Calculation of Jump Flight Time using a Mobile Device

Ivan Miguel Pires[1,2], Nuno M. Garcia[1,3] and Maria Cristina Canavarro Teixeira[4,5]
[1]*Instituto de Telecomunicações, University of Beira Interior, Covilhã, Portugal*
[2]*Altranportugal, Lisbon, Portugal*
[3]*ECATI, Universidade Lusófona de Humanidades e Tecnologias, Lisbon, Portugal*
[4]*UTC de Recursos Naturais e Desenvolvimento Sustentável, Polytechnique Institute of Castelo Branco, Castelo Branco, Portugal*
[5]*CERNAS - Research Centre for Natural Resources, Environment and Society, Polytechnique Institute of Castelo Branco, Castelo Branco, Portugal*

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Abstract: This paper describes the research and implementation and validation method of a smartphone application that calculates a vertical jump flight time, using the data collected from the accelerometry sensors in a smartphone. To validate the algorithm results, a statistical number of experiments were performed. While recording the experimental data with a commodity smartphone, a bioPlux Research device equipped with a pressure sensor and with a tri-axial accelerometer was also used to estimate the time the user was airborne while jumping, as a golden standard. The pressure sensor was placed in a jump platform built in the laboratory, and a tri-axial accelerometer was placed on the user's waist. The data collected by this device were compared with data obtained by smartphone in order to validate the algorithm and make the necessary corrections. The research data and the developed application are available for download and further research in a free and public repository.

1 INTRODUCTION

Regular physical activity helps people avoid sedentary lifestyles, one of the causes of several physiological and health conditions that decreases the quality of people's lives (Griffiths, 2010). A sedentary lifestyle is a class of activities such as sitting, watching TV or driving, characterized by little physical movement and low energy expenditure (Tremblay et al., 2010).

While the pervasive use of technology may contribute to facilitate a sedentary lifestyle, because technology is increasingly used on the move and everywhere, by the use of devices such as smartphones, notebooks and other portable devices, technology may also be viewed as an ally to help monitor and train healthy lifestyles, supporting applications that stimulate the user to perform physical activities.

This paper describes the research on the design, implementation and validation of an application whose purpose is to measure the time of flight of a person during a vertical jump.

For the estimation of physical activities and physical exercises such as vertical jumping some people use specific devices equipped with accelerometry sensors or others, such as cardio activity sensors (Electro, 2014). Jumping is one of the exercises that can be performed at home, with no additional equipment that helps to break the sedentary lifestyle vicious cycle.

A commodity smartphone was selected to host this application because these devices already include the necessary sensors for this task, and also because smartphones are the largest growing segment for handheld devices (Alexander, 2012).

The two platforms responsible for the largest market share are Android operating system (owned by Google) and iOS operating system (owned by Apple) (Alexander, 2012). Smartphones usually integrate various sensors to perform tasks that are related to the use of the phone in a telecommunications or multimedia-browsing context. Yet some of the sensors can be used to

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measure aspects of the human user activity. The embedded accelerometer allows us to identify the person's various activities, such as running, jumping, among others (Lau and David, 2010). Some signal patterns for physical activities have been already published (Lau and David, 2010, Das et al., 2010).

Jumping is a common recreational or athletic activity. Children, in their outdoor playing activities, have many games that include jumps such as jumping rope, jumping barriers or other activities. For example, the jump flight time can be used to infer the muscular strength of the athlete/user. Regarding a user's the muscular strength, jumping is an easy task to perform as it does not require any additional equipment such as a dynamometer, or weights, because it relies on the weight of a person and his/her leg muscles (and partially the torso muscles) to carry out the activity (Jun et al., 2012). The research regarding the jump time flight is integrated on a larger research regarding the measurement of energy expenditure of a smartphone user. In this larger research, the jump flight time will be used as a mean to assess the user's fitness in physical exercise, and will be recorded in its personal log, allowing him/her to keep track of their improvement and to set a new jump flight time goal (Pires, 2012).

A jump consists of three stages, there are: take-off, flight and landing (Linthorne, 2001, Quagliarella et al., 2010). These stages can be identified by the smartphone accelerometer, but due to the possibility of movement of the smartphone in relation to the user's body, during the exercise, the gravity sensor to reduce the value of the real gravity and compensate the movements, improving the detection of these stages. Thus, the jump acceleration data for a valid jump should show three *maxima* points.

Several authors have reported different methods to detect the peaks of accelerometry signals of the movement (Palshikar, 2009, Zhang et al., 2010) and thus to calculate the jump flight time, agreeing all on the different flight stages and on the start and finish phases of the jump flight time. The calculation of jump flight time and peak detection is performed in several phases. First, the algorithm is fed with data received from the accelerometer. Second, the magnitude vector is calculated every time data is collected, and iteratively isolates the peaks to a minimum of peaks (local *maxima*). Finally, if the jump is valid, the time between the first *minimum* point, which is between the first and second *maximum* peaks, and the second *minimum* point which is between the second and third *maximum* peaks, will be calculated and this time will be considered as the jump flight time (Quagliarella et al., 2010).

When the sensed acceleration is 0 or approximately 0, *i.e.*, it is equal or approximately equal to the acceleration of gravity of Earth, this means that the person is either standing on the ground, or is reaching the highest point in the air, or is falling back on the floor (Quagliarella et al., 2010, Enoka, 2008).

For validation and adjustment of the smartphone algorithm, a secondary device named bioPlux Research (Plux, 2010) was fitted with a tri-axial accelerometer and a pressure sensor. The bioPlux Research is a device that collects and digitalizes signals from the sensors, with a sampling frequency of 1kHz, and transmits them via Bluetooth to a computer where the signals are shown, processed and/or stored in real-time. The bioPlux Research device was used as a golden standard device to collect the secondary data with more accuracy to validate the jump flight time calculated by the algorithm. The pressure sensor was used to validate the jump flight time, calculated by the algorithm in the smartphone application, as it senses when the user is placing its weight on the sensor, or otherwise, the user is flying and not in contact with the ground. The tri-axial accelerometer from the bioPlux Research device was used to further allow comparison and validation with the smartphone accelerometer data.

This research aimed to estimate the correct jump flight time with a confidence level of 95%, so a statistical relevant number of experiments was calculated and performed to allow the correct calibration of the jump flight time algorithm implemented in the smartphone application.

Thus, this research aims to describe the creation of an application for mobile platforms (Android and iOS) to carry out the calculation of the jump flight time, and also the corrections made to the algorithm as result of the validation when the results are compared to those of a golden standard. The application makes a comparison between the jump flight time of the current jump and the jump flight time of the last jump done, and keeps a history of all jumps performed and its corresponding date and time.

This introductory section presented the research scope and goals, and its research framework. It also presented briefly the means and methods used. The next section will present the related work researched by other authors. Section 3 will present the problem and the materials and methods used for the research solution. In section 4, the application and implemented algorithm are presented. Section 5 further discusses the research and presents its results. Conclusions follow in section 6, thus ending this paper.

2 RELATED WORK

Besides the application presented in this paper, there are not many smartphone applications in this field. There is some research that shows some accelerometry patterns that can be used for different types of activities by the user, such as running, jumping and walking (Das et al., 2010). Although few studies have been conducted to detect the types of physical activity of the user, there are some studies in progress, that refer to activities such as running or jumping, aiming to establish standards for accelerometry signals (Das et al., 2010).

Despite the few studies on this topic, several studies were carried out in order to identify the characteristics of a jump. These studies were used to try to identify the time when people are not with their feet on the ground during the jump (Palma et al., 2008, Szmuchrowski et al., 2007). These experiments use jumping platforms (Favre et al., 2005, Júnior et al., 2011, Linthorne, 2001) with people of different ages, while also use accelerometry sensors to create the pattern of acceleration signals for the jump.

According to (Quagliarella et al., 2010), a jump is made up of three stages in which each user performs different activities. These are:

- **Stage 1:** Preparatory stage for the jump, which includes bending the legs and impetus to make the leap;
- **Stage 2:** Stage related to the flight, which is the time at which the user is suspended in air;
- **Stage 3:** Stage related to landing on the floor, which encompasses all activities of returning to the starting position (with their feet).

The aforementioned stages are detected by using the accelerometry sensors' data taking into account the acceleration highest points of the same jump after removing the value of the actual gravity using for this a peak detection algorithm (Palshikar, 2009, Zhang et al., 2010, Quagliarella et al., 2010).

If the original data of the accelerometer is used, including noise and the effect of the Earth's gravity, the result is:

- During stage 1, the values of the magnitude vectors for the collected data are above the value for the Earth's gravity (9.81 m/s^2);
- During stage 2, the values of the magnitude vectors for the collected data are below the Earth's gravity;
- And during stage 3, the values of the magnitude vectors for the collected data are again above the Earth's gravity.

Throughout this paper several experiments were carried out in order to more clearly identify the starting and ending points in the different stages of the jump, as some authors do not share the same ideas.

3 PROBLEM

Currently, in order to calculate the jump flight time of a person, a force platform is used to estimate how long the user is suspended in the air (Bonde-Petersen, 1975),

The calculation of jump flight time using a smartphone arose from the need to create a training application that could be used in a simple manner as a means to stimulate the user's physical activity. The larger research framework that integrates the jump flight time application includes the use of the accelerometer to measure the caloric expenditure of the user, and the recording of such values in a web platform. This framework also comprehends the jump flight time application, which can be used to monitor the user's fitness while jumping. Although jumping is an activity that only uses a subset of the person's muscular abilities, namely those of the legs and partially of the torso, it is also one of the simplest exercises that can be performed in a short period of time and does not require additional equipment. Furthermore, the accelerometers in the smartphone are able to measure the time of the flight with a reasonable precision.

While keeping a record of the user's jump flight time, the application allows the user to try to improve the time of the jump. The jump should be made vertically, and the user is instructed to hold the smartphone immobile and close to the chest while jumping (Favre et al., 2005, Linthorne, 2001, Palma et al., 2008, Jun et al., 2012). The duration of the jump flight stage is evaluated by analysing the accelerometer data (Palma et al., 2008, Quagliarella et al., 2010, Susana et al., 2007).

The identification of the airborne period is somehow complex especially when using a mobile device held in the user's hand. The identification of the several stages of the jump has additional complexity, for example if the smartphone is inadvertedly rotated during the jump (Mizell, 2003).

In order to minimize the movement of the smartphone during the jump, the application screen displays a warning with some rules that must be followed by the user in order to create a valid jump. If the stages of the flight are not clearly identifiable, this means that maybe the jump rules weren't followed, and the jump is considered invalid.

The data obtained by the smartphone application also varies with the age, weight, height, gender, lifestyle or fatigue of the person who is performing the jump. Therefore, it is not possible to compare the data across users, and there is the need to implement signal filtering to minimize the noise that can be generated by the users particular conditions.

The jump flight time must be presented as simple as possible by the application and it must be possible for the user to make a comparison of all jumps performed in the training sessions. The application should be able to save all jump data so that the user is able to check the evolution of his/her jump flight times.

An algorithm was created from previous research literature (Quagliarella et al., 2010). Yet the results returned by the algorithm need to be validated by comparing the obtained data to the data obtained by a *golden standard*. The algorithm implemented in this application was validated as described in the following sections and a model was created to minimize the error in the calculation of the jump flight time. For this validation several experiments were carried out. The user sample was formed by 10 healthy individuals, 3 female and 7 male, aged between 20 and 35 years old, with weights between 45kg and 80kg and heights between 150cm and 170cm. The users performed vertical jumps in the jump platform containing the pressure sensor while keeping both the smartphone and an additional accelerometer on the waist. The smartphone was running the developed application and the pressure and accelerometer sensors were connected to the bioPlux Research device serving as *golden standard* measurement device.

The algorithm results were compared with the results obtained by the bioPlux Research device and the algorithm was modified so its results can be as close as possible the results from the *golden standard*.

The final result of the algorithm is the jump flight time statistically and scientifically valid for helping to the detection of jumping activity.

4 APPLICATION

4.1 Application Construction and Development

Two applications were developed for iOS and Android smartphones, using its respective embedded sensors to collect motion data.

Initially, a prototype was developed and tested by different users comprehending different ages, lifestyles, weights and heights. The prototype allowed the development of the features that did not require validation, such as user input interfaces, application output, application communication with the web servers and so on.

Finally, the application was designed as to have a user-friendly design, with little user interaction. A 5 second delay was defined as the time between the user click on the start button and the beep indicating the user should jump. The user should use this delay time to place the smartphone device on a static part of the body to measure the jump flight time. The measurement of the jump ends when the user presses the stop button or 10 seconds after the initial beep. All jumps are stored in a local database on the device in order to check the progress of their jump flight times.

The developed application has a start screen with a start/stop button. The screen also shows the value of previous jump (if there is a jump in local database) and the state of the application (standby, waiting or jumping). Several screenshots of the application are shown if figure 1 (a) through (e). Figure 1 (a) shows the screen when the application is idle and ready for a new jump recording. After selecting the button to start to collect data to calculate of jump flight time, the state of application changes from standby to waiting (figure 1 (b)). After the 5 second waiting time, the state of the application changes to jumping (figure 1(c)).

The goal of the developed application is that the user may be able to compare his/her jumps in order to improve them. Thus, it is expected that this application motivate the user to try to improve his/her jump times. The application implements a screen that shows the user's jumps over time. This screen is shown in figure 1 (d).

This application has a multi-language implementation, implementing Portuguese, English, Spanish and French languages. This is customized in the screen containing the configurable settings of the application, visible in figure 1 (e). In this screen, the user will also be able to activate or deactivate the sound in the application.

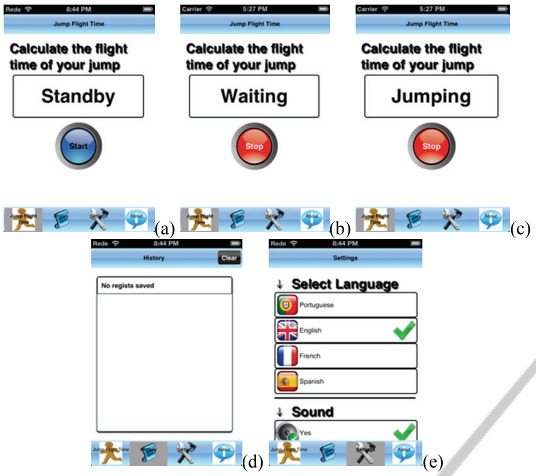

Figure 1: Application sample screens. Screenshot (a) shows the application start screen. Screenshot (b) shows the application screen while waiting for the beep sound to start collecting data of the jump. Screenshot (c) shows the application screen while application is collecting the data of the jump. Screenshot (d) shows the application history screen. Screenshot (e) shows the application settings screen used for changing the language and sound settings in the mobile application.

In general, the main screen layout of the application has very simple usage, consisting at a large start/stop button to activate the sensors capture.

In the next section, the experimental tests done for the construction of the mobile application are presented.

4.2 Experimental Setup

In order to create the application presented in the previous section, several experiments were conducted to optimize the algorithm previously created and based on what was described in the literature. Initially, the algorithm detected the maximum acceleration peaks in the all data collected during the jump. If there are three highest peaks, the jump flight time corresponds to the time between two acceleration minimum points between these three maximum acceleration higher peaks.

During the data collection, the application calculates the value of acceleration/magnitude vector of the movement (Felizardo, 2010), not considering the effect of gravity, *i.e.*, the movement resulting value is calculated as shown in equation (1),

$$\alpha = \sqrt{x^2 + y^2 + z^2} \qquad (1)$$

in which x, y, and z are the values returned by each of the axes of the accelerometer. The values of the magnitude vector/acceleration calculated are then stored in a data structure for further computation after the user has pressed the stop button or the timeout period has occurred.

Authors such as (Favre et al., 2005, Linthorne, 2001, Quagliarella et al., 2010, Susana et al., 2007), define the jump as composed of up to three variations of the acceleration: a more pronounced stage (the smallest) is the take-off stage, corresponding to the stage in which the person bends his/her legs and is still with his/her feet on the ground; the following two changes correspond to the time when the person performs the jump, giving the lift of impulse, and finally, when the person gets back with his/her feet on the ground. Thus, the acceleration value increases when the user jumps and when the user is falling to the ground, as it is shown in the figure 2. Figure 2 (a) shows the raw data plot with data collected during one jump, figure 2 (b) shows the three stages of the flight, and figure 2 (c) shows the interval that will be considered as the flight itself.

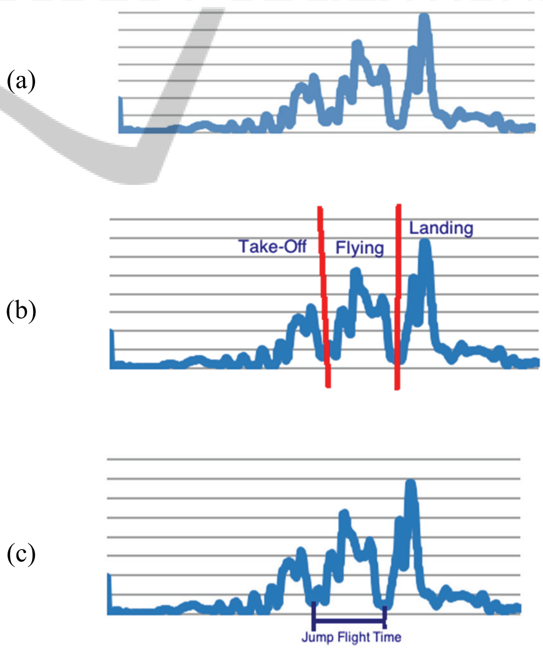

Figure 2: Sample jump graph, showing the raw data plot (a), the three stages of the jump (b), and the flight interval (c). The Y-axis is linear and represents an arbitrary unit returned by equation (1), related to the values returned by the accelerometer sensor in the smartphone. The X-axis represents sampling time, in a linear manner.

The data is processed to allow the location (timestamp) of the highest peaks (local *maxima*), and this is done recursively to obtain the three maximum higher peaks of a jump and calculation of the jump flight time, as follows:

1. After the process of collecting data, the data is validated according to some conditions in order to validate or invalidate the jump, checking whether the user jumped correctly or not. So in order to validate the jump, the data collected is checked to see if it passes the next following conditions (one or more):
   - The acceleration value of the initial time of collection data (first value of acceleration calculated from the accelerometer outputs) is lower than the acceleration value of the final time of collection data (last value of acceleration calculated from the accelerometer outputs);
   - The acceleration value of the initial time of collection data is lower than the acceleration value of final time of collection data plus one (used to introduce an error margin of $1 m/s^2$);
   - The last condition tested is if the acceleration value of the final time of collection data is lower than $2 m/s^2$.

   If any of the above conditions is considered as being false, the algorithm stops and the jump activity is considered invalid;
2. When a local maximum is found in the series, its location (timestamp) and acceleration value are stored to a new data structure;
3. This process is repeated for the values in the new data structure until there are three or less peaks and leaving three or more peaks of the previous execution;
4. If at the end of this process (if the average value is between zero and one) the jump is invalidated, it means that the user didn't jump and the algorithm stops;
5. If at the end of this process, more than three peaks are found, the average value of these peaks is calculated. The peaks whose value is below average are discarded;
6. If after discarding the values, the number of peaks is below three, the algorithm stops and the jump is invalidated;
7. When the previous steps of the algorithm are concluded, the three *maxima* discovered peaks will coincide with the three highest values of the series;
8. Finally, the algorithm searches the *minimum* value between the first and second *maximum* peaks and the *minimum* value between the second and third *maxima*. The difference of the locations (timestamps) of these two *minima* shows the jump flight time.

Figure 3 describes the algorithm implemented in the smartphone application, with an activity diagram. The execution of the actions is iterative, as referenced in the description of the algorithm and in the end the jump flight time is calculated and displayed, adjusted with a correction factor obtained

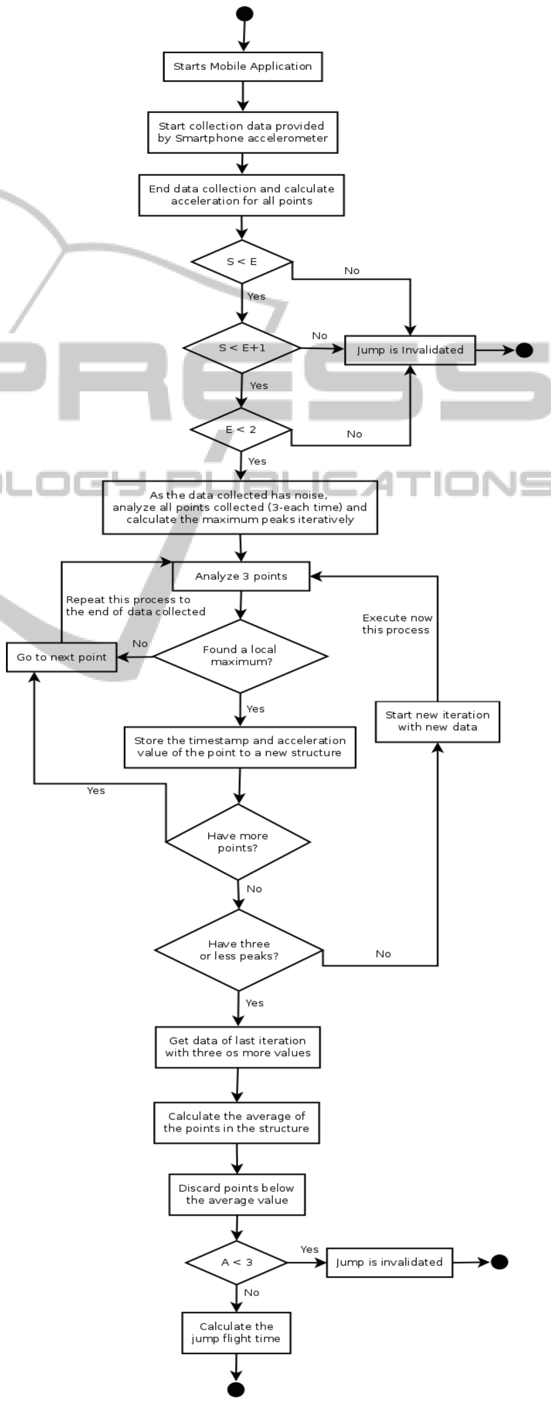

Figure 3: Activity diagram representing the algorithm implemented in the smartphone application.

by the validation phase and explained in the next sections of this paper. In the activity diagram is used some abbreviations, these are:

- *A* ➔ all points currently in the structure;
- *E* ➔ acceleration value of the end time of collection data;
- *S* ➔ acceleration value of the initial time of collection data.

The process of the calculation of jump flight time done, when the jump is invalidated of jump flight time is returned.

Yet, the values returned by the algorithm need to be validated. Furthermore, we need to calibrate the measurement of the sensors, and for this, an additional set of parallel measurements was taken.

4.3 Experimental Results

After the initial activities performed to create the initial draft of the algorithm, other experiments are performed with a pressure sensor and an accelerometer connected to the bioPlux Research device that returns the data in millivolts, and the mobile device sensors (accelerometer and gravity sensors) that return the data in m/s^2. The calculation and conversion of the units for the comparison between different data was performed, obtained a values of the 1G of the bioPlux Research device equals to 1528.01734mV.

Thus, after creating the initial draft of the application, a batch of sixty additional jumps was made, recording both the data from the smartphone accelerometer and the data from a pressure sensor, placed in a platform over which the jumps were performed. The number of jumps was defined according to the task at hand, the calibration of the pressure sensors and accelerometer of the bioPlux Research device. The pressure sensor was connected to the bioPlux Research device, returning a value of zero or close to zero when the user was in flight, *i.e.*, when the recorded values were very close to 0 in the data obtained by the pressure sensor, the foot of the user isn't on the ground and, therefore, this time the user is in the flying stage of the jump.

After completion of the sixty jump experiments, the comparison between the graphs of the data achieved by the various sensors was carried out. Thus, it was found that there are some differences in the jump flight time provided by the graphs of the data of sensors connected to the bioPlux Research device (accelerometer and pressure sensors) and the graphs of the data of sensors of the smartphone sensors (accelerometer without gravity, using gravity sensor to remove real gravity from

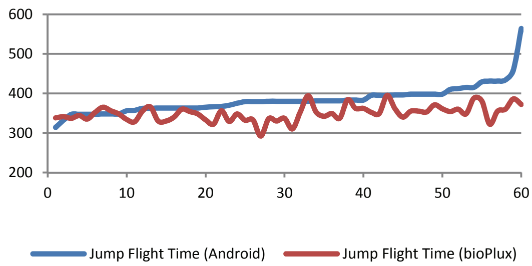

Figure 4: Graph comparing jump flight time calculated by the application in the smartphone and the time measured by a pressure sensor connected to a bioPlux Research device.

accelerometer values). In the figure 4 is showed a graph with a comparison between the jump flight time measured by the smartphone application and the jump flight time measured by the data collected with a pressure sensor connected to a bioPlux Research device. In the most number of experiments, the jump flight time measured by the smartphone application is highest than a real jump flight time measured by the pressure sensor.

The jump flight time presented in figure 2 (c) shows that unless you're evading the real gravity to the accelerometer data from the smartphone, the acceleration values will be negative when subtracting the value of terrestrial gravity (9.81 m/s^2). If the values of acceleration, when subtracting a real gravity from the acceleration calculated by data collected in the smartphone accelerometer were negative, the data would be recorded as the absolute value of these values. Thus, the acceleration is 0 when it is equals to the Earth's gravity. As a result, the jump flight time is the time between instants in which the acceleration is equal to zero, when acceleration increases and decreases, between two *maximum* peaks.

Figure 5 shows the data collected for a particular jump. Figure 5 (a) shows a graph generated by the data collected by the smartphone sensors and the algorithm presents a jump flight time of 380 milliseconds. Figure 5 (b) is a graph generated by the data collected by bioPlux research sensors (pressure and accelerometer sensors) and the real jump flight time has been calculated as having duration of 336 milliseconds. Considering that the measurement taken by the pressure sensor at the bioPlux Research device is the golden standard, the estimated error of the algorithm presented in smartphone application is presented in equation 2.

$$Error = \frac{380 - 336}{336} \times 100\% = 13.0952\% \qquad (2)$$

(a)

(b)

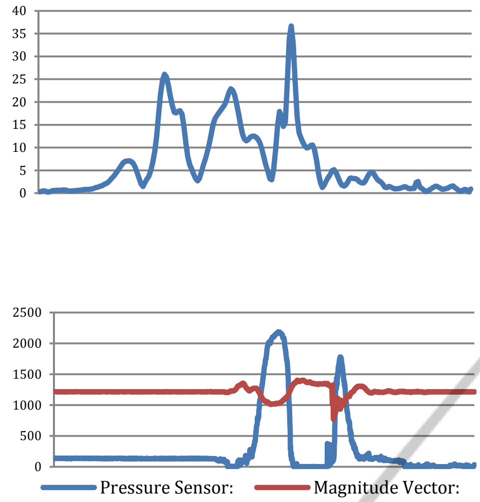

Figure 5: Jump Graph for data collected by smartphone sensors (a), and data collected by bioPlux research sensors (b). The Y-axis is linear and represents an arbitrary unit returned by equation (1), related to the values returned by the accelerometer sensor in the smartphone (figure a) or the values returned by the accelerometer (red plot in figure b). The X-axis represents sampling time, in a linear manner.

In the sixty jump experiments which were carried out, the errors were different in all jumps and the dispersion of the errors, when comparing data between value of jump flight time in smartphone algorithm and bioPlux research sensors, is very high.

In a second step towards the validation of the smartphone algorithm, and using the data from the sixty jump experiments, it was necessary to define the minimum number of experiments required to have a confidence level of 95%.

Thus, to have a confidence level of 95% in order to later be able to reduce experimental error, the Student T-test was used to determine the minimum number of experiments needed (Draper and Smith, 1998, He et al., 2007). It was found that the minimum number of experiments required was 542 jump experiments, approximately.

Due to errors obtained during the sixty experiments previously carried out and the highest dispersion found, another set of 550 jump experiments was conducted to attempt to determine the experimental error with a confidence level of 95%. In figure 6 is showed a comparison graph related to the jump flight time of various experiments measured by the smartphone application and by a pressure sensor connected to a bioPlux Research device.

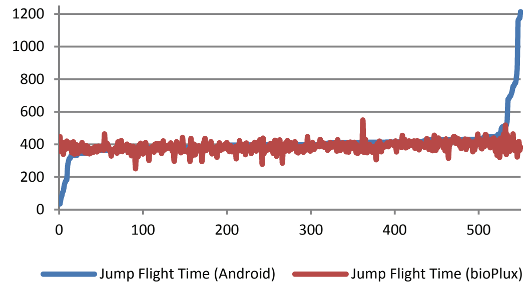

Figure 6: Graph related to the final validation, comparing the jump flight times calculated by the smartphone application and the jump flight times measured by the pressure sensor.

All jump experiments were done by healthy people, female and male, aged between 20 and 35 years, weights between 45kg and 80kg and heights between 150cm and 170cm. These people performed vertical jumps in the jump platform (with the pressure sensor placed in it) and with the smartphone placed on the waist, running the developed application, and also wearing the bioPlux Reseach accelerometer on the waist, attached to the golden standard device. The data from the bioPlux Reseach device, used as golden standard, was collected at a sampling rate of 1kHz, and transmitted wirelessly using Bluetooth to a computer nearby.

After carrying out the new experiments, a higher dispersion of error data was equally found. The most probable answer to this high dispersion is the highly variable parameters for each person during the jump, *e.g.* holding the smartphone in different ways. Yet, within the same person, the variability is minimum.

According to (Carrillo, 1989, Margulies, 1968, Selvakumar, 1982), the method of least squares adapted to the collected sets of data was used to reduce the experimental errors, returning an equation applicable to the value previously calculated in the algorithm that was already implemented in the smartphone application.

As showed in figure 7, comparing the jump flight time measured by the pressure sensor and a jump flight time measured by the smartphone application, the jump flight times calculated have a large dispersion of data errors. So, this algorithm needs an adaptation for show results with more accuracy. This number of experiments, as referred above is the minimum number of experiments needed for have results with a confidence level equals to 95%. The equation showed in the figure 7 allows reducing the errors, if applied to the errors obtained by the algorithm.

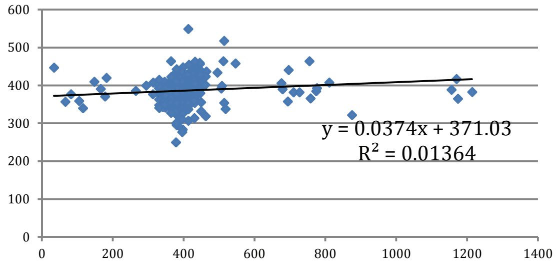

Figure 7: Graph comparing the values obtained from the bioPlux device and the values obtained from the application using the smartphone sensors. The Y-axis refers to the values measured by the bioPlux Research device and the X-axis refers to the values measured by the application in the smartphone. The solid line shows the linear regression obtained for this data set.

So, the algorithm presented earlier for the smartphone application was optimized by applying the equation obtained by the method of least squares of the value obtained by the algorithm, showed in Figure 7, and the value presented to the user is the value after applying equation 3,

$$y(ms) = 0.0374x + 371.03 \quad (3)$$

in which y is the final value showed to the user in the smartphone application and x is the value obtained by the smartphone application with the algorithm implemented before applying the equation 3.

As a result, in a jump with the smartphone placed on the user's waist, the implemented algorithm obtained an example value equals to 421 milliseconds, which corresponds to the value of the jump flight time. On the other hand, at same time, the value measured with the data collected by the sensors connected to the golden standard device is 386 milliseconds. This means that the error between measurements is equal to 9.0674%, as showed in equation 4.

$$Error = \frac{421-386}{386} \times 100\% = 9.0674\%. \quad (4)$$

So, the model represented by equation 3 is applied and the value of jump flight time obtained is equals to 386.7982ms, as showed in equation 5.

$$y(ms) = 0.0374 \times 421 + 371.03 = 386.7982 \quad (5)$$

Thus, the error obtained is equal to 0.2069%, proximately zero, as showed in equation 6,

$$Error = \frac{386.7986-386}{386} \times 100\% = 0.2069\%. \quad (6)$$

As shown in the equations 4-6, after the adjustment of the algorithm based on the method of least squares created with the last experiments, a verification of a low correlation between the results of various sensors is difficult to explore the statistic and scientific validation of the mobile application developed. However, the method of least squares adapted to the dataset of the values obtained minimizes the errors. After the implementation of the equation obtained in the algorithm, the experiments were repeated and the errors obtained by the algorithm are very small and the values of the jump flight time obtained are very approximated to the real values. Thus, the mobile application developed can be considered valid for the major part of the experiments, helping to improve the people's lifestyle, depending the results on the environmental features.

5 DISCUSSION AND RESULTS

As discussed in previous sections, the jump flight time will follow a certain pattern. If the jump does not follow the expected pattern, it will be invalidated. The jump can also be invalidated for other reasons such as the resulting from changes of the position of the smartphone during the jump.

Some errors may also be obtained due to the differences in the sampling rates in the smartphone and the sampling rate of the bioPlux Research device. The bioPlux Research device has a 1kHz sampling rate, *i.e.*, the samples are recorded each millisecond, and in the case of smartphone, due to its multitasking capabilities, it is estimated that each sample is collected at approximately every 10 milliseconds. Of course, when dealing with jump flight times in the order of hundreds of milliseconds, the lack of precision of the smartphone clock may introduce an additional level of uncertainly and error in the calculations.

The experiments were performed in the laboratory, and an effort was made to control all the variables as much as possible, particularly those related to the jumping conditions of the human subjects, namely, temperature, relative humidity number of consecutive jumps, and time of the day the experiments took place.

The ideal use application scenario would be to place the smartphone so as not to move in a precise position of the body (*e.g.,* the user's waist) but this is not always possible because of the movement the user needs to do in order to jump.

The errors are very dispersed, because the environmental conditions are difficult to control, and as a result of this, the collected data has noise and imprecisions. The major source of noise is the accidental mobility of the smartphone during the jump when placed on the waist of the user. The major source of imprecisions is the uncontrollable sampling ratio of the sensors in the smartphone (approximately, 10kHz). The tests were done with a set of volunteers, whose range of morph-physiological characteristics are not ergodic when representing the whole range of humans, and therefore, it can only be claimed that the algorithm is validated to the extent where the user shares some of these characteristics.

So, despite the dispersion of the errors obtained, the method of least squares was used to obtain an equation that reduces the error of the calculated value so that in 95% of cases, the mean percentage error (MPE) is equal to 5.99%.

The application source code, the application itself, and the data that was used in this research are available at the ALLab (*Assisted Living Computing and Telecommunications Laboratory*) MediaWiki website (Signals, 2012).

6 CONCLUSIONS

In conclusion, it is possible to say that a smartphone accelerometer can be used to develop methods to control the user's physical activity, particularly to calculate the jump flight time.

For this study, an algorithm that uses as input the data from the triaxial accelerometer embedded in a commodity smartphone was used. The algorithm was further validated with a golden standard, in this case, the bioPlux Research device equipped with a triaxial accelerometer and a pressure sensor. A relevant number of experiments was carried out and a new adapted equation for the estimation of the jump flight time was integrated in the algorithm implemented in the smartphone application.

The developed application is available in the Google Play and the iTunes online stores (links are: https://play.google.com/store/apps/details?id=com.imspdev.jumptimecalc; https://itunes.apple.com/us/app/jumptimecalc/id654811255?mt=8).

As future work, the researchers propose to estimate also the jumping height using the data from the built-in accelerometer of the smartphone. The users will be able to visualize the relationship between height and length of a jump, and relate this to the user's height, weight and physical fitness. Moreover, because of the inherent differences in the morphological and physiological muscle-skeleton systems for different genders, a new algorithm will be researched.

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