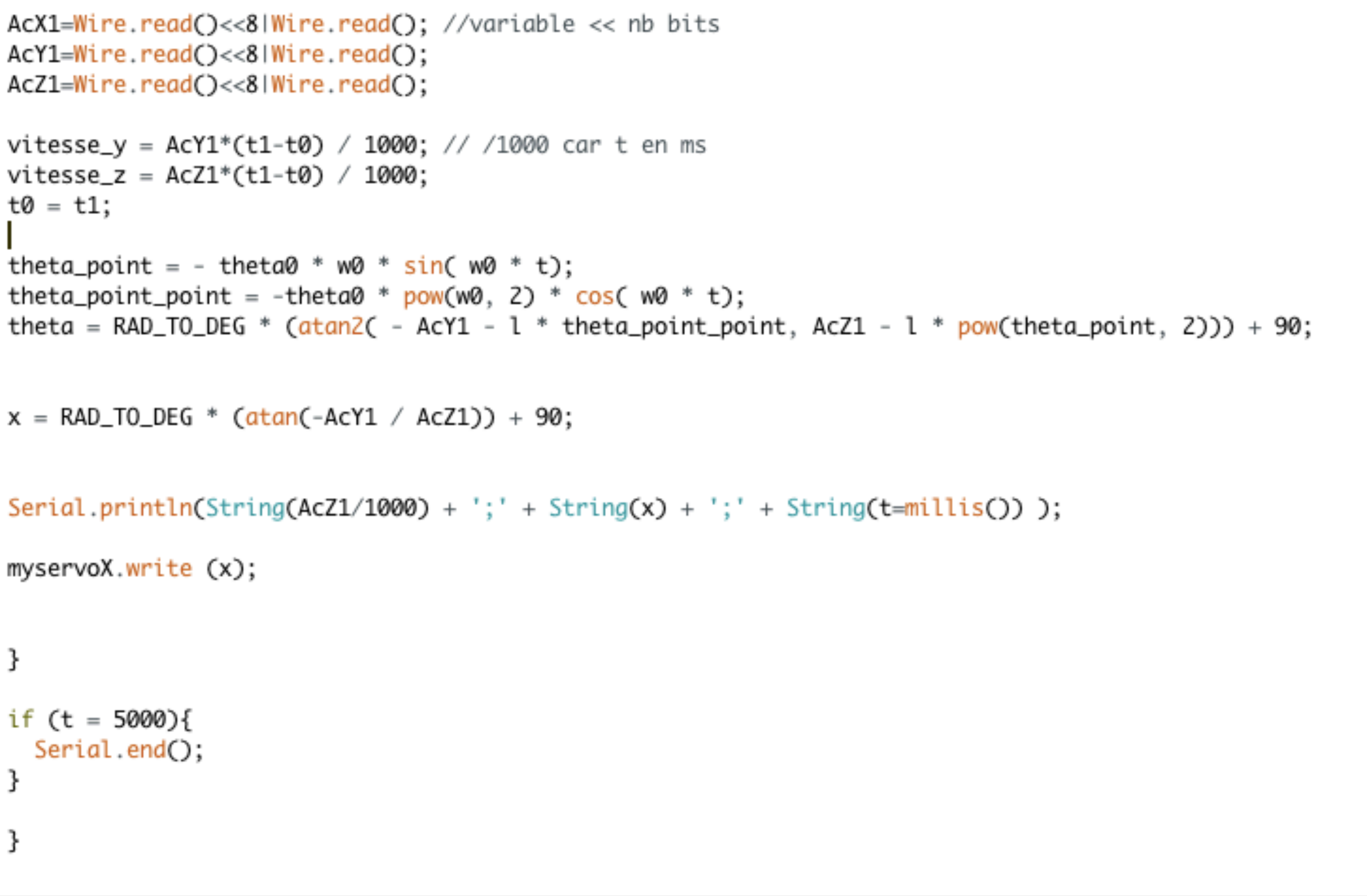
t = millis();

while(t<5000){

t1 = millis();

Wire.beginTransmission(MPU_addr);
Wire.write(0x3B);
Wire.endTransmission(false);
Wire.requestFrom(MPU_addr,14,true);
```

- Programmes sur Python



```
AcX1=Wire.read()<<8|Wire.read(); //variable << nb bits
AcY1=Wire.read()<<8|Wire.read();
AcZ1=Wire.read()<<8|Wire.read();

vitesse_y = AcY1*(t1-t0) / 1000; // /1000 car t en ms
vitesse_z = AcZ1*(t1-t0) / 1000;
t0 = t1;

theta_point = - theta0 * w0 * sin( w0 * t);
theta_point_point = -theta0 * pow(w0, 2) * cos( w0 * t);
theta = RAD_TO_DEG * (atan2( - AcY1 - l * theta_point_point, AcZ1 - l * pow(theta_point, 2))) + 90;


x = RAD_TO_DEG * (atan(-AcY1 / AcZ1)) + 90;


Serial.println(String(AcZ1/1000) + ';' + String(x) + ';' + String(t=millis()) );

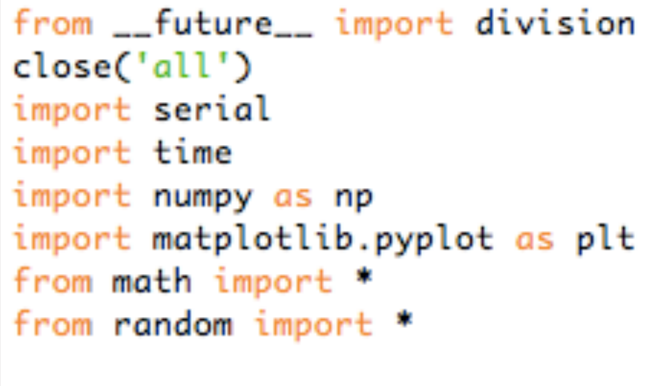
myservoX.write (x);


}

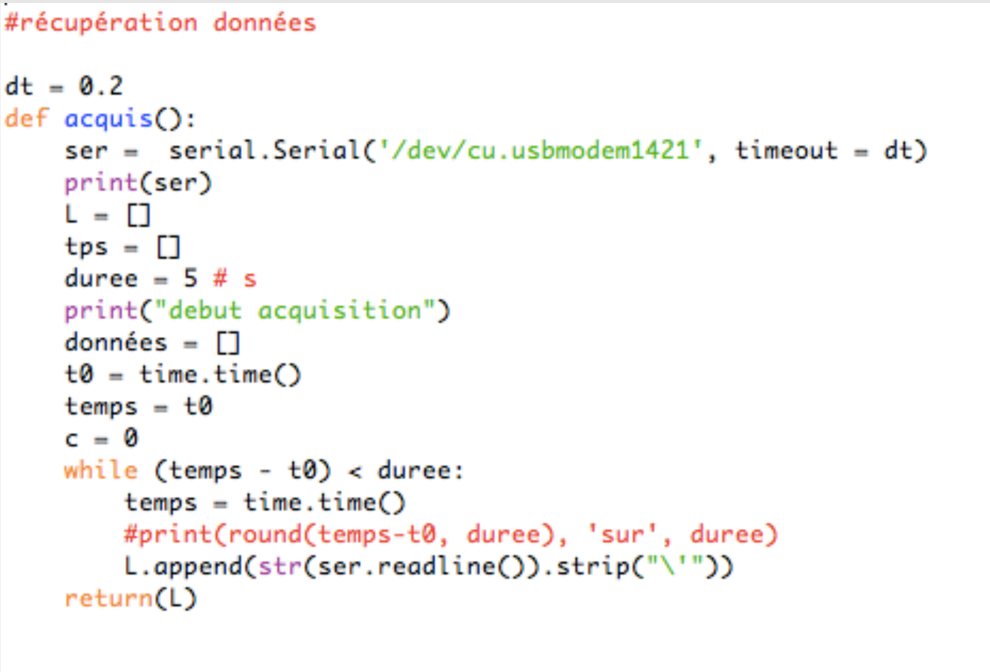
if (t = 5000){
  Serial.end();
}

}
```

- Programmes sur Python



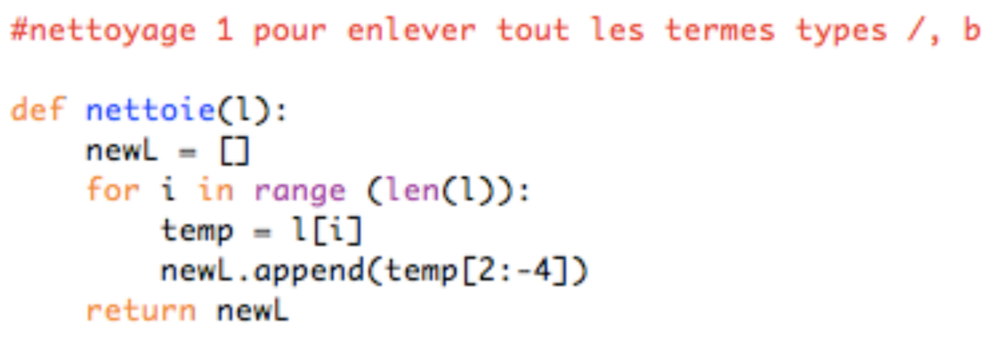
```
from __future__ import division
close('all')
import serial
import time
import numpy as np
import matplotlib.pyplot as plt
from math import *
from random import *
```



```
#récupération données

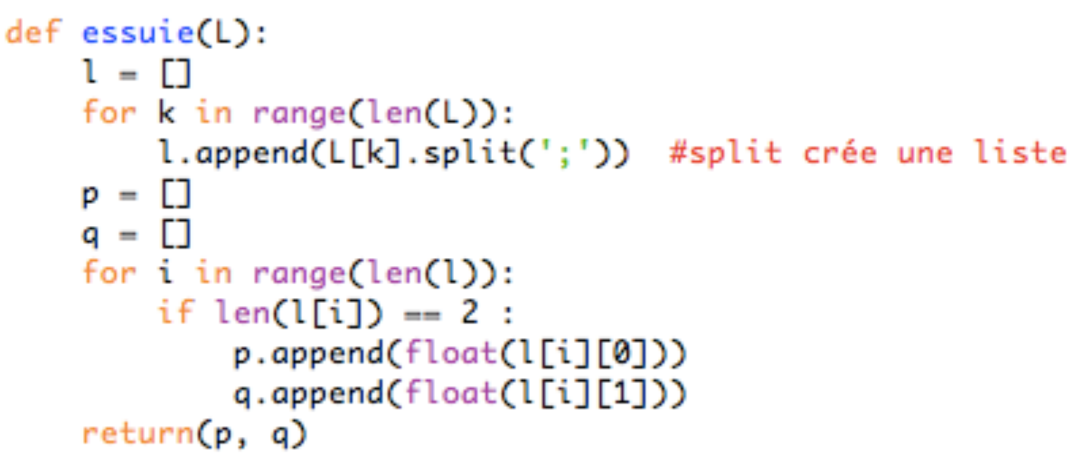
dt = 0.2
def acquis():
    ser =  serial.Serial('/dev/cu.usbmodem1421', timeout = dt)
    print(ser)
    L = []
    tps = []
    duree = 5 # s
    print("debut acquisition")
    données = []
    t0 = time.time()
    temps = t0
    c = 0
    while (temps - t0) < duree:
        temps = time.time()
        #print(round(temps-t0, duree), 'sur', duree)
        L.append(str(ser.readline()).strip("\'"))
    return(L)
```

- Programmes sur Python



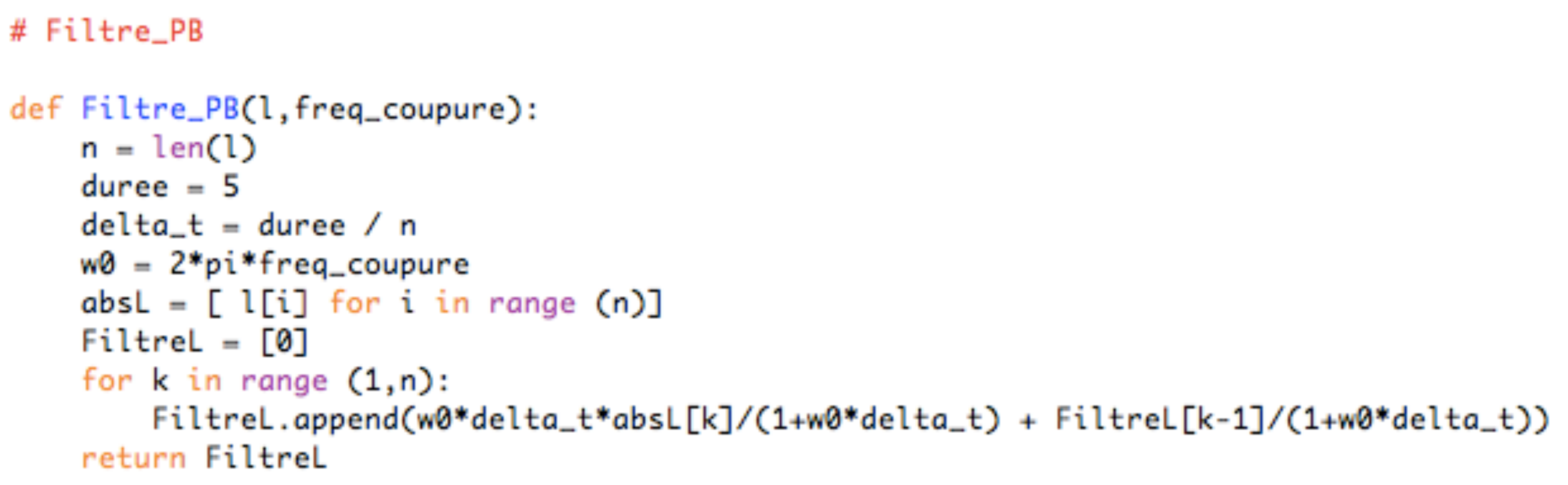
```
#nettoyage 1 pour enlever tout les termes types /, b

def nettoie(l):
    newL = []
    for i in range (len(l)):
        temp = l[i]
        newL.append(temp[2:-4])
    return newL
```



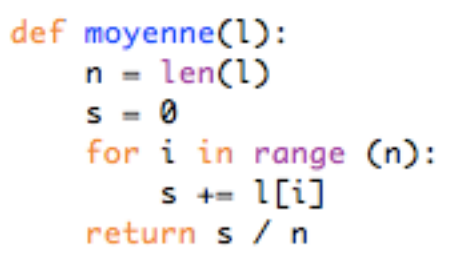
```
def essuie(L):
    l = []
    for k in range(len(L)):
        l.append(L[k].split(';'))  #split crée une liste
    p = []
    q = []
    for i in range(len(l)):
        if len(l[i]) == 2 :
            p.append(float(l[i][0]))
            q.append(float(l[i][1]))
    return(p, q)
```

- Programmes sur Python



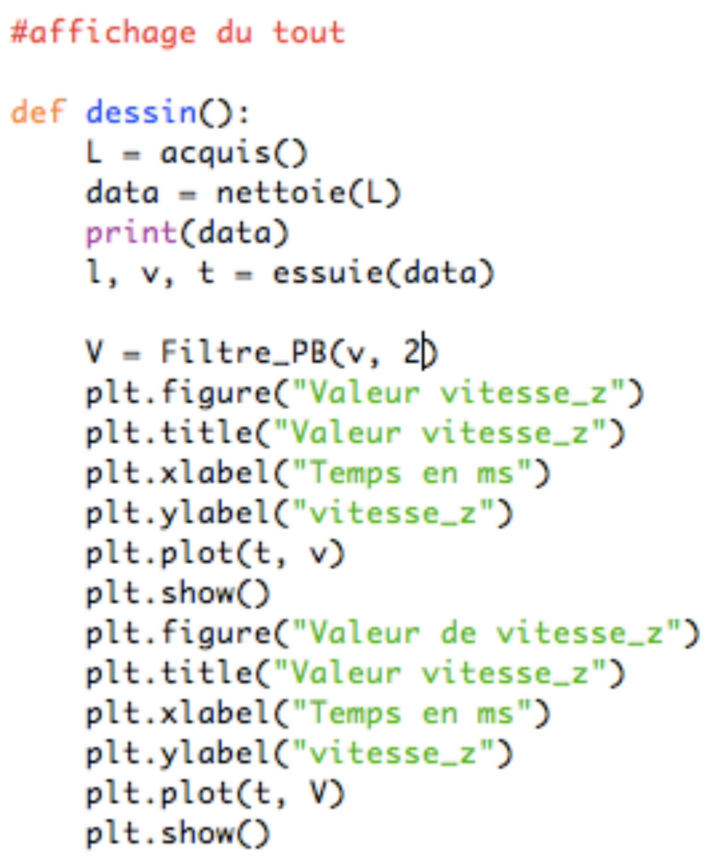
```
# Filtre_PB

def Filtre_PB(l,freq_coupure):
    n = len(l)
    duree = 5
    delta_t = duree / n
    w0 = 2*pi*freq_coupure
    absL = [ l[i] for i in range (n)]
    FiltreL = [0]
    for k in range (1,n):
        FiltreL.append(w0*delta_t*absL[k]/(1+w0*delta_t) + FiltreL[k-1]/(1+w0*delta_t))
    return FiltreL
```



```
def moyenne(l):
    n = len(l)
    s = 0
    for i in range (n):
        s += l[i]
    return s / n
```

- Programmes sur Python

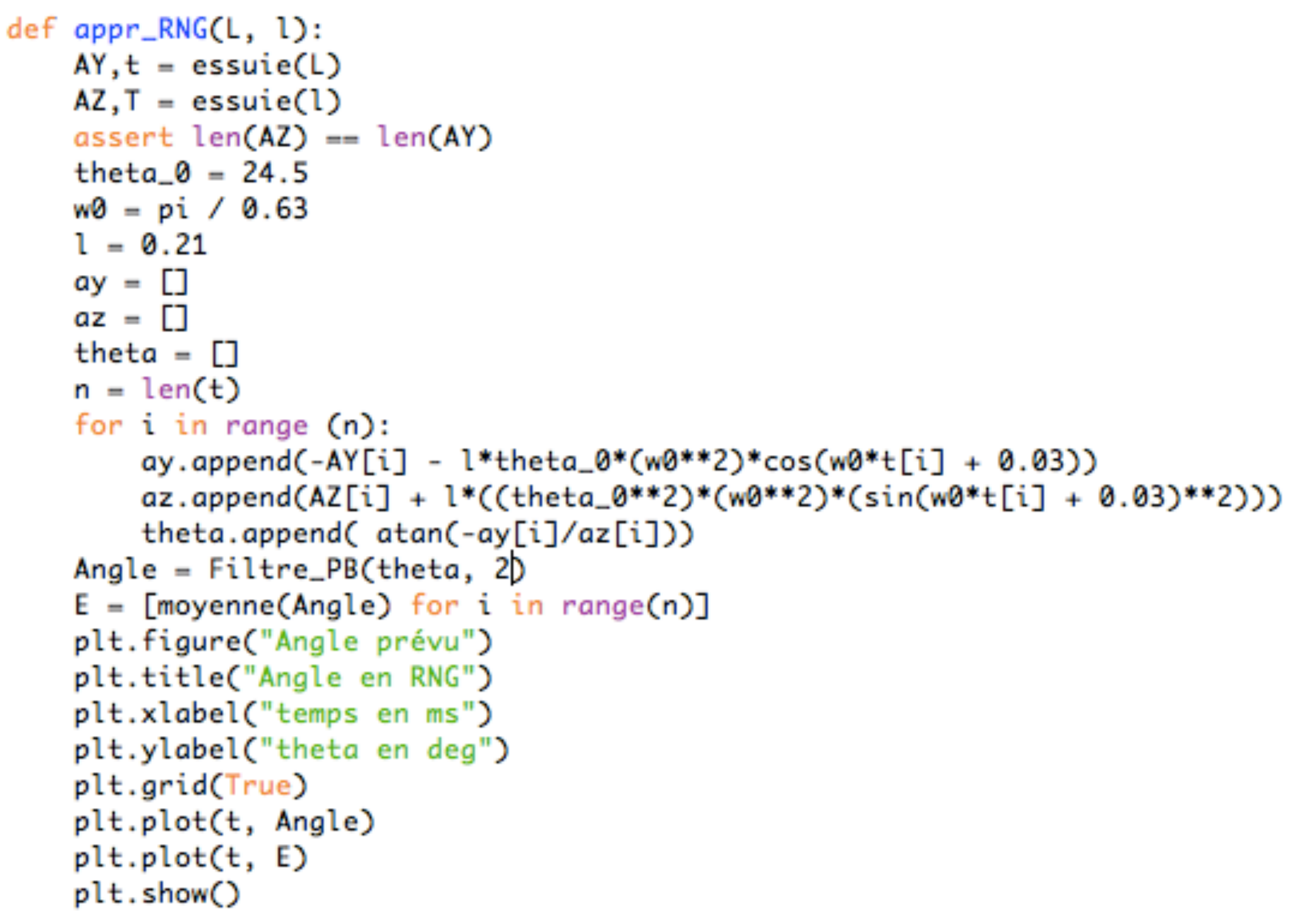


```
#affichage du tout

def dessin():
    L = acquis()
    data = nettoie(L)
    print(data)
    l, v, t = essuie(data)

    V = Filtre_PB(v, 2)
    plt.figure("Valeur vitesse_z")
    plt.title("Valeur vitesse_z")
    plt.xlabel("Temps en ms")
    plt.ylabel("vitesse_z")
    plt.plot(t, v)
    plt.show()
    plt.figure("Valeur de vitesse_z")
    plt.title("Valeur vitesse_z")
    plt.xlabel("Temps en ms")
    plt.ylabel("vitesse_z")
    plt.plot(t, V)
    plt.show()
```

- Programmes sur Python



```
def appr_RNG(L, l):
    AY,t = essuie(L)
    AZ,T = essuie(l)
    assert len(AZ) == len(AY)
    theta_0 = 24.5
    w0 = pi / 0.63
    l = 0.21
    ay = []
    az = []
    theta = []
    n = len(t)
    for i in range (n):
        ay.append(-AY[i] - l*theta_0*(w0**2)*cos(w0*t[i] + 0.03))
        az.append(AZ[i] + l*((theta_0**2)*(w0**2)*(sin(w0*t[i] + 0.03)**2)))
        theta.append( atan(-ay[i]/az[i]))
    Angle = Filtre_PB(theta, 2)
    E = [moyenne(Angle) for i in range(n)]
    plt.figure("Angle prévu")
    plt.title("Angle en RNG")
    plt.xlabel("temps en ms")
    plt.ylabel("theta en deg")
    plt.grid(True)
    plt.plot(t, Angle)
    plt.plot(t, E)
    plt.show()
```