Pedometer and Calorie Calculator for Fitness Tracking Using MEMS Digital Accelerometer

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Abstract — **This work focuses on monitoring the distance covered on feet by a person and the calories burnt due to walking, running or jogging. An algorithm is designed which relates the movement of arms of a person to his feet during walking. The motion of arms is detected by an accelerometer, which reads the dynamic change in the positions and variations. This work uses a 3-axis MEMS digital accelerometer ADXL345 interfaced to a microcontroller Atmega328P. The devised algorithm then calculates the number of steps taken by the person and follows it by displaying the total distance travelled by the person. Once the distance is obtained, a mathematical formula is applied to the data collected and the total calories burned by the person is displayed on a LCD display against the Basal Metabolic Rate (BMR) of the person.**

Keywords—ADXL; pedometer; accelerometer; calories; MEMS; BMR

I. INTRODUCTION

Walking is the most beneficial exercise for everyone without any bar on all age groups. Have anyone gave a thought on how much distance they have travelled on their feet ever since they were born? It would probably be in thousands of kilometers. Well, it's not counted and it's never too late. We can begin from now and monitor the distance travelled by us on our feet. Now the question arises – How are we going to monitor it? Well, it can be monitored using a pedometer. A pedometer is one that measures the distance walked/ran by a person. The next question surfaces – Pedometer! What's inside it? Who's is sitting inside and controlling it? How does it work? Is it reliable for everyone who uses it? The following section provides the answers to them. Let us get introduced to the most fascinating MEMS (Micro electro Mechanical Systems) sensor, ADXL345 – the accelerometer.

A. Acceleration

Acceleration is the rate of change of velocity. This is what we have learnt in our formative years. But what does it mean? How can one feel it?

Speed is the rate of change of distance. This means, how often one changes the distance in a period of time. For example – The first 5m may be walked in 1s, and then the speed is 5m/s. The next successive 10m is travelled again in 1s, now the speed is 10m/s. But the overall speed of the person is said to be 7.5m/s.

Velocity is nothing but speed with a given direction. Hence, it is a vector quantity. Now, acceleration is the rate at which the speed (for our convenience of understanding, let speed = velocity) changes. It means, how often one changes the speed in a period of time. For example – If we say, the walking speed of a person X is 10m/s^2. Then at the end of 1s, X has travelled 10m. From the start of 1s to the end of 2s, X has travelled 20m. And from the start of 2s to end of 3s, X has travelled 30m. It is clear that X increases the speed by 10m for every second. This is acceleration.

The total time taken by X is 3s and total distance covered is 60m. Hence, the speed can be said to be 20m/s, but the acceleration is 10m/s^2.

From the above illustration, acceleration is clearly understood. Since the definition of acceleration defines it to be rate of change in 'velocity', and velocity considers the direction and is a vector quantity. Therefore acceleration is also a vector quantity.

In this physical world, there exist only three dimensions or three planes or three axes. Therefore, the direction of displacement will be in of the axes. These axes are commonly named as x-axis, y-axis and z-axis.

Acceleration is measured in terms of g-force. This g-force is measured relatively to 0g, which is experienced during free fall. Earth's gravity is the cause of g-force, and hence is the reason to produce weight. When two objects move against each other on a surface, the reaction force produces equivalent weight for every unit of the object's mass. By interior mechanical stress, the forces are transmitted to the objects.

One g is the acceleration due to gravity at the Earth's surface and is the standard gravity, defined as 9.80665 meters per second squared or equivalently 9.80665 Newtons of force per kilogram of mass.

In order to understand and feel the acceleration of 1g, let us convert 9.8m/s to km/h, i.e., approx. 35km/h. So when a person is sitting inside a car and is moving at a speed a 35km/h and suddenly applies the brake, ensuring the vehicle comes to standstill in 1s, the amount of jerk the person experiences is 1g-force. This is how one feels the acceleration.

B. ADXL345 – The Accelerometer

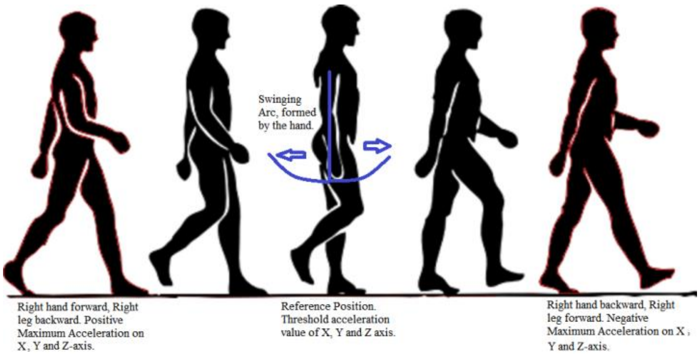


Fig.1. The hand swing movement while walking

In order to measure the distance travelled a person, this work focuses on the hand-swing movements of the person. The hand-swinging movement is rhythmic and synchronizes with the person's feet movement. There definitely has to be one full swing of the hand for the person to move forward by two steps. Therefore, by calculating and analyzing the acceleration of the person's hand-swing, the step counts are measured. Then by applying the algorithm discussed in further sections, the distance travelled by the person is measured. Thus, an accelerometer is used to measure the acceleration of the hand-swing movements.

The ADXL345 is a 3-axis accelerometer that works at low-power, with resolution up to 13-bit and provision to measure till ±16 g. It is a digital accelerometer that has in-built ADC and interfaced to the microcontroller via two-wire I2C routine or through 4-wire SPI. In this work, we interface the accelerometer through 4-wire [2].

II. INTERFACING THE ADXL345

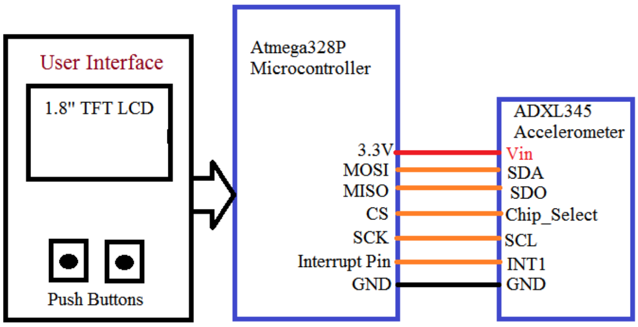


Fig.2. Interfacing Block Diagram

The ADXL345 is connected to the Microcontroller ATmega328P through Serial Peripheral Interface (SPI). The ADXL345 is turned on by supplying 3.3V. The activity and inactivity mode of the ADXL345 is detected to find whether the person's hand is in motion or at rest. This monitoring is assigned to the interrupt functionality of ADXL345 [2]. The basic information of the user such as age, weight, height, gender and the stride length (SL) are taken as input using the push buttons and displaying it on the LCD. The total distance travelled and also the calories burnt are displayed on the LCD. This is a low-power, 1.8" TFT LCD that is active at 3.3V. The further calculations are discussed in the following algorithms.

A. Configuring the ADXL345

The ADXL345 offers many features and has plenty of registers to configure. However, we focus on the following registers and set the corresponding values. The meaning behind the values set can be understood in the datasheet [2].

Name of Register	Address Location	Value set
POWER_CTL	0X2D	0X3C
DATA_FORMAT	0X31	0X02
DATAX0	0X32	INPUT DATA
DATAX1	0X33	INPUT DATA
DATAY0	0X34	INPUT DATA
DATAX1	0X35	INPUT DATA
DATAZ0	0X36	INPUT DATA
DATAX1	0X37	INPUT DATA
THRESH_ACT	0X24	0X08
THRESH_INACT	0X25	0X03
TIME_INACT	0X26	0X04
ACT_INACT_CTL	0X27	0XFF
INT_ENABLE	0X2E	0X18
INT_SOURCE	0X30	READ ONLY
INT_MAP	0X2F	0X00
BW_RATE	0X2C	0X09

Table I. Register Configuration in ADXL345

B. The Pedometer Algorithm

The output bandwidth of the ADXL345 is set at 50Hz at the BW_RATE register [2]. The data is read from the registers of X, Y and Z axis. The first 50 samples of each axes data are stored in respective arrays. The samples are sorted in ascending order and the maximum and minimum values of each axes is calculated. The average of the maximum and minimum values is called as the threshold value of respective axes – ThreshX, ThreshY and ThreshZ. This setting of threshold values is called as calibration. This is assumed to be the rest position (or reference position) of the arm for particular rhythmic swing movements. The successive data of corresponding axes are compared with the threshold values. If the data is exceeds the threshold, it is considered to be forward step (right leg or vice versa) and if it is lesser than the threshold, it is considered to be another forward step (left leg or vice versa). Thus, the steps are incremented. However, the movements of hand swing are dynamic and keep changing. Therefore, the calibration process mentioned occurs for every ten seconds to set new threshold values. If the current threshold values of all axes match exactly with the previous threshold values, that means the accelerometer was not moved. Hence, it indicates the device was at rest and an 'inactivity' interrupt is raised and puts the accelerometer into Sleep Mode. Once, the accelerometer starts moving and the values of the axes exceed the THRESH_ACT register, it comes out of sleep mode and measures again. The above mentioned algorithm will increment the steps for any rhythmic movement of the arm. Therefore an allowance window is set by taking many practical trials which is valid only for only valid walking hand swing movements.

The calculated steps are multiplied to the stride length of the user. This paper asks the user to provide his stride length instead of approximating values for a given height and age. The stride length is entered in centimeter and thus is converted to kilometers.

The output of the X, Y and Z axis are obtained using MATLAB. The results are viewed as waveforms and are studied to understand the changes in acceleration while walking and set the registers correspondingly in ADXL345.

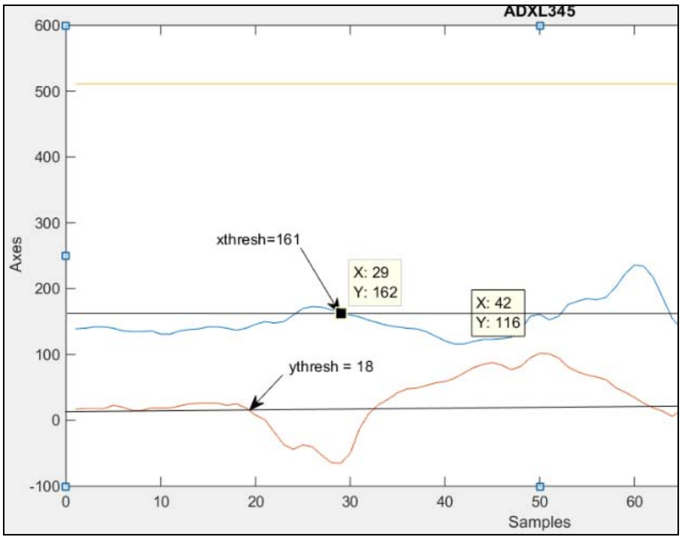


Fig.3. Matlab Output of Walking

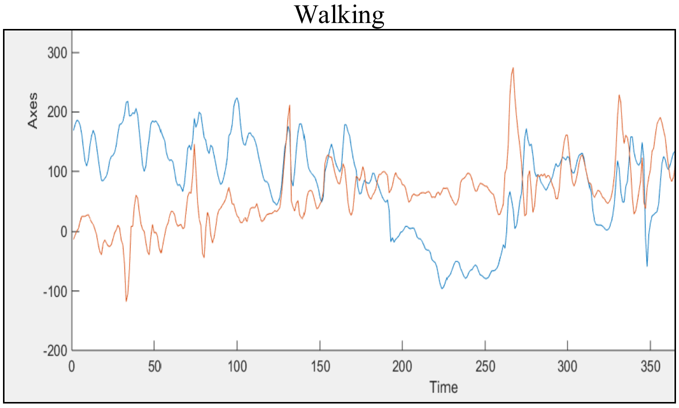


Fig.4. Walking at a faster pace

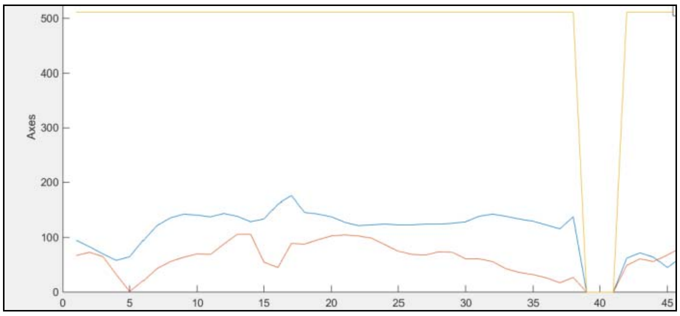
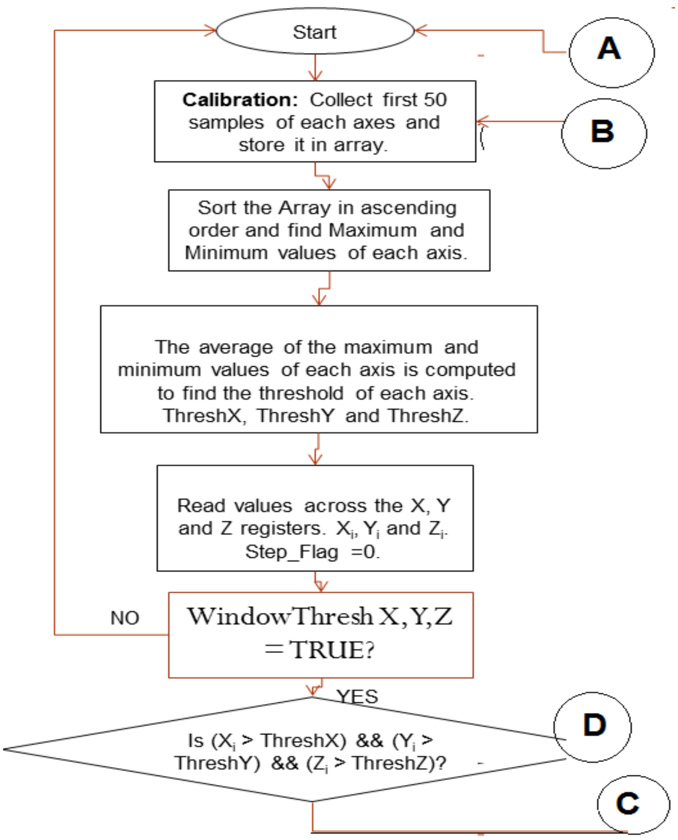


Fig.5. Inactivity Detected – Hands were at rest.

Trials	Actual distance covered	Algorithm calculated Resulted	Accuracy
Walking	22.5m	23.85m	94.33%
Jogging	24.4m	28.4m	85.91%
Device in Left Hand	27.5m	28.05m	98.03%
Right Hand	30m	30.5m	98.36%

Table II. Pedometer Algorithm Results

III. FLOWCHART OF PEDOMETER



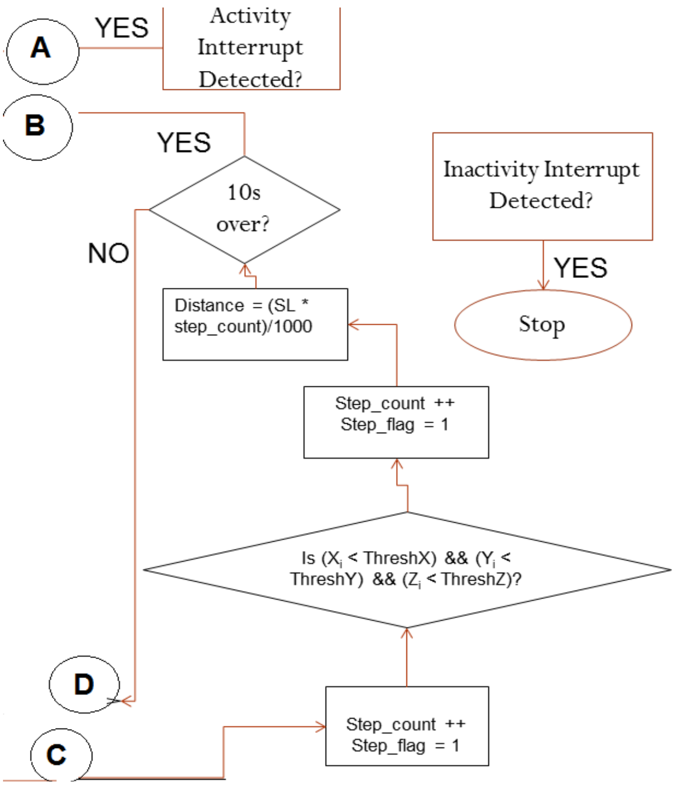


Fig.6. Flowchart for Pedometer Algorithm

IV. CALORIE COUNT

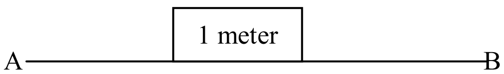
The origin of life: The Soul – It is energy. The first cry of a baby – It is energy. The breath, the sound and the light which causes the sensation of vision – They all are energy. From the first blink of eyes, the first smile of the face to the last breath of our life, there is a unique omnipotent source – The Energy. But how far have we understood what it 'Energy' means? From where does it come from? To where does it go? How do we measure it? This following section of this paper illustrates the above questions.

A. What is Energy?

To understand it, we need to first measure it. Energy is measured in Joules. What is a joule? One joule is the measure of energy, when one Newton of force is applied to an object to displace it by 1 meter.

What is a Newton? One Newton is the force that accelerates an object of 1kg at $1m/s^2$. We have discussed about acceleration in the previous section.

Now let's understand the practical meaning of this. When an object of 1kg changes its speed at 1m/s for every other second, it is said to be liberating a force of 1N. And when this object is moved from Point A to Point B (1m away), it expends 1 joule of energy. If it needs to spend energy, then it needs to have the energy in its stock at the first place.



In other terms, one joule of energy is needed by a body of mass 1kg to accelerate at $1m/s^2$.

To understand practically, consider Mr. Sunil who weighs 60kg. If Mr. Sunil starts walking at an acceleration of $1m/s^2$ (Walking speed = 1m/s and changes it every second), Mr. Sunil needs to apply 60N of force. Suppose Mr. Sunil moved from Point A to Point B, then he spent 60 Joules of energy. And if he walked for 100 meters at the same rate, then he spent 6000 (every meter needs 60 J) Joules of energy. Remember, Mr. Sunil is not carrying any other load other than his own body weight.

One Apple contains approx. 400,000 Joules of energy. So, if Mr. Sunil eats an apple, he will have the energy to walk 400,000/6000 = 6666.67 meters or 6.7 km.

This is just an illustration to understand energy. However, in practice, a person will consume in kilojoules of energy varying on his heart rate, speed of walking, hand and feet movement, variability in breathing, etc.

B. What are calories?

- Calories are just another unit of measurement for Energy. This unit is most commonly used for food. One calorie is nothing but the energy required to increase the temperature of 1 gram of water by one degree Celsius. One gram of water is too little a quantity and is compared to a water droplet. Thus, it is a negligible measuring unit. Hence, we use the terms of kilocalories. One kilocal is the energy required to increase the temperature of 1kg of water by 1 degree Celsius. (1 kg of water is approx. 1 liter or 34 oz).
- Why should we measure in calories? This is a good question. Why should we introduce another form of measuring unit rather than keeping it simple by measuring in joules? Well, after the ingestion of food, our stomach produces various acids and churns all solid food into bubbling liquid. These acids and chemicals produce heat in breaking down the food. This process is similar to that of heating 1 liter of water, whereas joules deal in the displacement of the object. Now, it makes more sense to measure our food intake in calories.
- 1 Kilocal = 4184 Joules
- In few countries like UK, the food packs are still labeled in joules. In US, the food packs provide the measurement in both kcal and joules as well. Also, the usage of kcal has been accepted conventionally. It is to be noted that the term 'cal' on food packs means 'kcal'only.
- How are the calories estimated in the food?

  Each food is distinguished at their basic levels, i.e. Proteins, Fats and Carbohydrates. The estimate of proteins, fats and carbs are calculated in the labs for a particular food using bomb calorimetry method.

Here, we have the standard measurement table –

Essentials	Kilocalories/gram
Proteins	4.36
Fats	9.02
Carbohydrates	3.7

Table III. Essentials vs Kcal

This estimation of calories is done by the Food securities of the particular country. In India, this is done at the labs of FSSAI (The Food Safety and Standards Authority of India). In USA, the NDL (National Data Lab) acquires this information.

C. *Influence Of Calories In Human Body*

Even when a person is at rest and sleeps whole day, he burns some calories. These calories are used up for his breathing, heart rate, metabolic rate, blood pressure etc. These are the basic needs for the survival. The extents to which the calories are burnt depend on the gender, height, age, weight and the activity of the person.

D. *Basal Metabolic Rate (BMR)*

BMR is the least amount of energy that is needed by any individual to keep functioning for 24 hours, even when the person is at rest or sleeping throughout the day.
The BMR is calculated as follows –
For males:
BMR = (13.75 x WKG) + (5 x HCm) - (6.76 x age) + 66
For females:
BMR = (9.56 x WKG) + (1.85 x HC) - (4.68 x age) + 655

Where,
HCm = Height (in centimetres)
WKG = Weight (in kilograms)

E. *Metabolic Equivalent (MET)*

It is the ratio of metabolic rate of body during work to metabolic rate of body while at rest. One MET is expressed as 1 kcal/kg/hour and is approximately equal to the energy spent while sitting quietly. Another way to express MET is the uptake of oxygen in ml/kg/min, where one MET (resting position) equals to 3.5 ml/kg/min.
The chart below by National Cancer Institute in USA provides Metabolic Equivalent (MET) values in American Time Use Survey (ATUS) for various activities –

Category	**MET value**
Sleeping	0.92
Talking	1.50
Shopping	2.16
Eating and drinking	1.50
Listening to Music	1.38
Relaxing	1.54
Dancing	4.50
Running	7.50
Walking	3.80

Table IV. MET table for different activities

F. *Mathematical Calorie Count*

After understanding all the above basics, the actual calorie count using a mathematical formula is as follows –

Calories Burnt = (BMR/24)*MET*T

Where,
BMR = Basal Metabolic Rate
MET = Metabolic Equivalent
T = Time duration of Activity (in hours)

Since this paper discusses about the total distance walked by the person, we will consider the MET of walking in our calculation. The duration of walking is calculated by how many number of calibrations has taken place with different ThreshX, ThreshY and ThreshZ at every reading. The total time is calculated from the start of Activity Interrupt and can be formulated as –

Total duration of walking time,

T = (10s * Number of Calibrations occurred) /3600

Where, T is in hours.

The Activity time and the calories burnt are stored in the EEPROM memory for permanent storage, so that it can be retrieved even if the device is switch off. These values are erased at the beginning of each new day, so the user can track the new day's activity. If the intake of food (in calories) is lesser than the actual calories burnt by the person, the person will lose weight. Also, if the intake of food (in calories) is greater than the actual calories burnt by the person, the person will gain weight.

V. RESULTS

Fig.7. Device fixed to the hand while walking

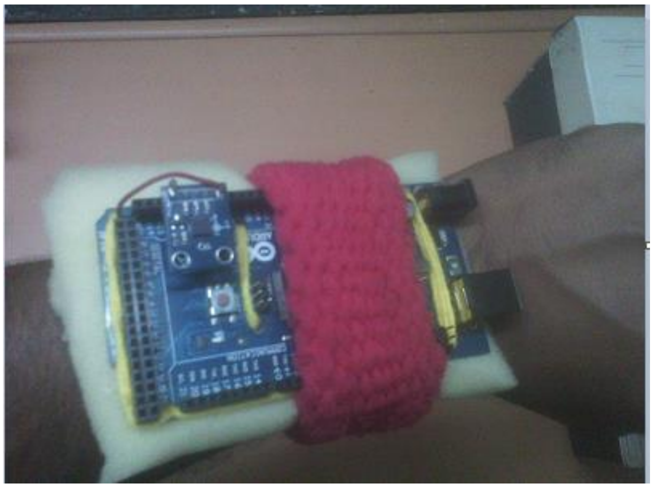


Fig.8. Device placed on hand firmly

Fig.9. The calories displayed on the LCD

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