SOFTWARE INTERFACE FOR ONLINE MONITORING OF PEDALING ON AN EXERCISE BIKE

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Abstract: The main purpose of this work is to create a user graphical interface (GUI) to register and visualize online on a computer both the angular velocity and position of an exercise bike's crank arm. An inertial measurement unit (*IMU) was selected in order to acquire both parameters, where the angular velocity was measured in degrees per second (DPS) directly from a gyroscope z-axis of the IMU, and the angular position was calculated by integrating the angular velocity over time.*

Keywords: *Pedaling**, Monitoring, Interface, Angular velocity, Angular position.*

1. INTRODUCTION

The monitoring of signals from a device is indispensable to get information in real-time processing systems, since this is used for modelling and analysis of a its behavior. Real-time data monitoring (RTDM) is a process through which an administrator can evaluate, modify, add, delete and use data on a software, a database or a system. This enables the administrator to review the overall processes and functions performed on the data in real time, or as it happens, through graphical charts and bars on a central interface/dashboard. RTDM can also provide instant notifications/alerts into specific data-driven and administrator-specified events, such as when a data value goes out of range (*Real-Time Data Monitoring (RTDM)*, 2015).

In many mechatronic systems it is often needed to know how various parts of the system are moving to control its behavior. The most common physical quantities in motor and rotary based systems are angular velocity and angular position, since those systems undergoes rotary motions. Devices such as rotary encoders and Inertial Measurement Units (IMU) are usually used for this application.

Rotary encoders are electromechanical devices used for sensing in many applications on motors paired with drives and automated machinery for everything from consumer electronics, elevators, and conveyor speed monitoring to position control on automated industrial machines and robotics. Whether incremental or absolute, magnetic or optical, rotary encoders track motor shaft rotation to generate digital position and motion information (Eitel, 2014).

Encoders are used in motor control applications to monitor the axes' angle, provide feedback for linear measurement and determine the position of an object relative to a known point, referred to as a registration mark (*Encoder Applications By Function*, 2017) . In (Chen *et al.*, 2014) an 8-bit rotary encoder is used with the finality to estimate the position and velocity, providing a resolution of 1,4063° per sample, which is independent of the bike's speed.

On the other hand, an IMU is an electronic device that measures and reports a body's specific force, angular rate, and sometimes the magnetic field surrounding the body, using a combination of accelerometers and gyroscopes, sometimes also magnetometers. IMUs are typically used to measure angular rates, linear velocity and position relative to a global reference frame.

IMUs can be used to analyze orientations and movements of a human body (Fenu and Steri, 2010), capture lower limb orientation in space (Kontadakis, D. Chasiouras and Proimaki, 2015), measure the orientations of upper arm and the forearm(Wang and Fu, 2011), measure the orientation and speed of arm (Eriksson, 2004) and analyze flexion, abduction, adduction, elevation, orientation, rotation of the shoulder and elbow flexion and extension (Kim *et al.*, 2012).

The main motivation of this work is to create a GUI that allows to get, save and visualize angular velocity and angular position online for a motorized exercise bike (for now on, MEB) during an assisted cycling rehabilitation therapy to ensure that the angular velocity is the adequate to the user in therapy.

2.   JUSTIFICATION

In rehabilitation, RTDM systems are widely used for control and feedback of assistive devices to ensure proper operation for each user's condition (Dao *et al.*, 2015) (Kushsairy et al., 2016) (Mata, Kuziemsky and Peyton, 2016) (Patel *et al.*, 2012). IMUs are often used in this area for assessing specific movements which is relevant to the diagnosis of a disease or trauma.

Because of the portability, coupling easiness with the device and dynamic resolution, an IMU was selected in this work instead of a rotary encoder to monitor the angular velocity and angular position of the static bike. Moreover, literature shows that IMUs can be used to control and monitor the activation and deactivation of a system of functional electrical stimulation (FES) to stimulate lower limbs for assisted cycling in sport and rehabilitation, considering the measurement of strength and angular speed during pedaling (FONSECA, 2015) (DORADO, 2017). They are also used to detect when a real start of the pedaling movement was produced measuring angular velocity in order to compare this measure with a BCI (Brain Computer Interface) model for detection pedaling intention through EEG signals (Rodríguez-Ugarte *et al.*, 2017).

IMUs on biomedical treatments usually work with sampling frequencies around 100 Hz because the movements are slow and limited. However, since the maximum angular velocity that the MEB can reach is 465 DPS, in this project a frequency of 500 Hz was used to decrease the integration error to less than 1 degree.

3.   SYSTEM ARCHITECTURE

For this work, angular velocity and angular position were monitored through an IMU on a crank arm of a MEB as shown in Fig. (1). The IMU is wireless, because if not, a wire could get entangled around the shaft causing measurement errors.
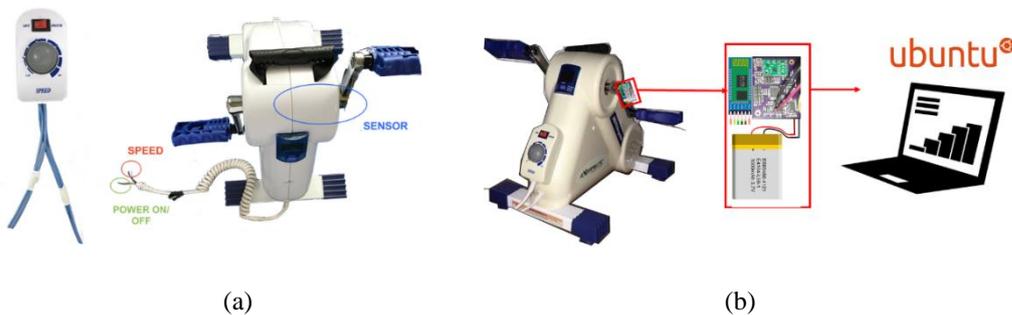

(a)   (b)

Figure 1. System architecture: a) Motorized exercise bike; b) Implemented scheme.

Figure (1a) shows the device used in this work, which has a wired control with a power on/off switch and a potentiometer for velocity reference control. This MEB has also a magnetic sensor for counting revolution. The system architecture implemented has a wireless custom made IMU and a computer with Bluetooth (Fig. (1b)). The GUI was developed in Python 3.5 and runs over Ubuntu operating system where Bluez library and an HC-05 Bluetooth module are used to make a Bluetooth connection and get data from the IMU into the computer.

4.   METHODOLOGY

The methodology involves three steps divided in IMU installation on the exercise bike, data acquisition and data processing.

4.1   IMU installation on the exercise bike

The IMU selected was a prototype implemented in our research group. This custom-made IMU contains two IMUs, a BNO055 that can work until 100 Hz and provide data fusion and a Pololu MinIMU-9 v5 that reaches until 1 kHz with 9 degrees of freedom. Moreover, this IMU has serial and bluetooth communication. Such as aforementioned, the IMU was installed on the bicycle crank arm to get the angular velocity and angular position. With that IMU's position on the exercise bike, only the z-axis in the gyroscope has a significant measurement.

4.2 Data acquisition

Gyroscope's z-axis was obtained from both BNO055 and MiniIMU to know which one has the best performance. Two tests were carried out, the first one with the minimum velocity for the MEB and the second one with the maximum velocity. In each test the z-component was integrated in order to calculate the angular position.

Since the BNO055 IMU's maximum frequency is 100 Hz, the tests were made at that frequency. The results are displayed in Fig. (2) and Fig. (3).
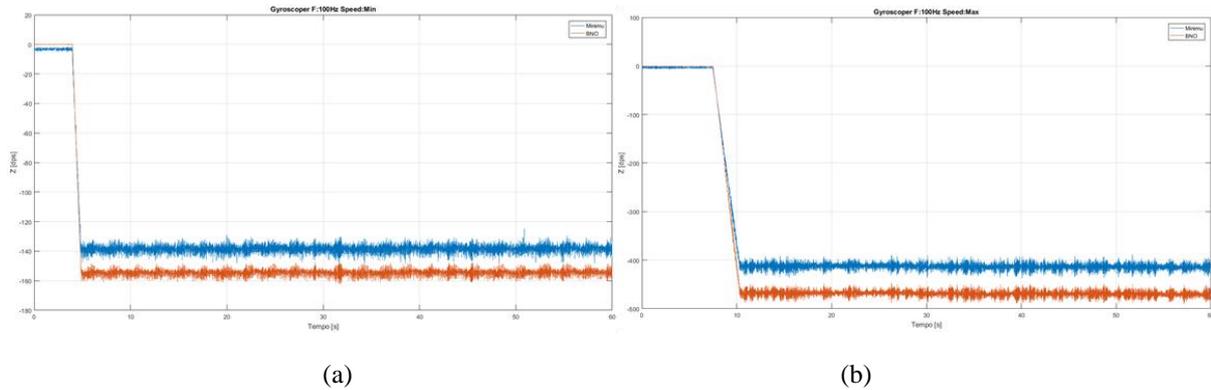

| (a) | (b) |

Figure 2. Angular velocity measurements in DPS: a) minimum velocity of 125 DPS. b) maximum velocity of 465 DPS.

Figure (2a) and (2b) show the angular velocity for both IMUs, BNO055 (Orange) and MiniIMU (Blue) for minimum and maximum velocities, respectively. It is evident that there is an error between those IMUs, not only in static mode at the beginning of each signal plotted, but also in dynamic mode. In static mode and for minimum and maximum velocities, the errors between IMUs were approximately 5 DPS. On the other hand, in the dynamic mode, the error in minimum velocity was 14 DPS and in maximum velocity was 53 DPS. These errors make a significant difference when the integration is made such as can be observed in Fig. (3a) and Fig. (3b).
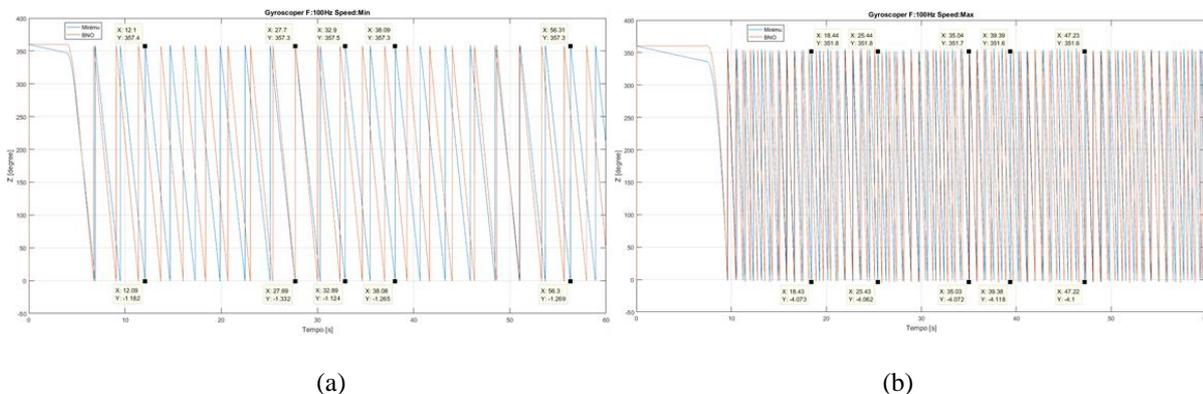

| (a) | (b) |

Figure 3. Integration errors with a) minimum velocity; b) maximum velocity.

The angular position in minimum velocity Fig. (3a) has a maximum error of 1,394 degrees for BNO055, and 1,332 degrees for MiniIMU. It seems that MiniIMU is a bit better than BNO055, but, when the number of revolutions is counted, the MiniIMU shows that the static bike did 20 revolutions while BNO055 shows that it did 22 revolutions. The number of revolutions was measured using a magnetic sensor located in the join between the motor shaft and the static bike's crank arm. That sensor was already installed by default inside the static bike.

The magnetic sensor counted 22 revolutions, which corresponds with the measurement made by BNO055. With this information, it is clear that the MiniIMU is missing revolutions, more exactly 2 revolutions for a minimum velocity. In maximum velocity, the MiniIMU missed 8 revolutions (58 revolutions counted) and obtained 4,1 degrees as maximum error, while the BNO055 counted 66 revolutions and presented a maximum error of 4,76 degrees. Although the error on BNO055 is greater than MiniIMU's error, the BNO055 gets to make measurements more approximated to the real ones. The measure error in BNO055 and MiniIMU could be due to the drift problem introduced by the integral approximation, which is greater in the BNO055 because it measures more revolutions.

4.3   Data processing

The error in angular position is also caused by the sample frequency, since this is 100 Hz, which is not enough to follow neither minimum velocity nor maximum velocity. The minimum sample frequency is 465 Hz, since the maximum velocity is 465 DPS, this way, an angular position error lower than 1 degree was obtained with steps of 1 degree between samples.

In order to use a sample frequency of 500 Hz, a regression was implemented to transform the MiniIMU's behavior into the BNO055's behavior, as the BNO055 cannot work in 500 Hz while the MiniIMU does. The static error and the dynamic error were analyzed to get information about the relation between behaviors. The result is shown in Fig. (4a) and (4b).
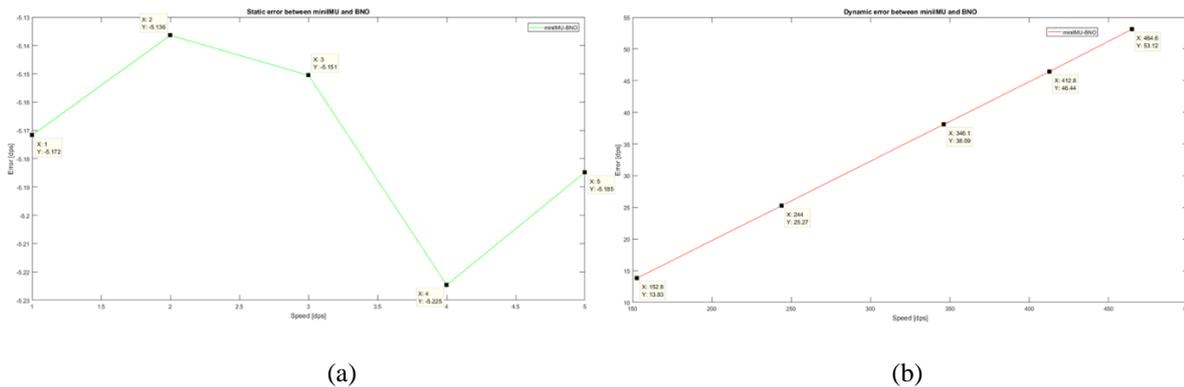

(a)   (b)

Figure 4. Error between BNO055 and MiniIMU: a) Static Error. b) Dynamic Error.

The static error between BNO055 and MiniIMU is almost constant, with variations of maximum 0.074 degrees. However, the most important error is the dynamic one because most of the data used to find the angular position is obtained in this mode. The results of the dynamic error show that the relation between IMUs is linear. Thanks to this behavior it was possible to do a linear regression where the following equation was found:

$$y = 1.1439x + 6.2106 \tag{1}$$

Equation (1) was applied online to the data from MiniIMU in a sample frequency of 500 Hz and with maximum velocity. Figure (5a) and (5b) show the obtained results.
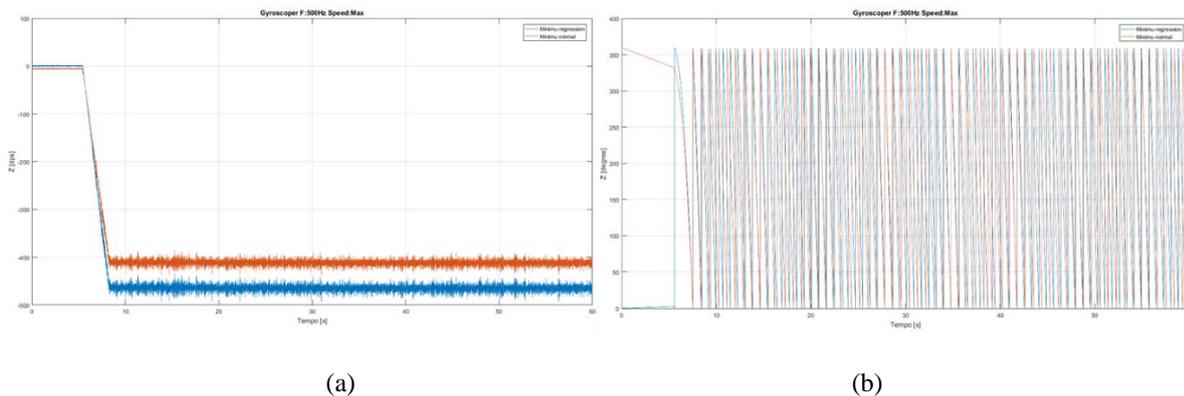

(a)   (b)

Figure 5. Regression Results. a) angular velocity; b) angular position.

After using the Eq. (1), the data obtained from MiniIMU in 500 Hz got the expected results, showing an angular velocity of 465 DPS (Fig (5a) blue signal) with the adjust, against 410 DPS (Fig (5a) orange signal) without it. The results were also satisfactory with respect to the angular position since the maximum error obtained was 0.2134 degrees, which is lower than 1 degree.

5. RESULTS

A GUI that allows the user to obtain online the angular velocity and angular position was developed. It also lets the user to communicate the IMU with a computer. The GUI has just one window, with two graphic plots and six buttons for plot control and data acquisition, such as displayed in Fig (6a).
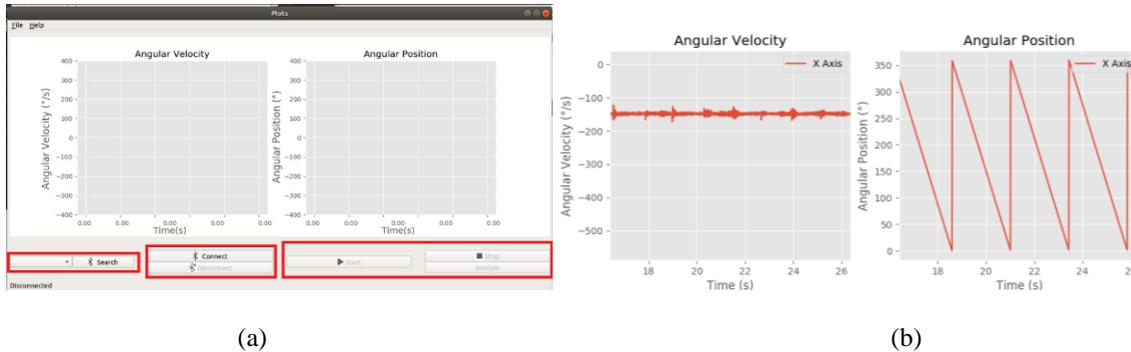

(a) (b)

Figure 6.a) Initial Window; b) Online plot with angular velocity and angular position.

This window has three modules that allow to find Bluetooth devices, create connections with those devices, get and plot data online and analyze the data obtained. The first module contains a button (Search) and a combo box that give access to Bluetooth devices. The second module has two buttons (connect and disconnect) which can begin or finish a Bluetooth connection with a desired device. The last module is composed of three buttons (Start, Stop and Analyze) which are used to start the data acquisition, plot the data as shown in Fig. (6b), pause the plot and analyze the data in the plot, as shown in Fig. (7a). The main window has also a menu in the upper side that contains two options (Quit and Save) as shown in Fig. 7b, which allow to close the window and save the acquired data respectively.
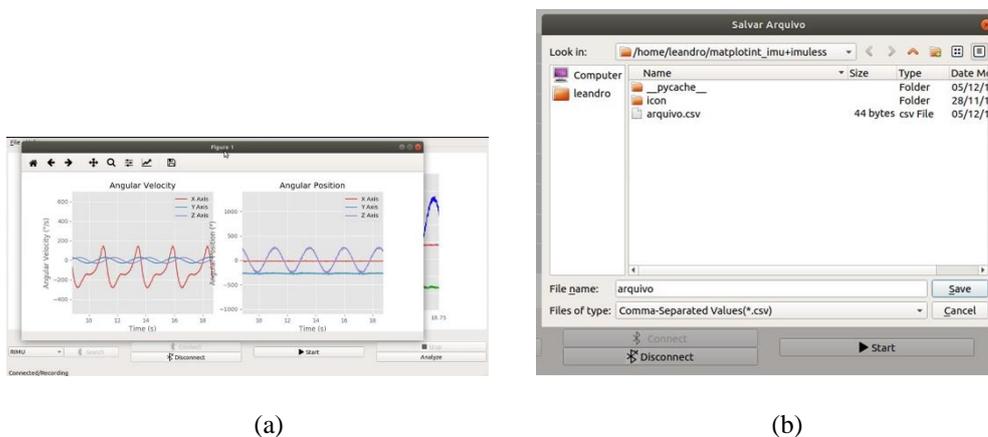

(a) (b)

Figure 7. a) Analysis window; b) Save window.

6. CONCLUSIONS

A GUI that allows the user to obtain both angular velocity and position online from an IMU in an exercise bike was developed. It also lets the user to communicate the IMU with a computer by a Bluetooth connection and the possibility of saving the acquired data for posterior analyzes.

The sample frequency is indispensable to get more accurate and reliable data, and for this application, the minimum sample frequency was adjusted and limited by the maximum angular velocity of the exercise bike.

The drift in the angular position due to the integration plays an important role when the application requires a lower error. For future works, this could be fixed by making use of accelerometer data and a fusion algorithm that provides quaternions. It is also possible to use the IMU sensor on the pedal of the bicycle in order to capture the ankle position, which is useful for detection and monitoring of ankle injuries that can occur due to overuse, trauma, and neural degenerations.

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