Distance Measuring using Accelerometer and Gyroscope Sensors

Bogdan Muset, Simina Emerich
Technical University of Cluj-Napoca, Communication Department
musetbogdan@yahoo.com
Simina.Emerich@com.utcluj.ro

***Abstract*— Distance measurement is necessary in various areas and applications. This project is an alternative to GPS and is able to measure the distance traveled by a person inside a building. An algorithm was implemented for the purpose of distance measuring. The measuring is done by integrating twice the acceleration, but the results are not satisfactory because the errors are accumulating much faster than expected. The second method implemented was an algorithm that measures the distance traveled by counting the number of steps. The step distance determination was made by an algorithm that takes the angle between legs made by the accelerometer and gyroscope. To eliminate errors a complementary filter was used. The advantages in using this method are low cost and portability sensor circuit.**

I. INTRODUCTION

Over the last decades there have been lots of devices that measure traveled distance. The best results have been obtained with GPS, but these systems are useless in closed spaces because a permanent communication with satellites is needed for pinpointing the location and measuring the traveled distance. The main sensors used for determining the distance are: GPS, ultrasonic, infrared, optical, inertial and electromagnetic sensors.

In this project we used MEMS sensors. These are inertial sensors made from micro-electrical and micro-mechanical elements that can measure acceleration, inclination, vibration, rotation and angular velocity.

The MEMS sensors are composed of two components:

- The sensitive element, that detects the force applied to it.
- A specific application for integrated circuit (ASIC), that amplifies and transforms the mechanical signal of sensitive element into an electrical signal.

Looking at the latest generation of sensors we see that the second component has the purpose of transforming the analogic signal into a digital signal and we can also see a temperature sensor and a memory cell.

The main characteristics of the MEMS sensors are: the small dimensions of the capsules, low weight, low power consumption, low cost, small starting time, high performances and a small number of additional components.

A. *The acceleration sensor*

The translational acceleration of a rigid body is described by Newton's second law of motion. A force F acting on an object of mass m causes the object to accelerate with respect to inertial space. The acceleration is given by:

$$F = ma \tag{1}$$

But, it isn't practical to measure the acceleration of the entire object. It is easier to measure the force that acts on a small part of the object. This small part is called seismic mass and consists in the primary element of acceleration sensor.

When the case of the instrument is subjected to acceleration along its sensitive axis, as indicted in figure 1, the proof mass tends to resist the change in movement owing to its own inertia. As a result, the mass is displaced with respect to the body. Under steady state conditions, the force acting on the mass will be balanced by the tension in the spring, the net extension of the spring providing a measure of the applied force, which is proportional to the acceleration. The total force *(F)* acting on a mass *(m)* in space may be represented by the equation:

$$F = ma = mf + mg \tag{2}$$

Where f is the acceleration produced by forces other than the gravitational field. In the case of a unit mass,

$$F = a = f + g \tag{3}$$

The acceleration *(a)* may be expressed as the total force per unit mass. An accelerometer is insensitive to the gravitational acceleration *(g)* and thus provides an output proportional to the non-gravitational force per unit mass (*f*) to which the sensor is subjected along its sensitive axis [5].

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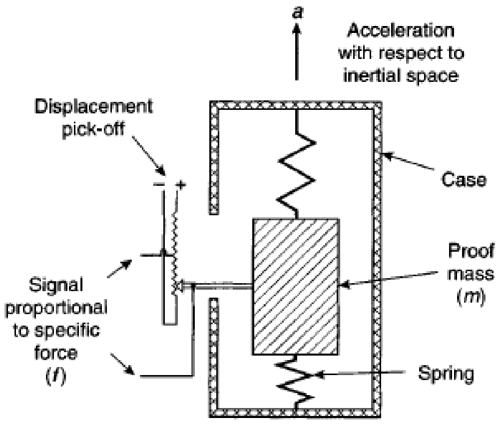

Figure 1. A simple accelerometer [5]

B. *Gyroscope*

Vibrating structure gyroscopes contain a micro-machined mass which is connected to an outer housing by a set of springs. This outer housing is connected to the fixed circuit board by a second set of orthogonal springs.
The mass is continuously driven sinusoidal along the first set of springs. Any rotation of the system will induce Coriolis acceleration in the mass, pushing it in the direction of the second set of springs. As the mass is driven away from the axis of rotation, the mass will be pushed perpendicularly in one direction, and as it is driven back toward the axis of rotation, it will be pushed in the opposite direction, due to the Coriolis force acting on the mass.

The Coriolis force is detected by capacitive sense fingers that are along the mass housing and the rigid structure. As the mass is pushed by the Coriolis force, a differential capacitance will be detected as the sensing fingers are brought closer together. When the mass is pushed in the opposite direction, different sets of sense fingers are brought closer together; thus the sensor can detect both the magnitude and direction of the angular velocity of the system.

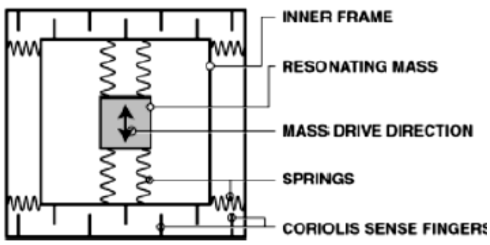

Figure 2. A simple Gyroscope [12]

II. TOOLS

The used microcontroller has 32 bits, with a clock frequency of 80 MHz. This microcontroller is powered by a 3.3v source from a power regulator TC1108. It has a flash memory of 128K bits and a data memory of 16 Kbits. For communication with other devices we have 2 SPI ports, 2 I2C ports and 2 EUSART ports.

The acceleration sensor used is ADXL345. It is an capacitive sensor, small, thin, ultralow power, 3-axis accelerometer with high resolution (13-bit) measurement at up to ±16 *g*. Digital output data is formatted as 16-bit twos complement and is accessible through either a SPI (3- or 4-wire) or I2C digital interface.

Taking into account the purpose of the proposed system, project we have chosen the measurement range of ±2g, where the resolution is 10 bits. The data output rate is selectable between 0.1 and 3200 Hz. For a low noise and a low power consumption we have made a reading every 20 ms, which is enough for this project. The connection between microcontroller and accelerometer is done through SPI. The communication speed is 5Mhz, which is the maximum speed that sensor can support.

The gyroscope chosen is L3G4200D. It is a low-power three-axis angular rate sensor able to provide unprecedented stability of zero rate level and sensitivity over temperature and time. It includes a sensing element and an IC interface capable of providing the measured angular rate to the external world through a digital interface (I2C/SPI). The communication interface used is also SPI with a 10 Mhz speed. The resolution of the sensor is 16 bits, and the full scale is ±250 dps which leads to a sensibility of 8.75 mdps/LSB.

To display the data we used a graphical LCD with a resolution of 101x64 pixels taken out for an mobile phone. The communication between microcontroller and LCD was made through a soft SPI.

The structure of the project is the following:

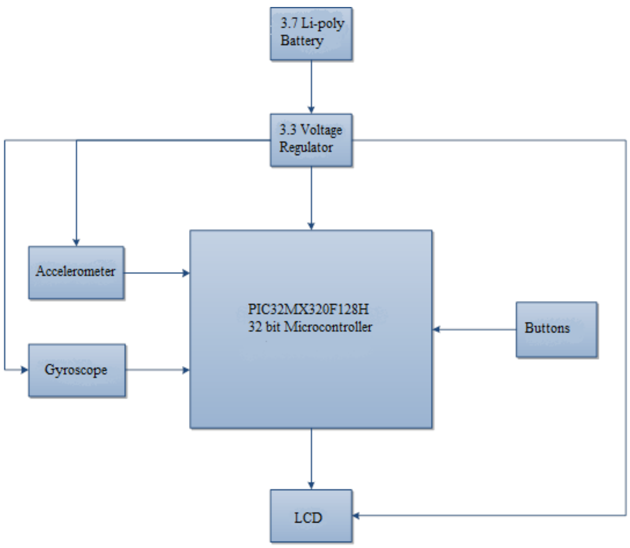

Figure 3. Project structure

III. IMPLEMENTED SOLUTION

For the measuring of the distance we have resorted to the counting of the steps. And for measuring the distance of every step we determined the angle between the legs. The device was attached in the upper part of the knee. If

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we know the length of a leg and the angle between the legs we can easily calculate the distance walk using the law of cosines.

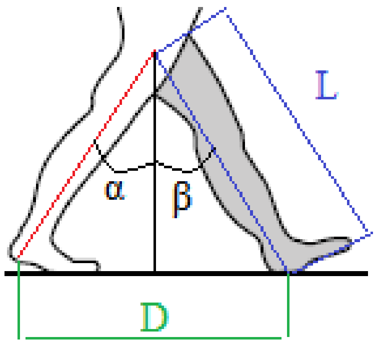

Figure 4. Legs angles

Where:

L – The length of the leg
D – Step distance
α,β – Angles between legs

Appling the low of cosines we have:

$$D^2 = L^2 + L^2 - 2L^2 \cos(\alpha + \beta) \quad (4)$$

$$D = L \times \sqrt{2 \times [1 - \cos(\alpha + \beta)]} \quad (5)$$

And for obtaining the final distance we have used the following equation:

$$D_{total} = \sum_{n=1}^{N} L \times \sqrt{2 \times [1 - \cos(\alpha + \beta)]} \quad (6)$$

N represents the number of steps.

The main problem with angular measuring is due to the errors that appear through the integration of the angular speed. To eliminate these errors we have used a complementary filter which eliminates noise and the drift error through a combination of a high pass filter and a low pass filter which acts like a single filter.

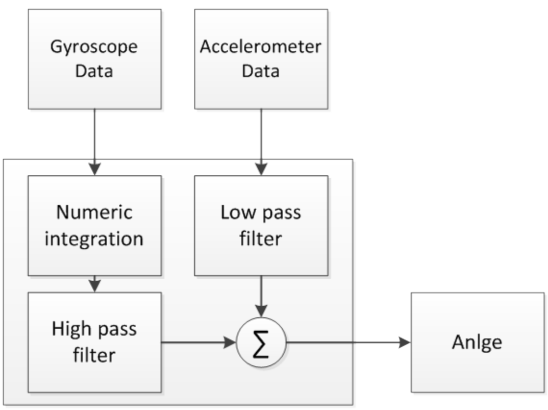

Figure 5. Complementary filter

Through integration we obtain the angle read by the gyroscope in relation with the first position.

The low pass filter and the high pass filter will highlight the value given by the gyroscope, but will keep the value constant taking into account the date from the accelerometer.

The goal of the low-pass filter is to only let through long-term changes, filtering out short-term fluctuations. One way to do this is to force the changes to build up little by little in subsequent times through the program loop.

$$\alpha = 0.95\alpha + 0.05Acc_x \quad (7)$$

Where:

α – Angle
Acc_x – Accelerometer angle

High-Pass Filter: The theory on this is a bit harder to explain than the low-pass filter, but conceptually it does the exact opposite: It allows short-duration signals to pass through while filtering out signals that are steady over time. This can be used to cancel out drift.

The time constant of a filter is the relative duration of signal it will act on. For a low-pass filter, signals much longer than the time constant pass through unaltered while signals shorter than the time constant are filtered out. The opposite is true for a high pass filter.

$$x = ax + (1 - a)\, y \quad (8)$$

$$\tau = (a\, dt)/(1 - a) \quad (9)$$

τ – time constant

The output of the complementary filter applied to the accelerometer and gyroscope in the time of the walk is the following:

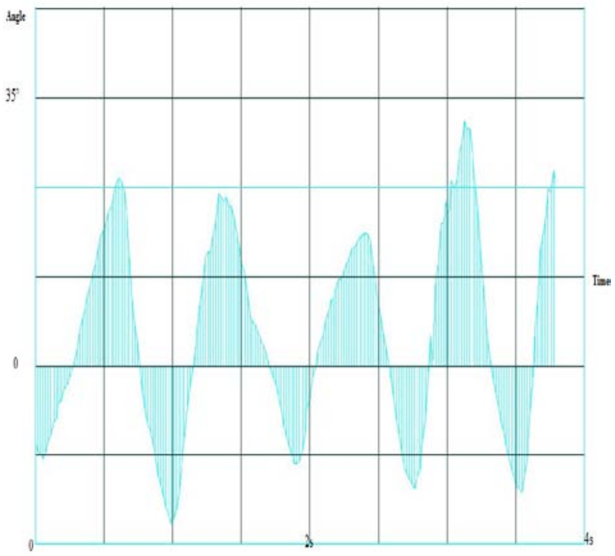

Figure 6. Accelerometer output

IV. EXPERIMENTS AND RESULTS

The device was tested on a 50 meter range. The first 10 measurements were made in normal walking conditions without stopping. The next five measurements were made with a low walking speed, and next five were done at high speed. The last three were made with stops. The results are represented in the following table:

TABLE 1
MEASUREMENTS

Nr. of tries	Real steps	Mea-sured steps	Real distance (m)	Mea-sured distance (m)
1	85	87		45.12
2	85	86		47.58
3	84	85		51.24
4	85	84		50.83
5	86	84		46.96
6	85	86		53.38
7	85	85		47.52
8	84	86		52.68
9	85	82		44.53
10	84	82		45.67
11	94	97		52.6
12	95	96	50	53.5
13	94	94		47.5
14	93	94		53.8
15	95	94		49.1
16	80	80		49.3
17	80	81		47.1
18	79	78		48.5
19	81	78		47.2
20	81	82		49.3
21	85	85		49.2
22	85	86		47.5
23	86	84		47.4

V. CONCLUSIONS

This project had the purpose of implementing a system of measuring the distance with the help of an acceleration sensor and a gyroscopic sensor.

It has been observed that the most important sensor is the gyroscopic sensor, but an accelerometer sensor was also needed for the compensation of the gyroscope's errors.

For the beginning the passing through the zero was detected to determinate the number of steps. Afterwards we have made an algorithm that determinates the distance of a single step with the help of the same signal used to give us the number of steps.

Some experiments were made to sort out the errors taking into account different tips of walking.

The measurement algorithm was implemented so that best results would be for the normal and constant walk. We also took into account the fast and slow walking.

Future plans for the project are:

- Another gyroscopic sensor on the other foot for better reading of the angle.
- the implementations of a Kalmann filter.
- An algorithm that compensates errors due to the incline of the earth.

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