Design and Implementation of a Three Axis Digital Pedometer

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***Abstract*—This paper presents the design and implementation of a three-axis digital pedometer for monitoring step counts. The device was built around the FRDM-KL03Z microcontroller, and uses a dynamic thresholding technique to identify if steps have occurred. The overall accuracy of the system was 92.7±3.86% when the step count was written to the console and 42.2±2.17% when the steps were printed onto an OLED display. The system power consumption is 242.01±62.04W on average.**

I. Introduction

According to the World Health Organisation, over 39% of adults are overweight, and 13% are obese [1]. Physical activity is one of the best ways to prevent and reduce obesity [2]. One way to motivate physical activity is by setting step goals and having immediate access to the step count during the activity [3, 4]. To achieve this, a pedometer, a device which counts the number of steps a person has walked, can be used. This paper presents the implementation of a digital pedometer, which counts steps and displays them on a screen so that they can be easily seen by the user to reinforce physical activity.

II. Background

A number of different pedometers exist on the market. Most use accelerometers to obtain the walking signals [5], but some make use of gyroscopic data [6, 7]. The commercially available pedometers differ largely in where they are placed to take the measurements. The most accurate pedometers are those worn on the ankle or the foot [5]. Others are worn on the waist, thigh, or in the user's pocket [5]. However, these do not offer users instant feedback on their step counts, as the devices are not worn in accessible locations. For this reason, a wrist worn pedometer with a digital monitor is preferable as it allows a user to constantly monitor their step count.

The existing pedometer algorithms can broadly be divided into time based, frequency based and those making using of feature extraction and machine learning [7–9]. Within time domain algorithms, the most commonly used is a threshold-based approach whereby the walking signal is compared to a pre-calculated threshold, and if some criterion relating to the threshold is met, the step counter is incremented [10–12]. [10] calculates a dynamic threshold which is updated every 500 ms to ensure that the threshold changes with changes in the amplitude of the signal. Other time domain techniques include performing autocorrelation or peak detection to count steps [8]. Problematically, these techniques require the storage of windows of samples. On a memory constrained microcontroller, this is not suitable, and so the threshold based approach is preferable. Frequency domain techniques include performing Fast Fourier Transforms or wavelet transforms [8, 9]. However, while these techniques obtain accurate results, they have large computational overheads, again making them less applicable for a microcontroller based system [8]. The final group of algorithms are those that use machine learning techniques to classify activity based on features extracted from the acceleration signals. These features include mean, standard deviation and entropy [9]. The features are then used with different machine learning algorithms including Support Vector Machines, Neural Networks or K-means clustering. However, the disadvantage of these techniques is that large quantities of training data are required, and the algorithms need to be trained offline [9]. Additionally, these techniques are computationally expensive, making them not appropriate for a microcontroller based system.

III. Design and Implementation

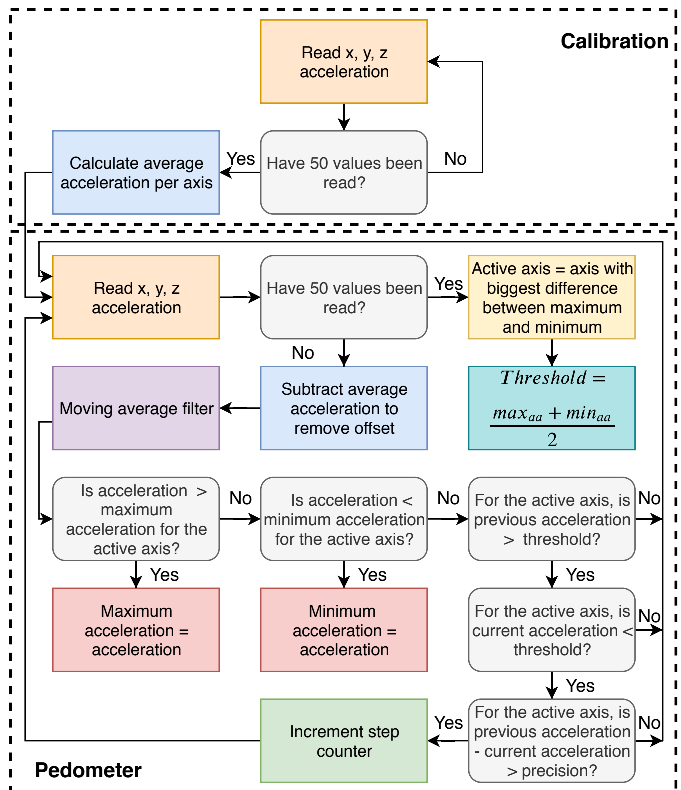

Fig. 1: Algorithm used to calculate the number of steps walked

Based on the review of literature in Section II, a wrist worn accelerometer based pedometer was designed. The system was built around the FRDM-KL03Z microcontroller and its inbuilt MMA8451Q three axis accelerometer. The algorithm, which is based on a time domain dynamic threshold technique [10], is provided in Fig. 1. Every 50 samples (corresponding to 1s), the active axis is selected as the axis with the greatest difference between maximum and minimum acceleration from the previous 50 samples. Thereafter, a dynamic threshold is calculated as the midpoint of the maximum and minimum acceleration for the active axis. In the loop, each new sample (a_{new}) is compared to the previous sample (a_{old}), and if $a_{old} > threshold > a_{new}$, a step is detected. An additional check is performed to ensure that the difference between the two samples is greater than an empirically determined precision to reduce the number of false steps. Once the step counter has changed, the steps are written to an OLED display.

IV. Results

Fig. 2 shows the acceleration and dynamic threshold for the maximum activity axis during walking. From the figure, it is clear that the threshold changes every second based on the magnitude of the signal in the previous window. Fig. 3 details the device accuracy over 10 trials in two testing conditions. For the first set of tests, the OLED display is turned off and the steps are written to the console. For the second, the steps are written to the OLED screen. Without the OLED screen, the accuracy is 92.7±3.86%. With the screen, the accuracy is 42.2±2.17%. It is thus clear that the accuracy is significantly lower when the steps are written to the screen. This is because the driver created to write to the display is inefficient, and so takes long to write each digit. Since this is a blocking operation, acceleration is not read for the periods when the OLED is being changed. This results in steps being missed, and significantly reduces the accuracy of the device. This is the greatest limitation of the designed system. For future work, the speed of the OLED driver needs to be improved so that other operations are not significantly slowed down while writing to the screen. Alternatively, an interrupt based system could be implemented so that new acceleration samples are read according to a clock, rather than once per loop. This would ensure that samples are not missed.

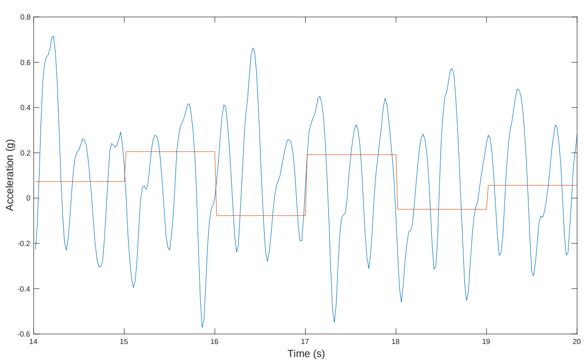

Fig. 2: Maximum activity axis with changing dynamic threshold during walking

Fig. 4 shows the distribution of the system power consumption. The average consumption is 242.01±62.04W. From Fig. 4, it is clear that there is a large variation in the power consumed by the system. This is because the consumption varies based on whether a step has been recorded or not. Once the step count has changed, a new step is written to the OLED display which results in additional current draw. This is seen in Fig. 5, whereby the periodic changes in power consumption during walking are evident.

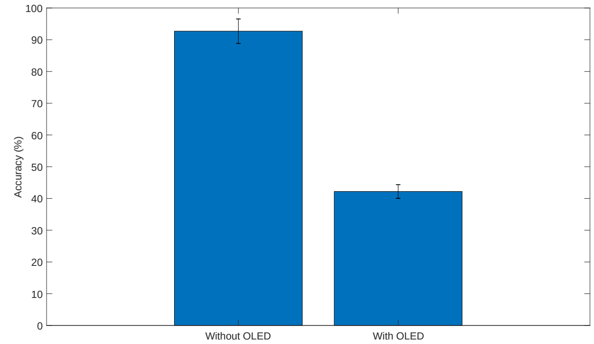

Fig. 3: Device accuracy and standard deviation over 10 trials for the pedometer with and without the OLED display

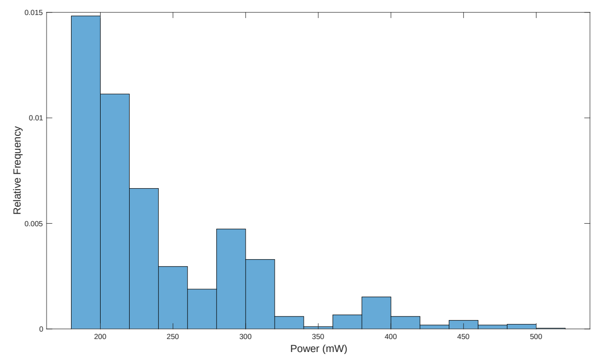

Fig. 4: Distribution of system power consumption while walking

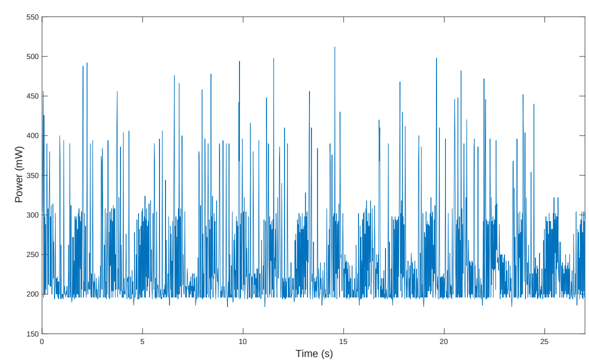

Fig. 5: Power consumption of the system while walking

V. Conclusion

Pedometers promote exercise and healthy behaviour by allowing users to monitor their physical activity throughout the day. To achieve this, the design and implementation of a three-axis digital pedometer was presented. The system has an overall accuracy of 92.7±3.86% when the steps are not printed onto an OLED screen and 42.2±2.17% when they are printed onto the screen. The average power consumption is 242.01±62.04W when using the OLED display. The power consumed by the device varies significantly as it increases when the step count is written to the screen. For future work, the OLED driver should be enhanced to improve the accuracy of the device when writing the step count to the OLED display.

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