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Use of Arduino for monitoring angles on oil platforms for didactics purposes

Uso do Arduino para monitoramento de ângulos em plataformas de petróleo para fins didáticos

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A B S T R A C T

Offshore platforms are floating structures, located at sea, that can develop drilling and production activities, in some cases, storage and transfer. For the proper development of the activities of operators, the platform shall remain in balance. If you have any movement, let these movements stay within tolerable limits. The movements of the vessels are mainly caused by environmental actions: current, wind and wave. For the mapping of movements, several sensors are installed in the structures in order to obtain more accurate information, having in many cases, more than one sensor mapping the same information. To read this information, acquisition systems must be connected to computers so that the correct interpretation of what is being measured can be performed. The use of Arduino has grown in recent years due to the possibility of its use with sensors and the associated low cost. Thus, this work proposes the use of an Arduino and MPU6050 system (sensor with gyroscope and accelerometer) for mapping turns on maritime platforms for didactic purposes. The code is implemented to read the information from the accelerometer and gyroscope and it´s verified that the results obtained are consistent with the movements that were imposed. It´s concluded, then, the feasibility of use for mapping the rotation of a platform.

R E S U M O

As plataformas marítimas são estruturas flutuantes, localizadas no mar, que podem desenvolver atividades de perfuração e produção, em alguns casos, armazenamento e transferência. Para o desenvolvimento adequado das atividades dos operadores, a plataforma deve permanecer em equilíbrio. Caso tenha algum movimento, que estes movimentos fiquem dentro de limites toleráveis. Os movimentos das embarcações são causados, principalmente, pelas ações ambientais: correnteza, vento e onda. Para o mapeamento dos movimentos, diversos sensores são instalados nas estruturas de modo que se obtenham informações mais precisas, tendo, em muitos casos, mais de um sensor mapeando a mesma informação. Para a leitura dessas informações, sistemas de aquisição devem ser conectados a computadores para que se possa realizar a interpretação correta do que se está medindo. O uso do Arduino tem crescido nos últimos anos devido à possibilidade de seu uso com sensores e ao baixo custo associado. Desta forma, este trabalho propõe o uso de um sistema Arduino e MPU6050 (sensor com giroscópio e acelerômetro) para mapeamento de giros em plataformas marítimas para fins didáticos. Realiza-se a implementação do código para leitura das informações do acelerômetro e do giroscópio e verifica-se que os resultados obtidos estão condizentes com os movimentos que foram impostos. Conclui-se, então, a viabilidade de uso para mapeamento de giro de uma plataforma.

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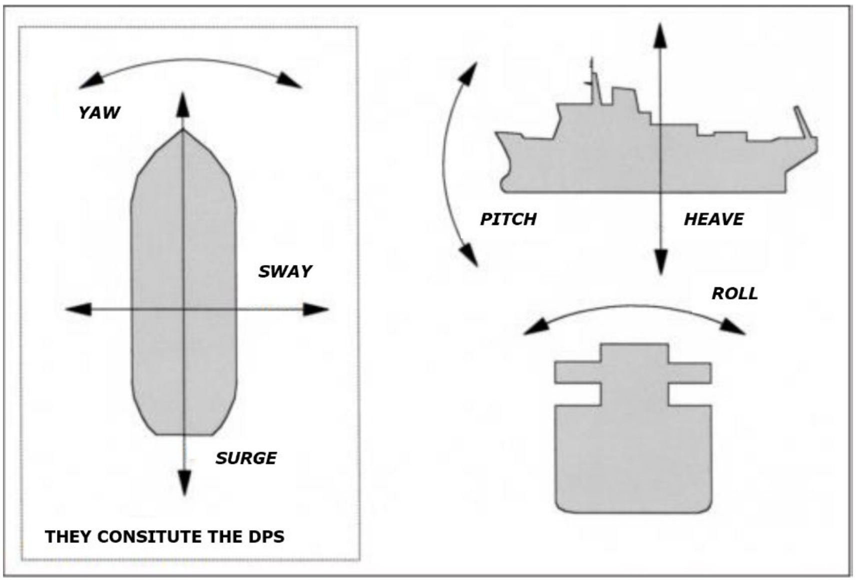
Introduction

The linear and angular displacements of a platform are caused, basically, by environmental actions: wave, wind and current, and can be divided into movements in the horizontal plane and movements in the vertical plane.

The movements in the horizontal plane (surge, sway and yaw) suffer restriction of the anchoring system, which must reduce them to acceptable values. The movements in the vertical plane (roll, pitch and heave) suffer little influence from the anchoring system and are limiting for the operation of the unit (Martins & Bezerra Neto, 2019). Figure 1 shows the degrees of freedom of a vessel.

Figure 1.

Six degrees of freedom of vessels.



Source: Adapted from Bray (2003).

The hydromechanical behavior of floating units affects the safety of passengers, crew, cargo and the unit itself; comfort of passengers and crew; dynamic loading on the structure of the floating unit, its cargo and equipment. For the monitoring of these movements, sensors are installed on the vessel, linked to data acquisition systems and computers so that decisions can be made that allow the continuity of the unit's operation.

The use of sensors can be performed linked to acquisition systems and specific software, such as, for example, the HBM Spider 8 acquisition system, linked to the CATMAN software, also HBM (HBM, 2021). However, low-cost devices with open source software are emerging, which allow, for example, the development of sensor applications with easy programming, low relative cost and functional, such as the Arduino (FILIPEFLOP, 2021). According to Arduino (2021), Arduino has been used in thousands of applications and projects.

The use of Arduino can occur in both full-scale and small-scale structures. Prototypes of floating platforms on a reduced scale are developed at the Federal University of Alagoas and buoyancy and balance tests are carried out in a test tank located in the same institution. Thus, this article aims to study the application of a gyroscope associated with an Arduino for the mapping of the rotation movements of floating units on a reduced scale.

Theoretical Reference

The study of the movements of floating units is of extreme importance both in terms of equipment and in terms of operators. Hoffman (1976) states that the design of ships or any other systems is controlled largely by seaworthiness, or, in the most common terminology, safety at sea, he states, also that the safety of a ship naturally includes the crew, the cargo and the hull itself.

Also according to Hoffman (1976), navigability reflects the ship's ability to survive all dangers at sea, such as collision, grounding, fire, as well as heavy weather effects related to the environment in general and waves in particular. The two most likely types of failure in these conditions are due to structural causes and overflow resulting from insufficient stability in severe weather conditions.

Several authors research on the stability of vessels. Calisal et al. (1997) conducted a study of a fishing vessel designed by the University of British Columbia and the British Columbia Research Incorporated, called the UBC Series, a ship designed to have a large deck area. Calisal et al. (1997) used an algorithm that was developed based on tests in test tanks, conducting a study of the behavior of this type of vessel.

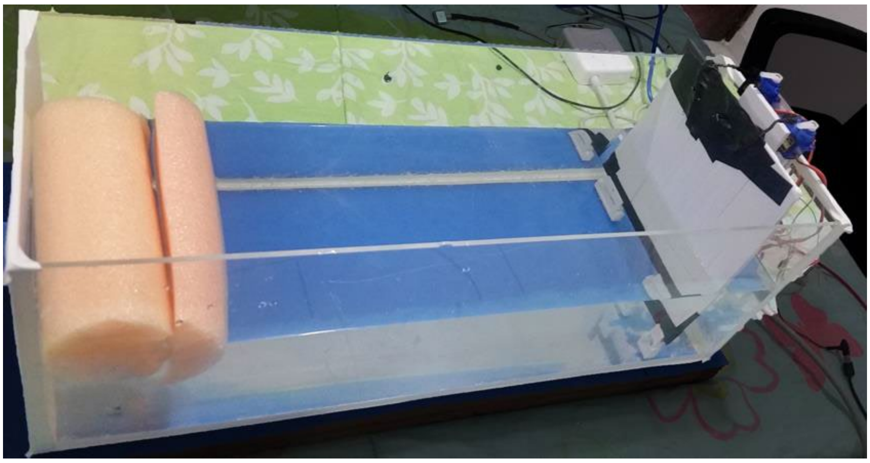
Zaraphonitis et al. (2015) studied the behavior of a vessel that performs the rapid transport of cargo and passengers, using numerical tools for the study of seakeeping.

The study of the behavior of vessels and offshore platforms is associated with the installation of sensors in the structures that will be monitored. This sensing must be planned properly, so that the sensors resist all the expected loads during the monitoring.

In addition to the studies applied directly in the industry, didactic applications are also carried out. Lopes et al. (2017) developed a flap wave generator (Figure 2) that uses an Arduino to control the actions that will be performed by the generator and a Raspberry Pi for processing and visualization of the generated wave data.

Figure 2.

Experimental environment developed.

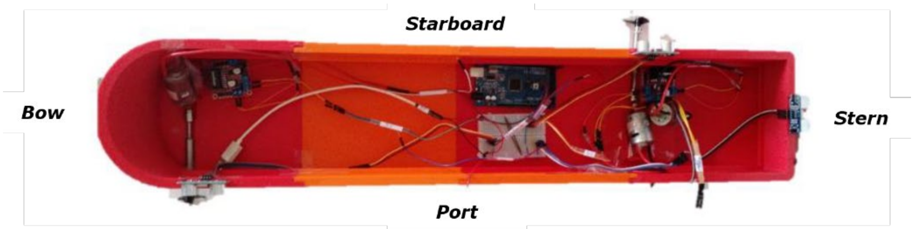


Source: Lopes et al. (2019).

Machado (2018) used an Arduino, with ultrasonic sensors and thrusters to develop a dynamic positioning system for ships, also for didactic use (Figure 3).

Figure 3.

Connected and positioned equipment.



Source: Machado (2018).

Other applications with Arduino can be found in the oil and gas sector, and one of the objectives of these applications is to reduce the cost of monitoring. Ileanwa et al. (2015) proposed the design of a remote module for monitoring oil and gas pipelines using GPRS, GPS and Google Maps for Android devices, where Arduino is used for receiving information from sensors.

Balch et al. (2016) conducted a technical and economic analysis of a wellhead produced water purification system based on humidification and dehumidification. The Arduino was used for monitoring water temperature and controlling water flow.

Materials and Methods

This article consists of the use of a gyroscope associated with an Arduino for the mapping of the angular movements of floating structures, on a reduced scale, tested in a test tank, for didactic purposes.

Materials and Equipment

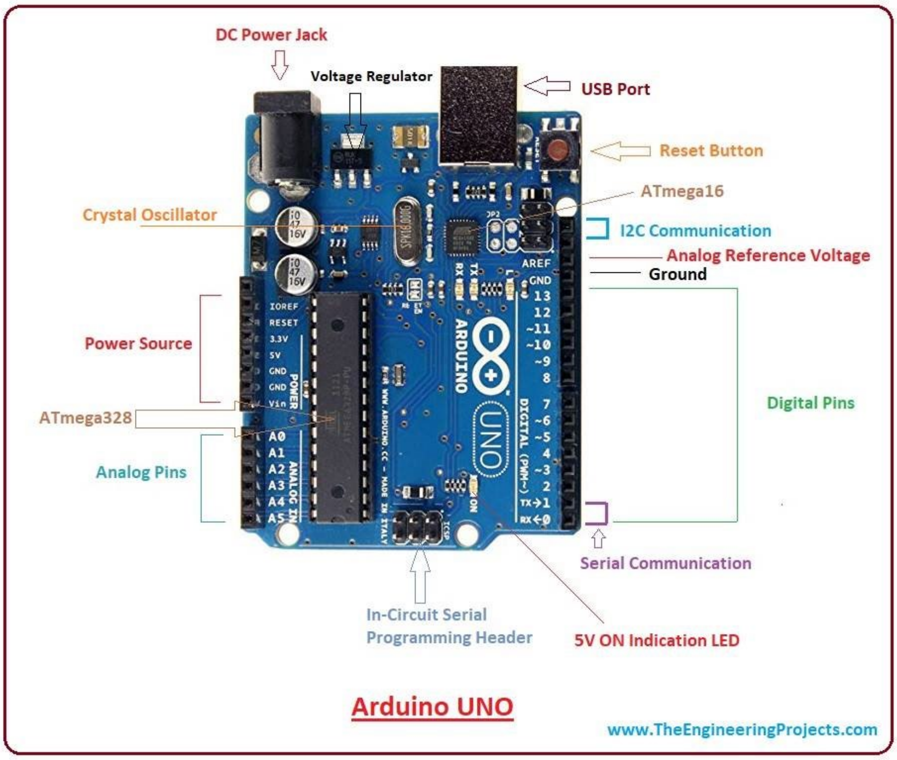
For the reproduction of the work, the materials and equipment used are described, as well as the formulation for the calculation of the angle from the gyroscope information.

Arduino Uno R3 Board

Arduino Uno R3 is a board based on the Tmega328 microcontroller. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power input, an ICSP connection, and a reset button (Figure 4). According to the "Baú da Eletrônica" (2021), it contains all the components necessary to support the microcontroller, requiring connecting it to a power supply to begin operation (Baú da Eletrônica, 2021).

Figure 4.

Arduino Uno



Source: The Engineering Projects (2021)

The Arduino Uno can be powered by the USB connection or with an external power supply. The feed is selected automatically. External power (not USB) can be either from an AC to DC adapter or battery. There is a 2.1 mm power connector with the positive in the center. Cables coming from a battery can be inserted directly into the GND and Vin pins of the power connector. This board can work with an external power supply from 6 to 20 volts. However if the power supply is less than 7 V, the 5 V pin can provide less than five volts and the board may prove unstable. And if the power supply is greater than 12 V the voltage regulator can overheat and damage the board. The recommended range is 7 to 12 volts (Baú da Eletrônica, 2021).

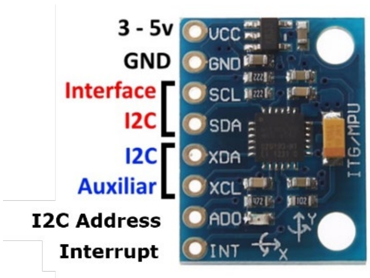
Each analog input has 10 bits of resolution, that is, 1024 different values, and measures by default from 0 V to 5 V.

Accelerometer and Gyroscope - MPU 6050

In the GY-521 module there is on the same board an accelerometer and a gyroscope of high precision, all controlled by a single IC, the MPU6050 (Figure 5).

Figure 5.

MPU 6050



Source: FilipeFlop (2021).

According to FilipeFlop (2021), communication with the microcontroller uses the I2C interface, through the SCL and SDA pins of the sensor. On the XDA and XCL pins it´s possible to connect other I2C devices, such as a magnetometer for example, and create a complete guidance system. The power supply of the module can vary between 3 V and 5 V, but for best results and accuracy it´s recommended to use 5 V.

According to Luis Llamas (2021), the MPU6050 is a six-degree-of-freedom (6DOF) inertial measurement unit (IMU) manufactured by Invensense, which combines a 3-axis accelerometer and a 3-axis gyroscope.

Also according to Luis Llamas (2021), this sensor has 16 bit digital analog converters (ADC). The range of the accelerometer can be adjusted to ± 2g, ± 4g, ± 8g and ± 16g, that of the gyroscope to ± 250, ± 500, ± 1000 and ± 2000°/sec.

An accelerometer is a device that measures the acceleration to which it´s subjected, while the gyroscope measures the angle of rotation rotated by a given mechanism.

According to Luis Llamas (2021) the 3-axis accelerometers are able to measure the acceleration to which the sensor is subjected in X, Y and Z independently, which allows to know simultaneously the magnitude and direction of the measured acceleration.

A vibrating gyroscope does not record the rotated angle, but the angular velocity ω, defined as the variation of the angle θ in relation to time t.

$$\omega = \partial\theta / \partial t$$

So the angle is given by:

$$\theta = \omega \Delta t$$

The direct reading of the acceleration or rotation values of the sensor, will be associated with noises, being necessary the use of a filter. In this way, a complementary filter is used, which is the union of the high-pass filter and the low-pass filter, given by:

$$Angulo = 0{,}98 \cdot (Angulo + AnguloGiro \cdot \Delta t) + 0{,}02 \cdot AnguloAcel$$

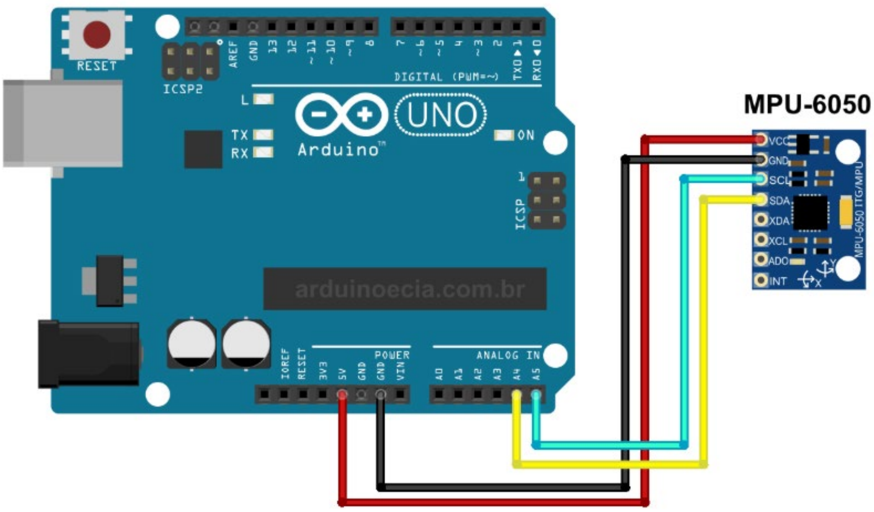
being $AnguloGiro$ the gyroscope angle and $AnguloAcel$ the accelerometer angle.

Methodology

Initially, the MPU6050 was connected to the Arduino through the jumpers (Figure 6). Then, the code is implemented so that it´s possible to read both the gyroscope and the accelerometer, so that the rotations are quantified in the three degrees of freedom of rotation, and the complementary filter is applied.

Figure 6.

Connection of the MPU 6050 with the Arduino.



Source: CallRobson (2021).

The implemented code is available in Figure 7.

Figure 7.

Implemented code.

```
#include <Wire.h>

//Direção I2C da IMU
#define MPU 0x68

//Conversão
#define A_R 16384.0 // 32768/2
#define G_R 131.0 // 32768/250

//Conversão de radianos para graus 180/PI
#define RAD_A_DEG = 57.295779

//MPU-6050 da os valores em inteiros 16 bits
//Valores RAW
int16_t AcX, AcY, AcZ, GyX, GyY, GyZ;

//Angulos
float Acc[2];
float Gy[3];
float Angle[3];

String valores;

long tempo_prev;
float dt;

void setup()
{
  Wire.begin();
  Wire.beginTransmission(MPU);
  Wire.write(0x6B);
  Wire.write(0);
  Wire.endTransmission(true);
  Serial.begin(9600);
}

void loop()
{
  //Ler os valores do Acelerometro da IMU
  Wire.beginTransmission(MPU);
  Wire.write(0x3B); //Pedir o registro 0x3B - corresponde ao AcX
  Wire.endTransmission(false);
  Wire.requestFrom(MPU,6,true); //A partir do 0x3B, pedem-se 6 registros
  AcX=Wire.read()<<8|Wire.read(); //Cada valor ocupa 2 registros
  AcY=Wire.read()<<8|Wire.read();
  AcZ=Wire.read()<<8|Wire.read();

  //A partir dos valores do acelerometro, calculam-se os ângulos Y, X
  //respectivamente, com a fórmula da tangente.
  Acc[1] = atan(-1*(AcX/A_R)/sqrt(pow((AcY/A_R),2) + pow((AcZ/A_R),2)))*RAD_TO_DEG;
  Acc[0] = atan((AcY/A_R)/sqrt(pow((AcX/A_R),2) + pow((AcZ/A_R),2)))*RAD_TO_DEG;

  //Ler os valores do Giroscópio
  Wire.beginTransmission(MPU);
  Wire.write(0x43);
  Wire.endTransmission(false);
  Wire.requestFrom(MPU,6,true); //A partir do 0x43, pedem-se 6 registros
  GyX=Wire.read()<<8|Wire.read(); //Cada valor ocupa 2 registros
  GyY=Wire.read()<<8|Wire.read();
  GyZ=Wire.read()<<8|Wire.read();
```

```
  //Cálculo do ângulo do Giroscópio
  Gy[0] = GyX/G_R;
  Gy[1] = GyY/G_R;
  Gy[2] = GyZ/G_R;

  dt = (millis() - tempo_prev) / 1000.0;
  tempo_prev = millis();

  //Aplicar o Filtro Complementar
  Angle[0] = 0.98 *(Angle[0]+Gy[0]*dt) + 0.02*Acc[0];
  Angle[1] = 0.98 *(Angle[1]+Gy[1]*dt) + 0.02*Acc[1];

  //Integração no tempo para calcular o YAW
  Angle[2] = Angle[2]+Gy[2]*dt;

  //Mostrar os valores no console
  valores = "90, " +String(Angle[0]) + "," + String(Angle[1]) + "," +
String(Angle[2]) + ", -90";
  Serial.println(valores);

  delay(10);
}
```

Source: The author (2022).

The Arduino has two main functions, the `void setup()` function and the `void loop()` function, in the first the connections with the sensors are initiated, in this case the MPU6050 and in the second function are the routines that will be repeated while the system is energized.

For this article, in `void loop()` function are the calculations of the turns recorded by the gyroscope and accelerometer.

Initially the code registers the values of the accelerometer in x, y and z and the angles y and x are calculated by the expression of the tangent. Next, the values of the gyroscope are recorded. Both the accelerometer and gyroscope values need to be converted, using factors specific to the range adopted for each of them.

Finally, the complementary filter is applied to quantify the turns without noise.

For code implementation and code passage to Arduino, the Arduino IDE is used.

Results and Discussions

To use the values of the accelerometer and gyroscope it´s necessary to make a conversion of the values read.

The range of ±2g is adopted for the accelerometer and ±250°/s for the gyroscope. Each sensor is 16 bit which means it has 65536 levels of resolution, ±32768. So the factors are, for the accelerometer:

$$A\_R = 32768/2 = 16384$$

and for the gyroscope:

$$G\_R = 32768/250 = 131$$

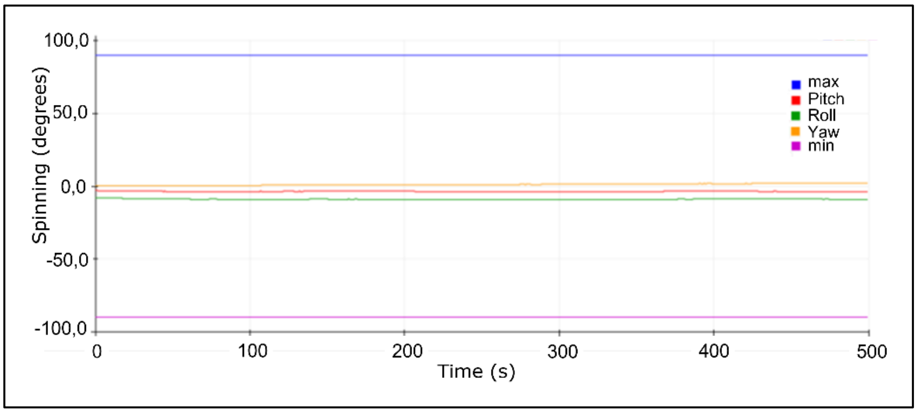
With the conversion factors calculated and included in the rotation calculations, the rotations applied to the MPU6050 are measured.

The Arduino IDE has two output screens, the serial monitor and the serial plotter. The serial monitor presents the numeric values, while the serial plotter shows variation curves of the values that are shown on the monitor.

Figure 8 shows the graph of the turns in the equilibrium position. It´s noticed that the three turns are close to zero.

Figure 8.

Spin plot with the sensor in the equilibrium position.

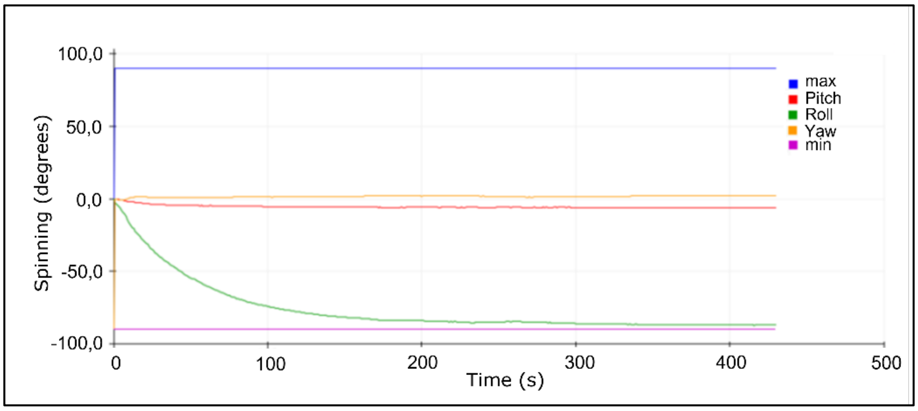


Source: The author (2022).

Making a 90º turn in Roll (Figure 9), a variation of one of the curves can be seen, approaching the 90º curve, while the others remain constant.

Figure 9.

Rotating graphic with 90º Roll movement.

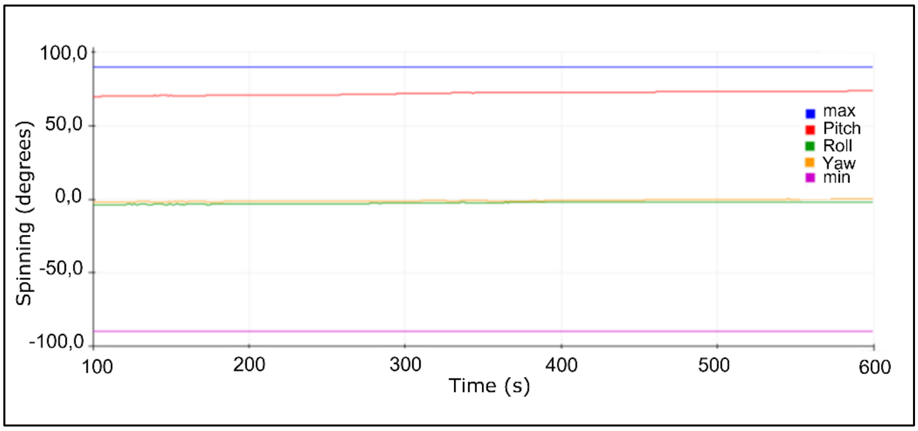


Source: The author (2022).

Similarly, the variation of the curves related to Pitch (Figure 10) and Yaw (Figure 11) can be observed.

Figure 10.

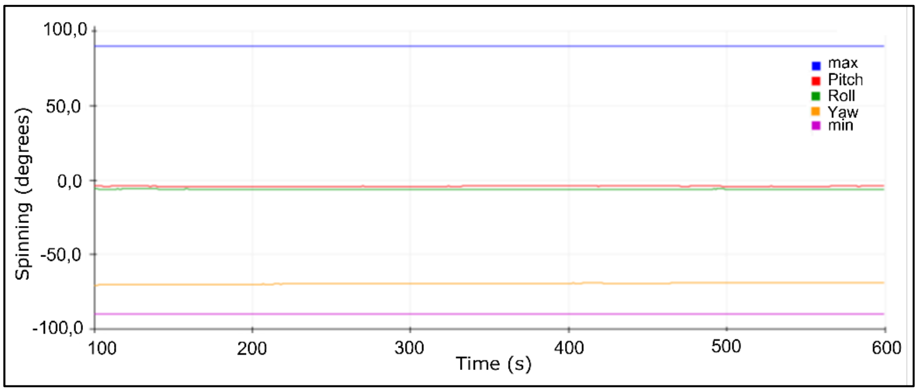
Rotating Graph with Pitch Motion.



Source: The author (2022).

Figure 11.

Rotating Graphic with Yaw Motion.

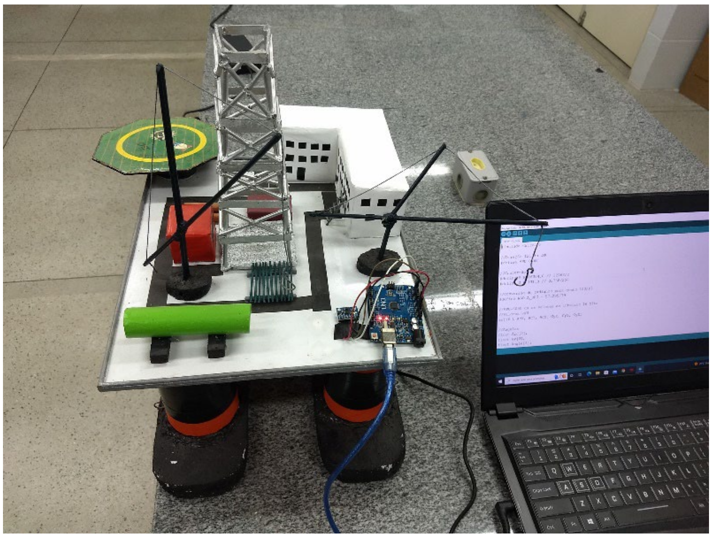


Source: The author (2022).

It´s verified that the implemented code manages to map the turns that are imposed on the MPU6050 sensor. It´s intended, therefore, to use this measurement principle and type of connection (MPU6050 and Arduino) to monitor floating structures (Figure 12), initially on a small scale, applied to a test tank located at the Federal University of Alagoas (*Universidade Federal de Alagoas*).

Figure 12.

Prototype of Semi-submersible Platform with Arduino and MPU6050 coupled.

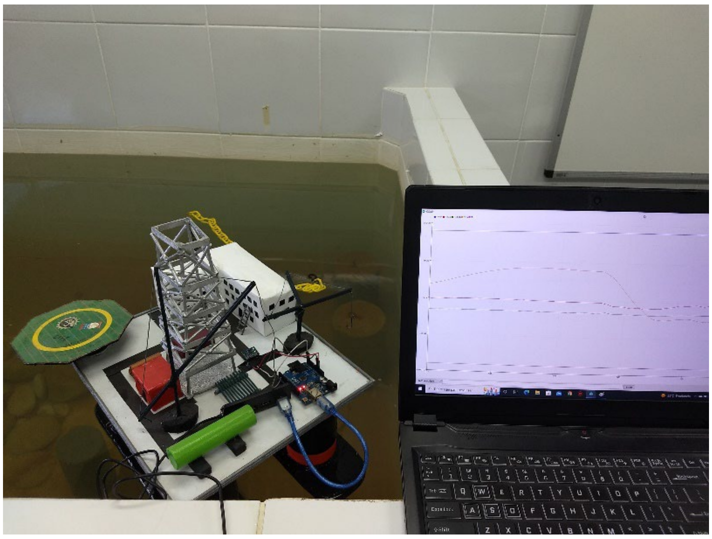


Source: The author (2022).

A small-scale semi-submersible platform is developed and the Arduino Uno and the MPU-6050 sensor are connected to the platform and a computer. To verify the results, the platform is placed on a reduced scale in a tank with dimensions 1.35 m x 2.07 m and in a water depth of 0.70 m (Figure 13) and movements are applied on the platform to verify the response read by the sensor.

Figure 13.

Testing of the Platform Prototype in the tank.

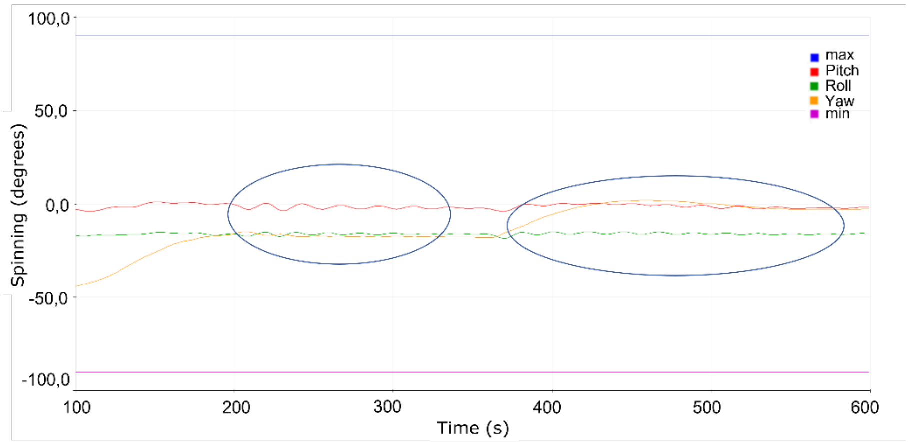


Source: The author (2022).

In the laboratory where the platform is tested, there are limitations regarding the simulation of the effects of the environmental actions acting on the structure (wind, wave and current actions). In this way, angular movements are imposed on the platform and the behavior of the structure in relation to the return to the equilibrium configuration is observed. Figure 14 shows the result of the application of Roll and Pitch turns on the platform, sections highlighted with blue ellipses, where the mapping of the turns as well as the movements performed for the return to the equilibrium configuration are verified.

Figure 14.

Result of the application of Roll and Pitch spins in the platform prototype.



Source: The author (2022).

Thus, it´s verified the feasibility of applying the developed code as well as the equipment used for the mapping, for didactic purposes, of the rotation movements (Roll, Pitch and Yaw) of the prototypes of floating units.

Other sensors can be attached to the equipment used, such as a magnetometer, which brings direction indications (simulating a compass), as well as alarms, signaling the violation of the maximum values of allowed turns that ensure that the crew can perform their tasks comfortably and safely.

Final considerations

The use of Arduino has been present in various applications for both industrial and educational purposes. The low cost of equipment associated with the simplicity of implementation and development of systems has led to the increasing use of this system.

The proposal is made to use an MPU6050, a module that contains accelerometer and gyroscope, associated with an Arduino UNO to map the rotations of floating structures for didactic purposes.

With the results obtained, it´s verified the feasibility of using the set, as well as the possibility of coupling other sensors and equipment, for example, alarms, to improve the project.

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