Inertial Measurement Unit: Evaluation for Indoor Positioning

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Inertial Measurement Unit: Evaluation for Indoor Positioning

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***Abstract*—In this paper, we tackle the problem of indoor positioning, where the GPS signals are unavailable and the energy consumption of battery powered mobile devices should be carefully considered during the positioning process. For this purpose, we study the inertial navigation system (INS), which uses only a set of inertial sensors, that represent an Inertial Measurement Unit (IMU), attached to the mobile without referring to any external positioning system. This technique is characterized by its low cost and low energy consumption, while ensuring an effective positioning in indoor environments. The aim of this work is to evaluate the IMU in order to develop an indoor positioning application. A set of tests were made with the accelerometer to examine its accuracy and its use in the process of positioning. The obtained results are encouraging and allowed us to develop an android based positioning application with an acceptable degree of accuracy.**

I. Introduction

The geo-location or the positioning, is the process of finding a position of a person or an object related to one or more reference points (with known positions). The geo-location has been a concern for the human from the most primitive times, using various techniques, starting with smoke signals, passing through the magnetic compass and arriving in our days to the use of satellites. The GPS (Global Positioning System) [1] has achieved a great success in various fields such as marine, terrestrial, fleet tracking, etc. This system is based on GPS receivers that receive freely signals sent by satellites to accurately calculate (in open areas) the global coordinates of the receiver [2][6]. Recently, the GPS receivers were integrated into Smart-phone devices, allowing the former to act as a practical navigation tool. However, the GPS is known by its high energy consumption and its low precision in closed areas (indoor) which limits its use for devices with limited energy resources, such as Smart-phones [7].

The INS (Inertial Navigation System) is an approach fully autonomous that is based on an Inertial Measurement Unit (IMU) which integrate velocity and acceleration sensors to track the movement of a mobile [2][9]. This approach does not require any external information, reason why was used for locating the missiles used during the First World War and still preferable for flight safety and military vehicles. This independence considerably reduce the energy consumption during the localization process and allows the positioning for both indoor and outdoor areas.

The purpose of this work is to study and use the INS to develop a positioning application for devices that has a limited energy resources in confined areas. The study of the INS requires a good understanding and the evaluation of inertial sensors embedded in Smart-phone devices. In this paper, we focus our study on the evaluation of the *accelerometer* sensor and its use for movement detection and velocity calculation. Therefore, two test scenarios were defined in which we show how the accelerometer can be used to estimate the position of the mobile.

The rest of the paper is organized as follows. Section 2 provides a background on the accelerometer inertial sensor and reports the results of two experiments that evaluate the accuracy of a commercial accelerometre sensor embedded in a HTC Smart-phone. The implementation of the different obtained results, to develop an Android application, is presented in Section 3. We give a conclusion to this work and evoke future works in Section 4.

II. Test and evaluation of the inertial accelerometer sensor

The accelerometer measures the acceleration of a mobile during its movement, which represents the strengths applied to one of the accelerometer axes (x, y, z) (see Fig. 1(a)). These forces can be statics, due to the gravity, or dynamics, due to the movements and by measuring the dynamic acceleration, it will be possible to analyze the movement of the mobile [5]. Its principle is based on the fundamental law of the dynamics $F = M.a$, where F represents the force applied on an object, M is its mass and a is its acceleration.

The accelerometer is integrated into most of the new generation Smart-phones and the directions of its three axes are as shown in Fig. 1(b).

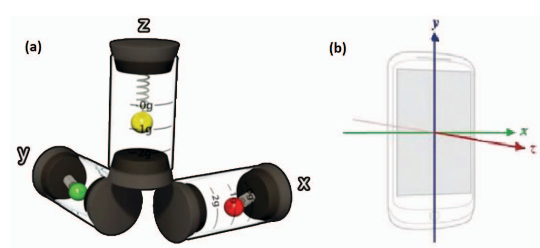

Fig. 1. The axis (x, y, z) of accelerometer.

To evaluate the accuracy of the accelerometer and use it

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in the process of positioning, we define two test scenarios. The first scenario consists of analyzing the acceleration values to detect if the mobile is in movement or in rest state. This information will be used to track the mobile position, where the speed is considered as constant. The second scenario consists of analyzing the values of the acceleration to calculate the mobile velocity. According to the calculated velocity, if the mobile direction is known, the position of the mobile can then be calculated and its accuracy depend on the accuracy of the measured acceleration.

A. Scenario 1: Position calculation based on mobile state detection with a constant velocity

This scenario simplify the process of the position calculation, based on some abstractions, by assuming that the mobile velocity and its direction are constant. Usually, the walking speed of a person which hold a mobile, is constant. The accelerometer in this case is used to determine in which state the mobile is, i.e., in movement or in rest. The starting point can be obtained through a WIFI, GPS network or by a manual configuration. During the experience, at a starting point, a person holds a Smart-phone horizontally on his hand (the axis z point towards the sky), makes a walking during a period of time and after that he stops. The graph in the Fig. 2 represents the values of the measured acceleration on the three axes (x, y, z) during the different states of the mobile.

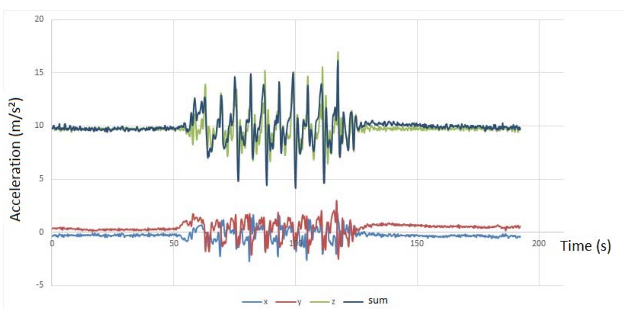

Fig. 2. Accelerations graph of a mobile in walking and stop.

We notice that the values of the acceleration on the axis z are always different than zero (greater than $9.89m/s^2$), even in stopping state, and it is due to the gravity effect. To eliminate this effect, which prevents to distinguish between the stopping and walking states, we use the variation of the acceleration between the values of two measured accelerations. The variation of the acceleration is then calculated using the following formula:

$$Variation = |OldAcc - CurrentAcc| \tag{1}$$

Where $OldAcc$ is the previous measured acceleration and $CuurentAcc$ is the current measured acceleration. It's clear that during a movement, the variation between two values of the acceleration is different than zero and should be null during the rest. The graph in Fig. 3, plots the variation of the acceleration measured during the rest. As the sensor is very sensitive to the small shacks of the hand, even in stopping state, the recorded values are different from null. To overcome this problem, it is necessary to make a calibration, which consist in adjusting the values of the acceleration due to the mobile shaking. After some experiments, we have observed that when the Smart-phone is kept on the hand, without movement, the value of the variation of the acceleration is around $0.38m/s^2$. This value will be used as a reference for the rest state.

To put into practice this first scenario, a test of walking was made, and the obtained results are illustrated in the table 1.

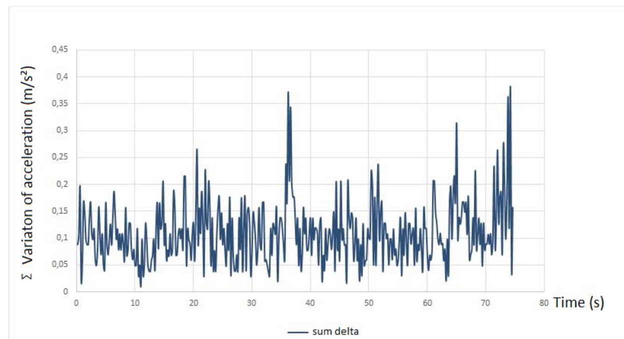

Fig. 3. Graph of acceleration variation's sum of mobile in hand.

TABLE I
RESULTS OF THE FIRST SCENARIO

Real distance (m)	11	22	33
Estimated distance (m)	10.92	21.87	31.72
Error (m)	0.08	0.13	1.28

The real distances traveled during the test are given in the first line of the table. During this test, we moved on a linear trajectory, and we stopped twice. The estimated distance is very accurate when the travailing distance is short, but we can notice that when the distance increases the error increases with. This is due to the fact that we have assumed a constant velocity of the mobile, which is not a very accurate assumption.

B. Scenario 2: Position calculation with an unknown speed

This scenario achieves a more advanced experience than the previous one. The experience has for objective to calculate the velocity during the movement of the mobile, contrary to the first scenario where the speed is supposed constant during the entire test.

This scenario is divided into two experiences; the first experience required the manufacturing of a fixed platform to eliminate the shacks. This platform contains:

- An iron bar of two meter.
- A Smart-phone fixed to a wooden object which can slide on the bar.

This platform eliminates the shocks of the hand. In this test, we shall slide the object which carries up the Smart-phone to a meter, then we stop during 5 seconds and at the end we push away the object until the end of the bar (see Fig. 4).

The second experience consists in holding the Smart-phone in the hand of the moving person and maintaining a linear direction which follows the y axis of the Smart-phone. The experience will take place as follows: a walk of four meters then a stop, then a walk of four meters. The calculation of the position in this scenario will be made through three steps, at the beginning, the acceleration will be measured from the accelerometer, then integrate it to obtain the velocity. The integration of the calculated velocity gives the position. The following formulas illustrate the calculation of the position:

$$V = \int a \ dt \tag{2}$$

Where V is the velocity and a is the acceleration.

$$P = \int v \ dt \tag{3}$$

Where V is the velocity and P is the position.

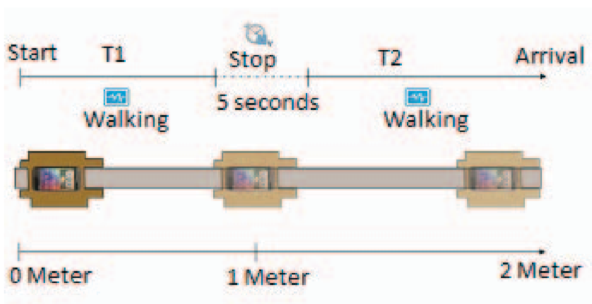

Fig. 4. Experience of the second scenario.

The first test consists in analyzing the values of the acceleration measured on the platform after the calculation of the speed and the distance with the formulas seen previously, the results are plotted in the Fig. 5.

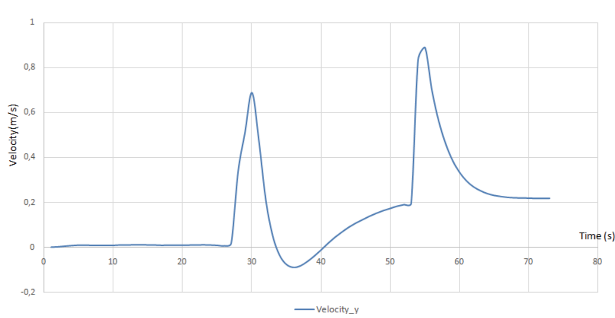

Fig. 5. Velocity's graph of the axis Y using the platform.

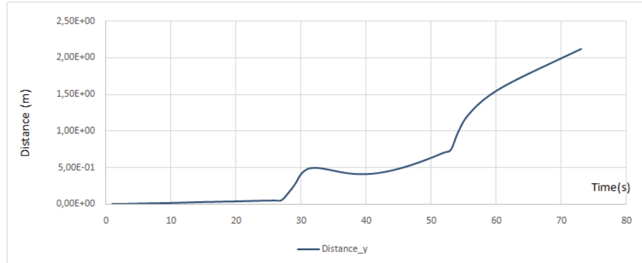

Fig. 6. Distances graph of the axis Y using the platform.

After the observation of the results of the distance on the platform, we notice that the distance increases with time, but the values are not coherent with the experience. For example, in the real experience the first stop is made in the middle of the bar (1 meter) except the graph indicates that the first stop is made at $0.5m$ from the starting point. To eliminate these errors, due mainly to noises, we will use later filters.

1) Filters: A filter is a linear electronic circuit whose behavior depends on the observed amplitude and frequency. In other words, it attenuates (reduces the amplitude of) signals with a specific frequencies and let passes the others signals [8]. In our case the filter eliminate the noises due to the shocks during the movements. Two types of filters were chosen in order to obtain a correct results.

High pass filter: is a passive filter which allows to pass only the high frequencies of the entered signal and filters low frequencies [8]. We use this filter to eliminate the gravity effect and then calculate the linear acceleration which allow us to estimate the velocity. The following formula is used to calculate the linear acceleration:

$$Gravity = \alpha \times gravity + (1 - \alpha) \times Acceleration \tag{4}$$

$$LinearAcc = Acceleration - gravity \tag{5}$$

Where $gravity$ is the value of the gravity force, $Acceleration$ is the acceleration measured by the accelerometer sensor and α is a weighting coefficient of the filter. α takes values between 0 and 1, this coefficient associates a weight to the old filtered value. For the fixed platform experiment, after several tests we noticed that the value of the coefficient $\alpha = 0.25$ is the most adequate. For the second experience, where the Smart-phone is hold on the hand, we noticed that the previous value of α doesn't lead to accurate results. For this, we made several others tests using different values of α. The value which gave a coherent results with the experience is 0.18. The graph in the Fig. 7 illustrates this results.

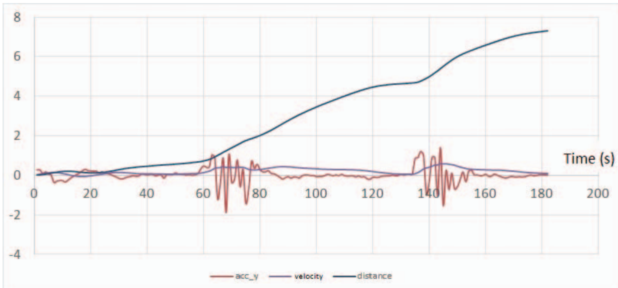

Fig. 7. Graph walk test with $\alpha = 0.18$.

The graph shows that the mobile has moved for 4 meters then stopped, then had another 4 meters movement.

Infinite Impulsive Response (IIR) filter: is a digital filter, called recursive filter because its output depends at the same time on the input and the output signal. The impulsive response is a varied value which takes a lot of time to stabilize or will never stabilize even in the infinity. Its formula is as follow:

$$FilterAcc = (\alpha \times OldAccelFil) + (1 - \alpha) \times LinAcc) \quad (6)$$

After applying the filter on the measured acceleration, we plot both the calculated velocity and distance in Fig. 8 and Fig. 9, respectively.

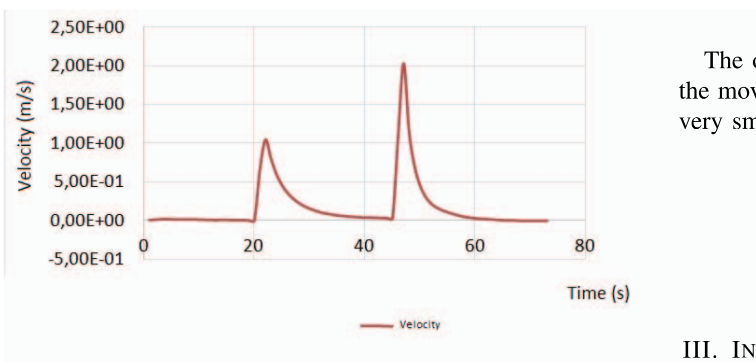

Fig. 8. Graph of the final velocity on the axis Y using filters on platform

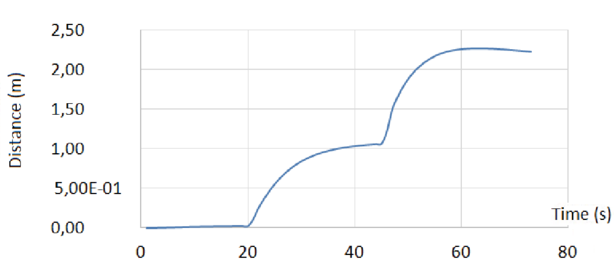

Fig. 9. Graph of the final distance on the axis Y using filters on platform

The graph in the Fig. 9 indicates that the calculated distance on the platform, when using filters gets a closer results to the reality. From the graph we can observe the stop moment at the beginning, then the walking of a meter, then stop, and finally another walking of a meter, which reflect the real experiment.

For the second experience, where the Smart-phone is hold on the hand, we plot the results in Fig. 10. The graph shows the estimated distance in function of times based on the filtered acceleration values of the Y axis.

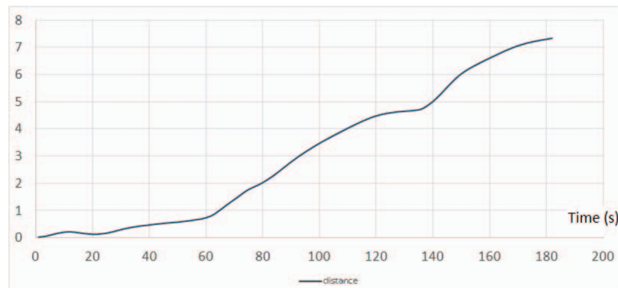

Fig. 10. Distances graph of the axis Y using filters, where the Smart-phone is hold on the hand.

The obtained results indicates that the traveled distance by the moving person is very close to the real experiment with a very small errors.

III. Indoor-Dalil: Smart-phone indoor positioning application

To implement the results of the previous tests, we designed a mobile application for Smart-phone; this application is named Indoor-Dalil (Guide). The global architecture of this application (see Fig. 11) is structured in 3 sub systems (positioning, mapping and user interface). The main sub-system of processing is called positioning, it receives in input the the measures values by the accelerometer and gives in output the calculated position of the mobile. The sub-system mapping treats maps, their structures and draws the estimated position on the map. The sub-system user interface shows the information handled by the sub-system of positioning, and shows the position of the user on the map.

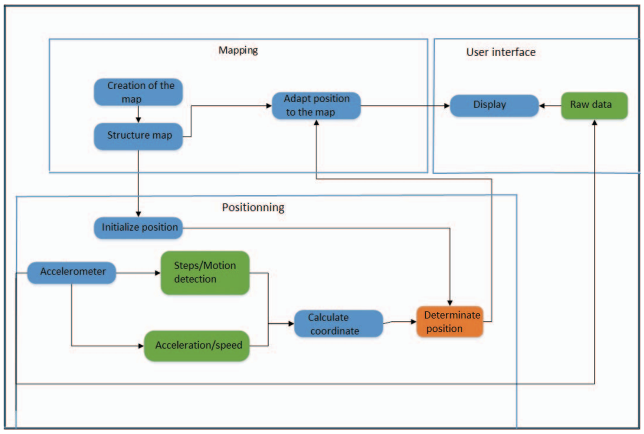

Fig. 11. General architecture of the application.

We have developed our application under the Android system [10], this choice was made on the fact that Android is an Open source, powerful platform, and modern. Android allows the developers to obtain the permission to integrate, to enlarge, and to replace the existing components.

The project was implemented in Java, the most adequate environment to realize such implementation is eclipse, which is an Integrated Development Environment (IDE), the most performing, and by installing the plug-in SDK Android, this plug-in install all the necessary tools for the development of Android applications. The Smart-phone used during this work is an HTC sensation provided with an Android operating system version 4.0 ”Ice Cream Sandwich” OS.

The results obtained during the tests of both scenarios were merged and the different results are presented in the following paragraphs.

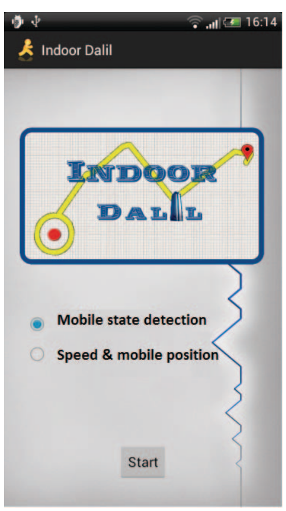

Fig. 12. Main interface of the indoor-Dalil application

Fig.12 represents the main interface of the application, it proposes to choices between two type of application scenarios, i.e. (i) calculate the position by detecting the state of the mobile or (ii) calculate the position by calculating the velocity of the mobile. If we choose the first scenario (see Fig. 13), the user can see the details of its movement process which express the times when the user is walking and where he is in stop as well as the traveled distance.

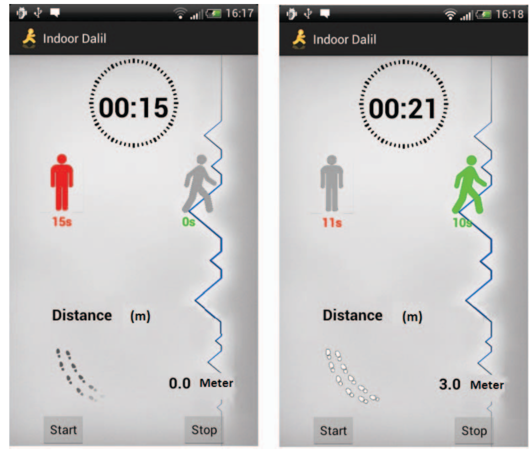

Fig. 13. Calculations details of position of the first scenario

In the previous interface, the green person indicates that the user is walking and the red person indicates that the user is in a rest. the Steps represent the traveled distance. If the user chooses the second scenario i.e. *speed and position of the mobile* he will have the same detailed interfaces as those of the first scenario with the difference that his velocity will also be shown in the interface.

Finally the user can switch to another interface (see Fig. 14) which shows the map and also its position on the maps. This interafce shows also the elapsed time, the distance, and the speed. The black circle represents the initial position of the user.

Fig. 14. Mobile position in the map

A. Creation of the map

The creation of maps or cards consists of collecting information which describe the structure of the place where the user is located. This information will be converted under a usable shape by other processes. For our case we created a map of the library of the research center C.E.R.I.S.T where our evaluation and experiments have been made. The library consists of aligned tables and six pillars. These details were put on the card (map) by specifying their exact dimensions in reality. The map is under the JPEG format, the application suggests then making the conversion of dimension of the library to the meter for the pixel. The Fig. 14 represents a real picture of the library C.E.R.I.S.T as well as a picture that is loaded in the Smart-phone.

IV. Conclusion

In this paper, we have evaluated the inertial navigation that is the most adequate for Indoor navigation/positioning. The inertial navigation is based on the use of a set of sensors attached to the mobile. These sensors measure a physical quantities about the movements of the mobile and allow the calculation of its position. We have made several tests on these sensors, mainly the accelerometer, to evaluate its accuracy and to use it in the process of positioning. The tests were made on two different scenarios, in the first one we assumed that the velocity and the direction of the mobile are known at the beginning of the experiment, however, in the second scenario the velocity is assumed unknown. The calculation of the mobile position was possible only after the analysis, the calibration, and the filtering of the acceleration measured by the accelerometer. The obtained results turn out logical and very close to real world in term of distances and velocity. For the implementation of these results, we have defined and designed a mobile application based on Android operating system. The application, named Indoor-Dalil, allows the user to visualize his traveled trajectory on a map and the information bout its distance and its velocity. As perspective to this work, which we consider as a basic study, we plan to evaluate other inertial sensor, i.e., gyroscope and magnetometer, for the estimation of the position in the case where the movement is made in various directions.

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