

Design and Implementation of a Wearable Pedometer Based on Paired Infrared Radiation Sensor

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Abstract: Walking, jogging or running are the most common and easiest form of physical exercises to implement. Usually, users like to wear pedometer devices when exercising to detect the specific number of steps and thereby assess the amount of exercise. Common pedometers include fitness bands, fitness watches, or mobile phone apps. However, these devices require users to swing their arms regularly during exercise, otherwise the step counting data will be inaccurate. To address this issue, this paper proposes a new solution, namely the principle of detecting staggered legs using infrared intrusion sensors. Unlike previous solutions, this approach only requires wearing the device on one side of the leg. The experimental results indicate that the proposed design scheme exhibits high accuracy in step counting and remains unaffected by arm swinging.

Keywords: Running; Step Counter; Infrared sensor; Wearable Pedometer

1. Introduction

Sports are general terms for physical activities that consciously exercise the body, enhance physical fitness, improve sports skills, and enrich social and cultural life in the process of human development. According to their functions, forms, and organizational characteristics, they can be divided into the following major categories. Competitive sports are sports activities centered on competition and aimed at achieving excellent athletic performance ^[1], such as athletics, swimming, ball games (football, basketball, volleyball, table tennis, badminton, tennis, etc.), gymnastics, weightlifting, wrestling, judo, boxing, fencing, rowing, ice and snow sports, etc. Mass fitness activities, also known as national fitness or leisure sports, are aimed at promoting health, leisure, and entertainment. They are suitable for a wide range of people and include activities such as running, power walking, cycling, swimming, yoga, Pilates, square dancing, Tai Chi, and various ball-related leisure sports. Traditional and ethnic sports encompass physical activities that embody regional culture and ethnic characteristics, such as martial arts, dragon and lion dances, Loong Boat, archery, wrestling, and more ^[2]. Among all forms of exercise, running is a type of periodic aerobic exercise, which is one of the most basic and widely practiced sports. Its advantages can be scientifically expressed from dimensions such as physiology, health, socio-economics, and accessibility ^[3]. Improving cardiorespiratory function and aerobic capacity through running can significantly increase VO max, enhance myocardial contractility, increase cardiac output, improve pulmonary ventilation and gas exchange efficiency, enhance the blood pumping and oxygen supply capabilities of the cardiovascular system, and reduce the risk of cardiovascular diseases. Regular long-term running that regulates metabolism and body composition can increase basal metabolic rate, promote fat oxidation and decomposition, and effectively control body fat percentage; it also improves insulin sensitivity, playing a positive role in preventing and assisting in the control of type 2 diabetes, hyperlipidemia, and obesity. As a weight-bearing exercise, running provides moderate mechanical stimulation to the bones of the lower limbs, which is beneficial for enhancing bone density and delaying osteoporosis. Additionally, it can strengthen the lower limbs and core muscle groups, improve endurance, and enhance joint stability. Promoting neural and psychological health Running can promote the secretion of neurotransmitters such as endorphin and dopamine, alleviate anxiety and depression, and improve sleep quality; long-term adherence can enhance attention, reaction speed, and cognitive function of the brain, and positively promote neural plasticity. Low entry threshold and strong accessibility: Running has extremely low requirements for venues, equipment, and gear. It is not strictly limited by age, gender,

occupation, time, and space, making it easy to persist and promote over the long term. It has high social popularity value and public health benefits. It boasts a high degree of quantifiability, facilitating scientific research. Indicators such as running speed, distance, time, pace, heart rate, and energy consumption are easily and precisely measurable and monitorable, making it suitable for experiments and data analysis in fields like exercise physiology, sports rehabilitation, ergonomics, and sports technology.

During running or jogging, a device that records step counts is very necessary and serves the following functions.

(1) Objectively quantify exercise load ^[4]. The pedometer achieves objective measurement and digital recording of parameters such as step count, step frequency, exercise duration, and energy consumption through inertial sensors, compensating for the errors in subjective perception of exercise intensity and providing a traceable and quantitative basis for running training.

(2) Standardize exercise behavior and training management ^[5]. Providing runners with standardized and repeatable exercise indicators to facilitate the formulation of training plans, control of exercise dosage, avoidance of under-training or overtraining, and enhance the scientific and normative nature of running training.

(3) Supporting sports health monitoring and risk prevention and control ^[6]. By combining data such as step count and exercise intensity, it is possible to indirectly assess cardiorespiratory load and physical recovery status, providing basic data support for sports risk warning, health intervention, and sports prescription formulation.

(4) Lower the technical threshold for scientific fitness and research. Pedometers, with their low cost, easy operation, and high popularity, enable both ordinary runners and scientific researchers to obtain exercise behavior data at a low cost, promoting the scientific approach to fitness for all and the popularization of sports science research.

However, these pedometer devices each have their own advantages and disadvantages, as outlined in Table 1. Literature [7] provides a comprehensive review of these popular pedometer devices, certainly, there are some other methods and devices ^[8-10].

Table 1: Running step counting device and its advantages and disadvantages.

Classification of products in the market	Advantages	Disadvantages
Pedometer (mechanical / electronic)	Low cost, low power consumption, easy to operate.	Only capable of counting steps, accuracy greatly affected by gait and wearing position, no extended data such as heart rate and distance.
Smartphone (with built-in accelerometer)	High portability, no additional equipment required, and can be combined with an APP to estimate movement trajectory, pace, and energy consumption.	Large errors when carrying is inconvenient, GPS relies on outdoor environment, and background operation consumes high battery power.
Smart bracelet / watch	Stable wearing, high accuracy of multi-axis sensors, support for continuous step counting, heart rate, sleep, and sports modes, real-time data synchronization.	Requires regular charging, high cost for high-end devices, algorithm differences may lead to deviations in step counting.
Smart running shoes / insoles (embedded sensors)	Close proximity to the foot, high accuracy in gait and step detection, capable of monitoring running posture parameters such as ground contact time, stride length, and impact force.	High price, sensor relies on battery life, limited versatility and high replacement cost.

In fact, there is no device on the market that can possess all advantages while avoiding all disadvantages. The majority of wearable fitness bands and watches currently have inaccurate step counting^[11,12]. The core issue lies in the fact that relying solely on wrist acceleration cannot distinguish between real walking and random hand flailing. The device equipped with this type of accelerometer

interprets the occurrence of periodic acceleration in the up-down or front-back direction as one step. However, actions such as swinging hands, waving hands, holding a cup, shaking wrists, bumps in a car, and shaking hands while riding a bike can all produce acceleration waveforms similar to walking, leading to misjudgment of steps by the algorithm. To address this issue and enable the function of counting steps while the user is actually walking, this article designs a pedometer based on infrared radiation sensors. The experimental results indicate that our design possesses stability and precision. The specific design principles and techniques are described in the following content .

2. Overall Design Scheme

The inspiration for this pedometer design stems from pedestrian detection at the entrance of large supermarkets [13,14]. When a pedestrian passes through the access control facility at the supermarket entrance, a welcome voice will be broadcast, and the supermarket's pedestrian flow data will be incremented by one. Through observation, it is found that during walking or running, people's legs constantly cross and exhibit periodic alternating changes, as shown in Figure 1. Therefore, a pedometer can be designed based on this distance variation feature.

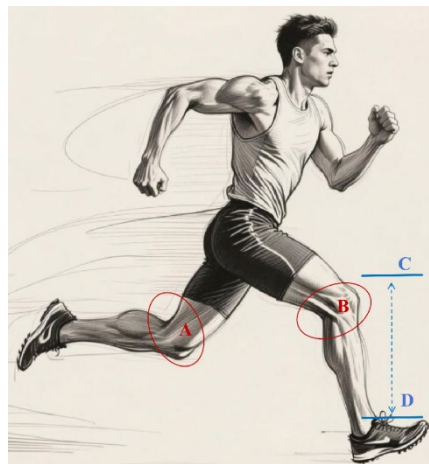


Figure 1: Side display of running posture.

Unlike the scheme described in Reference [7], where a sensor transmitting module is attached to one leg and a sensor receiving module is attached to the other leg, the approach presented in this paper involves fixing both the transmitting and receiving ends on the same module. Although the previous solution was feasible, it was inconvenient as both legs had to be equipped with devices and independent power supply modules. Due to the physical characteristics of the intersection between the two legs, only the knee areas of A and B can be aligned, otherwise it will be difficult to align the transmitting and receiving ends. The latter scheme is much more concise and practical to use, and can be fixed at any position within the $|CD|$ area in Figure 1. Therefore, this is feasible in terms of biokinesiology principles.

The schematic diagram of system principle is shown in Figure 2. The core functional modules are located on the right side of the diagram, including the power module, core processor, display module, alarm prompt module, and data signal transmission and reception module. In fact, the most crucial module is the infrared transmitting and receiving module which is a paired infrared radiation sensor [15].

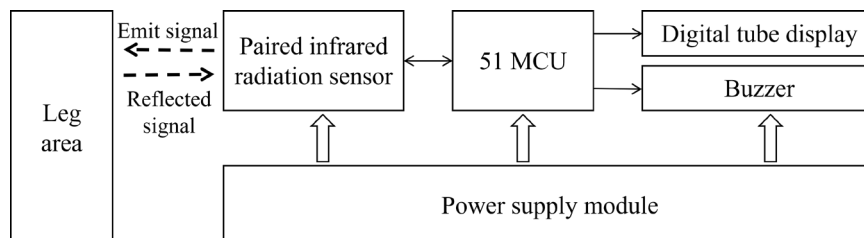


Figure 2: Schematic diagram of system principle.

When infrared light is emitted from the device, if it encounters no obstacles, no light will be reflected back, and thus there will be no signal at the infrared receiver end. On the contrary, if a pedestrian is walking or running, their legs will cross, and a reflection signal will be sent back. In this case, the infrared

signal receiver can receive the signal and trigger the counting condition. In terms of specific implementation, the area from the knee to the ankle can be equipped with the step-counting device module. In addition to step counting, this design project also features running data display, buzzer audio prompts when the target threshold is reached, and other functions.

3. Hardware Design

Since the entire control system requires processing of only a small amount of data from input and output modules, there is no need for a complex processor like a 32-bit one. In the project described in this article, an 8-bit 51 microcontroller can handle the relevant data. The STC89C52RC was chosen because of an enhanced 8-bit microcontroller compatible with the 8051 instruction set. It supports a main frequency range of 0-40 MHz and 6/12 clock modes. In terms of memory, it's equipped with 8KB of Flash memory, 512B of SRAM, and EEPROM functionality. Additionally, it features three 16-bit timers, four external interrupts, one UART serial port, and up to 39 general-purpose I/O ports. It supports ISP/IAP downloads and idle/power-down low-power modes. Integrated watchdog and dedicated reset circuits are also included. In addition, the MCU is available in multiple package options. The circuit schematic diagram the minimum system of microcontroller is shown in Figure 3.

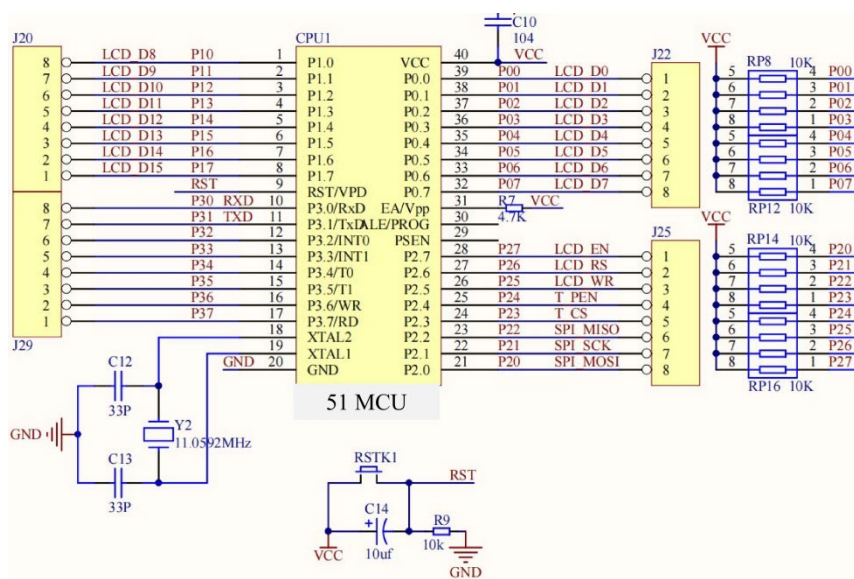


Figure 3: Circuit schematic diagram of the minimum system of microcontroller.

As the display part of the system, the schematic diagram of the digital tube circuit is shown in Figure 4. Compared to small-sized OLED modules, digital tubes display more clearly, allowing users to see the displayed values clearly when they bow their heads.

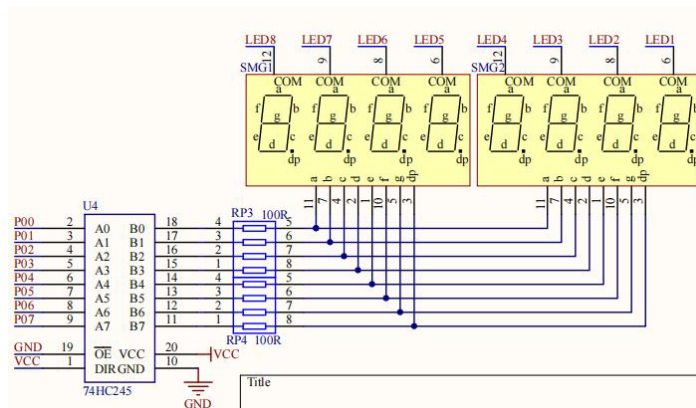


Figure 4: Circuit schematic diagram of the digital tube display.

Usually, there is a saying about taking 10,000 steps a day^[16]. When the device detects that 10,000 steps or other target step counts have been taken, it can sound an alarm through the buzzer to provide a reminder. The circuit schematic diagram of the buzzer is shown in Figure 5(a).

The circuit schematic diagram of the paired infrared radiation sensor is shown in Figure 5(b). The core principle is that when there is no reflective object in front of the sensor, the receiving tube is almost without light, in a high-impedance cut-off state, and the output terminal is pulled up to high level by $10k\ \Omega$. When there is a reflective object (such as white paper, black tape, or obstacle) in front of the sensor, infrared light is reflected to the receiving tube, the receiving tube becomes conductive, the output transistor pulls down the level, and outputs a low level. The role of the Schmitt trigger is to eliminate signal jitter, provide hysteresis threshold, greatly enhance anti-interference capability, and avoid false triggering.

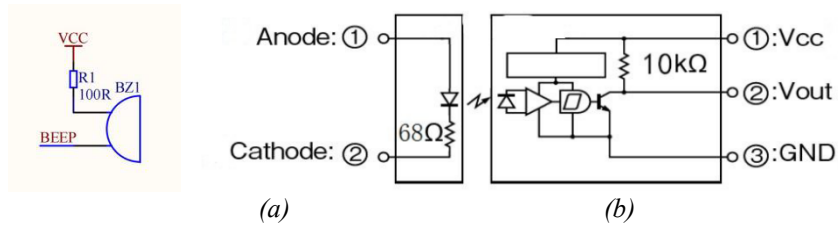


Figure 5: Circuit schematic diagram of the buzzer (a) and the paired infrared radiation sensor (b).

4. Software Design

The software flowchart of this system is shown in Figure 6. After the program starts, users can set the target number of steps, such as the suggested value of 10,000 steps. This function can be set through external buttons or built into the program. When the number of steps taken by the user reaches the target value, an alarm will be triggered for notification. otherwise, the step counting will continue.

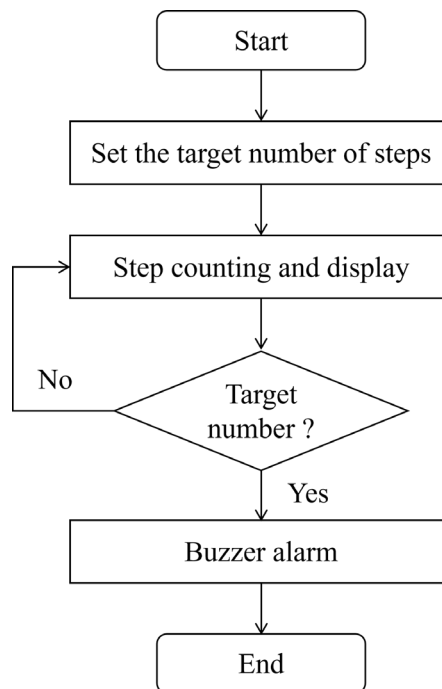


Figure 6: Software flowchart.

5. Experiments and Analysis

To verify the effectiveness of our design scheme, we built a physical hardware module and successfully loaded the software code. The experiments was conducted in outdoor and indoor scenes to test the difference between running and walking. The platform and experimental scenes are shown in Figure 7.

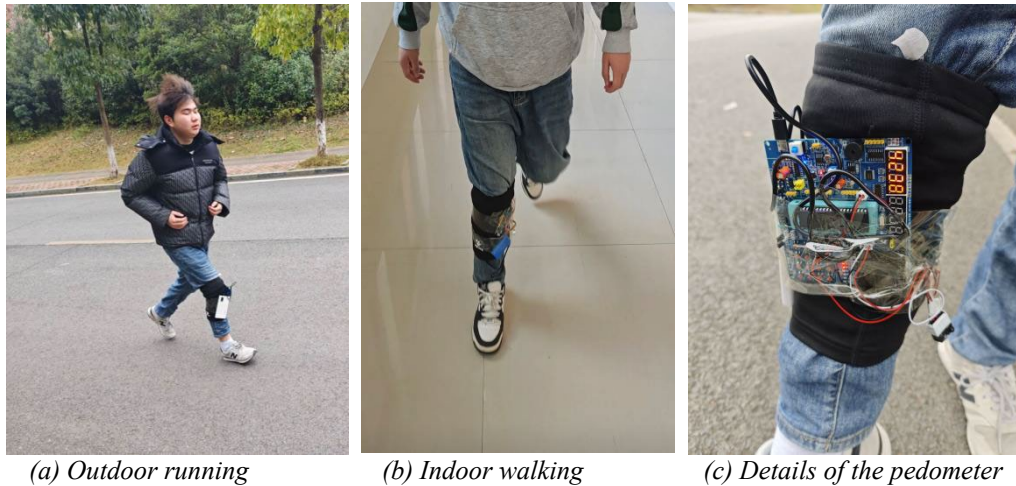


Figure 7: Designed products and test cases under different scenarios.

Table 2 shows the results of indoor and outdoor tests, with relatively small errors. The real steps are the numerical values counted orally by the tester. Due to the varying results of each test, the data presented in the table is from one of the tests and is provided for reference. It should be noted that the speed of running or walking is not fast, and the distance between the two legs is relatively close.

Table 2: Experimental results of different scenarios.

Scene	Real steps	Estimated steps	Wrong steps	Relative error
Outdoor running	500	496	-4	0.8%
Indoor walking	500	503	+3	0.6%

In addition, to verify the superiority of the method proposed in this paper over other devices or design schemes, additional experiments comparing it with some other devices were conducted. The products as comparative options include WeChat step-counting mini-program [17], Huawei sports watch and Xiaomi Band [18]. In figure 8(a), the sports watch and band worn on the hand synchronously count steps, and the final step count is obtained by subtracting the initial value from the final value. Figure 8(b) shows the step-counting leaderboard of WeChat which belongs to the software product of Shenzhen Tencent Computer System Co., Ltd. To avoid disclosing user privacy, we have obscured the usernames on the leaderboard.



(a) Huawei sports watch and Xiaomi Band (b) WeChat step-counting leaderboard.

Figure 8: Other devices for comparison.

The experimental data was collected from tests conducted on the school sports field, and multiple running states have been considered. The main consideration is the situation of pedestrians' arm swinging during walking or running. Table 3 shows the numerical results obtained under various testing conditions. Since the equipment we designed is not intended for use on the hand, it has received less impact. Wrist-worn pedometers have been significantly impacted. In fact, there are many scenarios where step counting at the wrist is affected, such as teachers writing on the blackboard in their daily work, or people making

phone calls while walking, and so on. For mobile app users, the results vary greatly when the phone is placed in a spacious pocket or held in hand.

Table 3: Compared with mobile phone software and fitness tracker devices.

Running states	Real steps	WeChat step-counting	Huawei sports watch	Xiaomi Band	Our wearable device
Normal arm swinging while running	1000	987	995	989	997
Swing arms freely	1000	853	912	874	995
Walk slowly, with small changes in arm movements	1000	659	726	708	991

6. Conclusion and Future Work

This article briefly summarizes the popular pedometer solutions currently on the market and the existing issues. Addressing the issue of inaccurate step counting data, we have designed a wearable pedometer solution from the source. Experiments have shown that our proposed solution has high accuracy.

In future work, we will consider optimizing our product solutions to make them more suitable for users' wear. Meanwhile, this program can be applied in many fields, such as military training, sports training, and serving as a reference for amateur runners. In addition, elderly care facilities can utilize this device to monitor the physical activity levels of the elderly, thereby maintaining their health.

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