# Healthcare Based on IoT Using Arduino, MPU6050 Accelerometer and Gyroscope Sensor and FSR-174 Strain Gauge for Fatigue

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**Abstract.** The term "fatigue" refers to a change in task performance over time due to both psychological and physiological factors. No universal fatigue definition has been reached due to the strong subjective component attached to it. Fatigue assessment techniques vary from subjective scales to objective assessment tests such as isometric and finger tapping tasks performance. A low-cost, portable, and simple equipment is the most suitable option for the implementation of fatigue evaluation tasks during clinical visits.

The main goal of this work is to design and implement a biomedical device for muscle fatigue evaluation characterized by being portable, simple, and affordable. Additionally, correct functioning should be provided, and signal registration must be ensured.

For its development, an Arduino programmable board, a strain gauge sensor and a gyroscope and accelerometer sensor have been employed. The most appropriate sensors were selected: FSR-174 strain gauge and MPU6050 accelerometer and gyroscope sensor. Additionally, circuit design, assembly have been carefully implemented for the proposed goal.

Different fatigue measurements have been obtained and fatigue presence on the different recordings attributed by the new biomedical device have been demonstrated. As a conclusion, the design and implementation of an objective fatigue assessment equipment has been finalized and its correct functioning and signal registration capability have been proven. Near future daily clinic visits may provide the performance of fatigue assessment tasks with the biomedical electronic device created in this project after further investigations on register analysis, fatigue measurement computation and the device Internet connection.

**Keywords:** Fatigue · Finger-tapping task · Biomedical Electronic Device

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## 1 Introduction

Fatigue is a condition commonly suffered among the general population. It can be defined as the maximal force decrease or difficulties in sustaining or initializing voluntary activities, however, there is no universal definition for fatigue since it is a subjective perception [1, 2].

Fatigue's high prevalence growth has given rise to a significant interest in the impact of fatigue on neurological disorders and neurorehabilitation [2]. When it comes to evaluating fatigue, there are no clear guidelines or a universal established standard leading to a wide variety of results. As a result, any posterior results comparison can be hardly carried out.

The measurement of fatigue by means of fatigue scales is a widespread technique. The scales that are usually used to evaluate the perceived fatigue are the Fatigue Severity Scale (FSS), the Modified Impact Fatigue Scale (MFIS) and the Borg scale [3, 4]. These scales rely on a strong subjective component which has given rise to the appearance of new different evaluation methods. This is the case of the Isometric (ISO) [5] and the Finger Tapping (FT) [6] performance tasks for fatigue assessment: two specific tasks that rely on an objective basis enhancing the posterior analysis of results. The ISO task entails sustained maximum voluntary contraction (MVC) over the time it is performed. Central fatigue is developed and motor units firing rate is diminished during maximal voluntary ISO tasks, leading to a decrease of voluntary activation [7]. Furthermore, literature reports high evidence of excitability reduction in the spinal cord and motor cortex produced by ISO tasks [8–10]. A smaller number of studies demonstrating the relationship between fatigue induced by means of repetitive movements have been reported [8, 10].

The FT test is a valid task to assess pathological and physiological mechanisms [11]. It is based on performing repetitive movements at the fastest possible rate leading to a frequency decrease in very few seconds from the beginning of the test. Frequency drop suggests fatigue induction.

ISO and FT tasks require a specific fatigue evaluation equipment which is usually expensive, bulky, and difficult to use [11, 12]. For these reasons, the following consequences are arisen:

- Expensive equipment: a reduced number of clinical health care groups and centers are provided with this particular equipment. It can be stated that it is an exclusive equipment.
- Bulky equipment: ISO and FT tasks can only be carried out to a limited number of subjects who can move to healthcare facilities equipped with the necessary biomedical devices for fatigue assessment. The possibility of carrying out fatigue evaluation tasks at subjects' homes is ruled out.
- Difficult to use: health professionals need training to be able to use this equipment and in most of the occasions it takes a long time to become familiar with it.

This is the case, for example, of the device we used in our previous studies [13, 14]: a general-purpose programmable data acquisition device (Biometrics DataLink DLK900 [15]) used with a goniometer and a dynamometer to perform ISO and FT tasks for fatigue assessment. There are other devices in the literature can use to FT and ISO, but the data obtain from these apparatuses cannot be used to measure the decrease in the motor performance [16, 17].

Due to the previous considerations, the main goal of this project is to develop a biomedical device for muscle fatigue assessment with the following characteristics:

- Valid and reliable: it should provide accurate fatigue measurements and be as effective as commercially available devices.
- Affordable: equipment cost should be reduced by means of low-cost devices (for example: open-source platforms, low-cost sensors…) making it possible to expand the use of fatigue assessment tasks to healthcare centers, outpatients, primary and secondary health care centers. In this way, fatigue assessment can be generalized.
- Portable: ISO and FT tasks will be carried out on a large scale, and it will be possible to perform fatigue evaluation tasks at subjects' homes.
- Simple: easy-to-use equipment should be developed to ensure no long learning procedures are required to healthcare operators.

The main goal of this study is to design and implement a biomedical device for muscle fatigue evaluation characterized by being reliable, affordable, portable and simple. Its correct functioning and valid signal registration must be ensured. Due to the presence of numerous studies that have demonstrated a strong relationship between both tasks (ISO task and FT task) and fatigue measurements these two tests are the basis of this project.

## 2 Device Design

In order to design and implement a low-cost equipment to assess fatigue, different devices and sensors have been chosen and evaluated. The device consists of an Arduino module and two sensors: a resistive strain gauge, for measuring the applied force, and a gyroscope and accelerometer module, for finger angle measurements.

### 2.1 Arduino

A commercially available microcontroller is used as the core of the device: Arduino UNO [18]. Arduino UNO is an open-source microcontroller-based board. It exposes 6 analog pins (input and output) and 14 digital pins (input and output). The Arduino Integrated Development Environment (IDE) can be used to develop and run the required software for muscle fatigue assessment test. Arduino UNO has been selected because of its portability, affordable price and flexibility in terms of input/output connections, of which only 5 will be used.

### 2.2 Sensors

A sensor to measure the force applied is required: it must have enough diameter to fit the index finger as this finger will be used to exert the force in the fatigue tests. For this reason, a resistive strain gauge, the Force Sensing Resistor FSR-174 from IEE Sensing, is used. For the detection of the index finger tilt angles, an Inertial Measurement Unit (IMU), consisting of a gyroscope and accelerometer module (TDK Invensense, MPU6050) is used. It is placed on top of the index finger during the fatigue test, taking advantage of its small size and light weight.

**Strain Gauge: FSR-174**
Strain is the deformation of a material when a stress is applied over it. A strain gauge is defined as an element with variable resistance which changes by means of tensile and compressive stresses. On the other hand, stress can be defined as the force exerted on a material divided by its cross-sectional area. In order to measure strain, the strain gauge must be connected to an electrical circuit capable of accurately detecting small resistance changes.

For the project development, a unique strain gauge connected to an electrical circuit has been used: the FSR-174. Its characteristics include: length, 63.7 mm; width, 27.8 mm; strain gauge resistance, higher than 1 MΩ; maximum electrical current, 1 mA; minimum and maximum operating temperature, −30 ºC, 170 ºC; force measurement, tension and compression stresses [19]. These characteristics have made it possible to measure resistance variations after surface pressure exertion thanks to a voltage divider.

**Inertial Measurement Unit**
The IMU combines an accelerometer and a gyroscope for the measurement of linear and angular accelerations, respectively.

The MPU6050 sensor is an IMU formed by 6 Degrees of Freedom (DoF): 3 axes to detect inertial forces (accelerometer) and 3 axes to detect rotations (gyroscope) to determine its instantaneous position. Its small size (21.2 mm × 16.4 mm × 3.3 mm) and weight (2.1 g) allows its use as a wearable sensor.

The accelerometer is responsible for detecting inertial forces applied to the sensor and projecting them onto three axes. The force direction decomposition into three axes of MPU6050 sensor is based in piezoelectric effect. The gyroscope is able to detect centrifugal forces and convert them into spin's velocity taking into account the three main reference axes: x, y, z. Combining the accelerometer and gyroscope measurements, it is possible to obtain the sensor's tilt angles and find its orientation [20].

## 3 Device Implementation

### 3.1 Hardware Connections

The circuit design, assembly and Arduino connections are described below. Circuit design is formed by 3 different main elements:

- Arduino UNO: a programmable microcontroller board made up of 6 analog inputs and 14 digital input/output pins.
- Strain gauge: it is formed by 2 pins, one of them connected to a 5 V source, the other one should be in series with A0 (analog pin) and a 10 kΩ resistance. The resistance should also be connected to the ground.

- IMU: 4 different connections are established between Arduino UNO and the sensor following the scheme below (see Fig. 1) [21], where A4 and A5 correspond to the analog ports 4 and 5 from Arduino UNO.

The complete circuit including all the aforementioned components and its positions can be identified (see Fig. 2).

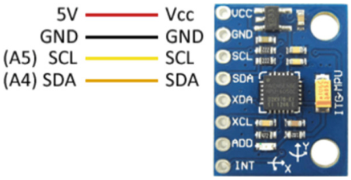

**Fig. 1.** Arduino UNO-MPU6050 connections.

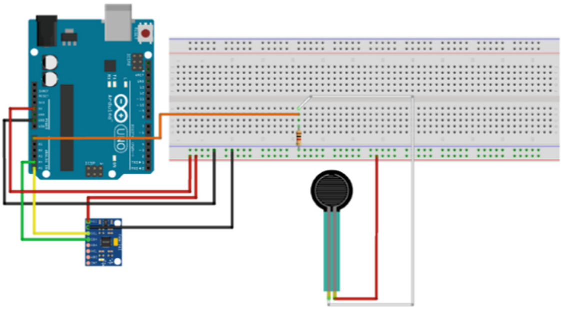

**Fig. 2.** Circuit design: components and connections.

## 3.2 Software Programming

The code running on the Arduino board was firstly divided in two different “sketches”: strain gauge programming sketch and accelerometer and gyroscope sketch. After the completion of both sketches, they were unified in a single code.

A voltage divider is used to obtain the value of the resistance of the strain gauge, for converting the resistance reading into a voltage reading. To do this, the sensor is connected to an analogue pin that reads values between 0 and 1023. These values are converted to voltage (0–5 V) to obtain the strain gauge variable resistance.

In first place, it is necessary to add two libraries to control MPU6050 sensor, MPU6050.h and Wire.h. Subsequently the sensor initializes. In the next step, three variables storing raw values of inertial forces range from −2 g to 2 g (ax, ay, az) and three variables storing raw values of angular velocities range from −250°/second to 250°/second (gx, gy, gz). Moreover, the tilt angles of the sensor in the x and y axes are calculated.

### 3.3 Calibration Procedure

The IMU needs to be calibrated following a standard procedure [22]: The IMU is kept still on a flat surface and no movement should be performed. In this way, the expected or correct values should be ax = 0, ay = 0, az = 1 g for the acceleration among the 3 axes and gx = 0, gy = 0, gz = 0 for the rotation rates of the gyroscope. Offsets reading is continuously performed, and the values are corrected every 100 readings with the average offset. Finally, the corrected values are scaled to international units (*m*/*s*: ax = 0, ay = 0, az = 9.81; °/s: gx = 0, gy = 0, gz = 0).

Strain gauge calibration is defined as the procedure in which a weight value in kilograms (measured by the dynamometer of Biometrics Datalink) has been assigned to each voltage value (produced by FSR-174 strain gauge). It is carried out by means of 8 recordings in which the strain gauge has been superimposed on top of the dynamometer from Biometrics DataLink during data registration process for the voltage-weight value assignment. Each recording is composed of 25 s with the following structure: 5 s without applying force over the strain gauge, 15 s applying force continuously over the strain gauge at a specific voltage and 5 s without exerting force over the strain gauge.

## 4 Results

### 4.1 Data Acquisition Process and Fatigue Measurements

For the data acquisition process, ten different task recordings have been acquired: 5 FT task recordings and 5 ISO task recordings. All measurements have been acquired using the right index finger of the same and one-and-only subject, in order to obtain task recordings to compare the results provided from the electronic biomedical device that has been developed in this project and the current biomedical equipment Biometrics DataLink.

The IMU, comprising the accelerometer and gyroscope, is placed on the middle phalanx of the index finger. The strain gauge is placed just below the index finger in order to measure the pressure exerted by the index finger on it.

Furthermore, FSR-174 strain gauge is located on top of the dynamometer from Biometrics DataLink during data acquisition process for the posterior fatigue measurements comparison (see Fig. 3). Each FT recording and ISO recording stores five different data variables:

- Timestamp (ms): is the time in milliseconds from the starting point of the program to the end. Each data acquired during the recording is assigned a timestamp.
- Voltage (V): is the strain gauge voltage value that varies depending on the force applied towards it.
- Resistance (kΩ): is the resistance exerted by the strain gauge depending on the force applied towards it. The higher the force exertion, the lower the resistance value.
- X-angle (°): indicates the MPU6050’s sensor tilt in the reference to the x-axis.
- Y-angle (°): indicates the MPU6050’s sensor tilt in the reference to the y-axis. Data registration process involves different sampling rates for each biomedical device.

The sampling rate of the Arduino equipment is 85 Hz, approximately. On the other hand, Biometrics DataLink equipment sampling rate is 100 Hz. Once the data was

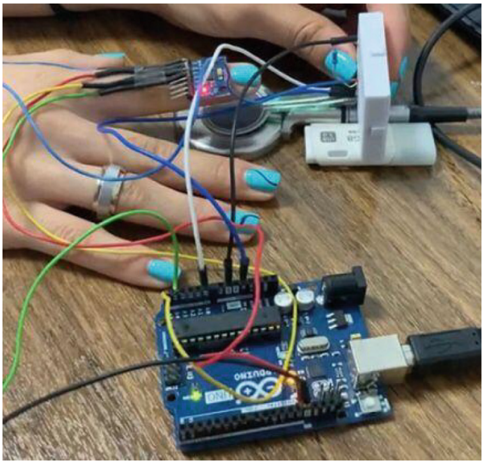

**Fig. 3.** Superposition of electronic equipment during data recordings for strain gauge calibration.

acquired with the biomedical device designed in this project, it was exported to.csv files by means of an Arduino plug-in named ‘ArduSpreadsheet’ for further analysis [22].

A unique fatigue measure for each task (ISO, FT) was evaluated and compared between the systems, the decay over the 2 min as a marker of the fatigability by computing the ratio of the motor output in the last 20 s compared with the first 20 s in both tasks [11, 13]. In the case of the ISO task, motor performance was measured as the ratio of the area of the curve between the initial and final 20-s blocks, while in the FT task it was measured as the ratio of the tapping frequencies. Areas were calculated using the so-called Q = trapz(Y) from MATLAB and the number of finger taps was calculated using the so-called [pks,locs] = findpeaks (data) function from MATLAB.

Strong differences in the acquired signal during the same registration process can be seen during ISO task and FT task (see Fig. 4 and Fig. 5). With respect to similarities during the ISO task, in all the recordings regardless of the equipment, the area obtained in the first 20 s is higher than the area obtained in the last 20 s. As a consequence, muscle fatigue is present in all the recordings: force exertion declines over time due to muscle fatigue in the index finger which performs the MVC.

Regarding FT task, as it can be observed in Fig. 5, the measurement of the tapping frequency obtained by means of peak detection is more correct with the Arduino device. The algorithm is not capable of marking the peak extreme of some finger taps recorded with Biometrics DataLink equipment. Moreover, it should be noted that the ratio of the tapping frequency between the first 20 s and the last 20 s of the task, as measured by the Arduino board, is greater than 1, which indicates fatigue.

## 5 Discussion

There is a need to design and implement a new biomedical device for muscle fatigue assessment because the currently available commercial equipment do not meet the needs for portability and low costs of healthcare.

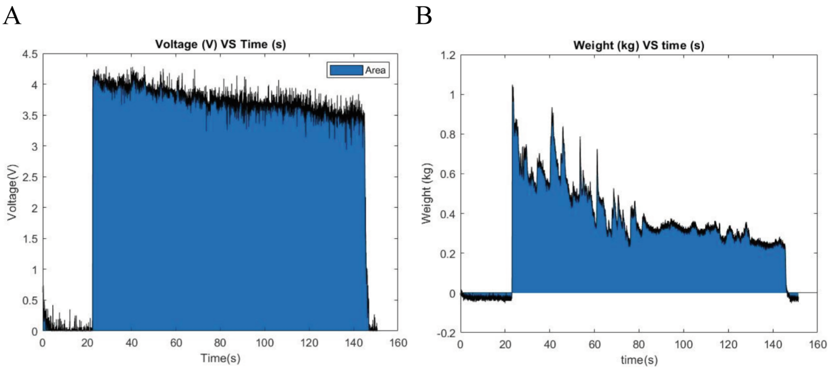

**Fig. 4.** (A) Area of the signal acquired with Arduino (B) Area of the signal acquired with Biometrics DataLink device during ISO task.

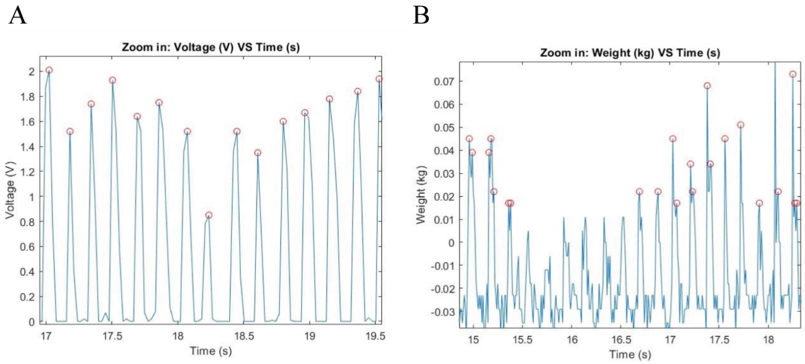

**Fig. 5.** (A) Zoom in of FT task signal with local maxima for Arduino equipment (B) Zoom in of FT task signal with local maxima marks for Biometrics equipment.

Different features take part in fatigue assessment equipment: complexity, static devices, non-portable equipment and high-cost. Each of these characteristics have been challenged thanks to the design and development of the biomedical device carried out in this project for muscle fatigue evaluation.

The following attributes characterize this new equipment with the same purpose, fatigue assessment:

- Simplicity: it has been accomplished by means of open-source platforms for electronic projects like Arduino. Moreover, plain sensors, which have been previously used by a large number of users worldwide, have been manipulated: strain gauge sensor and accelerometer and gyroscope sensor.
- Portable: Arduino-computer connection is established by means of a USB cable. In this way, the biomedical equipment and a computer are the two necessary elements for the development of fatigue evaluation tasks. As a consequence, ISO and FT tasks could be carried out in subjects' homes for populations who cannot attend healthcare facilities.

- Low-cost: the biomedical device equipment cost is established at 40€, approximately. For this reason, fatigue assessment equipment is characterized by being affordable falling within the healthcare budget.

Apart from the design and implementation of the new biomedical device, reliable recordings derived from its correct functioning have been achieved, capable of measuring fatigue induced in two 2-min fatigue tasks performed with the index finger, an isometric task and a finger tapping task. In this way, the main goal of the project has been completed: the creation of a biomedical device characterized by its simplicity, portability and low-cost that ensures solid and valid fatigue registrations thanks to its correct functioning.

In relation to fatigue measurements calculations, further analysis should be performed. The acquisition method for ISO and FT signals, in which equipment overlapping has taken place, has given rise to imprecise signal acquisitions with Biometrics DataLink equipment. The equipment of Biometrics DataLink is designed for direct signal acquisition. As a consequence, erroneous fatigue measurements have been obtained: frequency ratio and area ratio for FT and ISO tasks, respectively.

A frequency analysis (for example, Fourier transform analysis) for signal recordings may provide a more valid and reliable fatigue measurement than the peak detection algorithm implemented in this project.

A higher number of registrations should be acquired for solid fatigue measurements. An average of all of them should be performed in order to establish a valid and reliable equipment comparison.

### 5.1 Limitations

Different limitations have arisen in the course of this project which have affected its development and the outcomes of the new biomedical device:

- Strain gauge diameter has constrained calibration procedure by means of heavy and small weights. As a result, only few voltage-weight estimations accomplished through force exertion recordings have been obtained. The low number of registrations used for strain gauge calibration constrained these approximations.
- The superimposition of both equipment for posterior fatigue measurements analysis have given rise to imprecise Biometrics DataLink fatigue signals due to the essence of this equipment: nothing but the index finger should be on top of it during signal acquisition.
- Peak detection algorithm for FT tasks have demonstrated imprecise results for Biometrics DataLink acquisition. In this way, erroneous ratios have been obtained for an already tested and valid fatigue assessment equipment.
- A greater number of registrations entails more accurate and therefore, well-founded fatigue measurements attainment.
- We tested the device only on one subject, more tests should be done with real patients.

## 6 Conclusions

The result of this project shows how a complex, static and high-cost equipment the use of which is restricted to a small group of population due to its characteristics; can inspire the design of a simple, portable, and low-cost equipment the use of which can be extrapolated to daily clinical visits. Its correct functioning and solid data acquisition can provide healthcare professionals objective tests for fatigue assessment that can be standardized in the near future.

Further research should follow analysis of the recorded data and strain gauge calibration. Potential improvements for this electronic device include transmission of the data will to a server and the possibility of wireless connection to the Internet.

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