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Design of a Bicycle-Based Real-Time Information Feedback System

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Abstract In recent years, cycling has rapidly emerged as a city sport. Although bicycles have various functions, they fail to provide cyclists with sufficient cycling-related information and post cycling analysis. Extant bicycle devices can provide cyclists with partial cycling-related information but cannot provide fully integrated information. In addition, these devices cannot perform post cycling analysis or cycling information sharing. Therefore, this paper proposes a bicycle-based real-time information feedback system, which is used to integrate and provide various types of real-time information for cyclists and help them achieve their desired cycling results. After cycling, the cyclists could view cycling-related information through software analysis. The information included cycling routes taken, total cycling distance, and total calories burned. The proposed system also saved information related to cycling routes such as acceleration, deceleration, directional changes, and slope changes. By analyzing the recorded information, cyclists not only gained further insight into their cycling results but also were able to share cycling-related information through the Internet, which would benefit cyclists who has not cycled along this road before. Finally, we hope the proposed system could provide cyclists with real-time, accurate, and complete information, and enabling them to enjoy a perfect cycling environment.

Keywords: bicycle, cycling analysis, real-time, information feedback.

1. Introduction

In recent years, the rapid development of cycling in Taiwan has increased the public visibility of cyclists. Because cycling is healthy, environmentally friendly, and internationally popular, it has emerged as a city sport. Modern bicycles have various styles and functions, and ease of use has become crucial for bicycle design [1]. Bicycles can primarily be divided into the following categories: road bicycles, mountain bicycles, folding bicycles, and electric bicycles. Although bicycles have a myriad of functions, they fail to provide cyclists with sufficient exercise-related information while they cycle. For example, contrary to professional cyclists, who train with coaches, average cyclists cannot ascertain whether they have achieved their desired exercise results while cycling. This has contributed to a loss of motivation and interest in cycling.

Thus, identifying an effective method to obtain cycling-related information is key to designing new-generation bicycles. The use of embedded systems with sensors has therefore become increasingly common. Currently cyclists' experiences are typically converted into numerical data, which are collected for dietary, health, and fitness measurements [2]. The sensor systems used for bicycles typically display basic data such as wheel speed; total riding distance and calories burned are also calculated through simple deduction. As technology advances, these systems also increase in function and decrease in volume. Embedded systems in bicycles can be employed in a variety of fields [3]–[6] such as parking lot management [3], position trajectory management [4], and particularly in bicycle-based rehabilitation [5] and cycling posture management [6]. Moreover, because of their growing popularity, smartphones have also increasingly used sensors. These sensors include inertial sensors, G-sensors, M-sensors, gyroscopes, short range sensors, and ambient light sensors. Smartphones with these sensors are therefore used for various purposes [7]–[12] such as tracking user coordinates through GPS [7], recording the number of steps walked, caring for elder people, and preventing falls [8]–[10]; smartphones are even more widely used in fitness games [11],[12]. Therefore, when designing embedded systems for bicycles, designers may use smartphones as replacements for sensors to acquire information. This reduces the volume and capacity of embedded systems as well as power consumption.

Therefore, this study presented a bicycle-based event data recorder. This recorder was constructed by combining a smartphone with an embedded system. The event data recorder, which comprised a "smartphone-based event data recorder" and "bicycle-based real-time information feedback system," displayed and recorded cyclists' exercise-related information while they cycled. Regarding hardware planning and design, this study assumed that all cyclists carried smartphones at all times because of the popularity and convenience of these devices. This substantially reduced the development cost of the event data recorder. In this study, the sensors used by smartphones were categorized as "smartphone-based event data recorders" and divided into five modules according to their function. The five modules were the accelerometer, gyroscope, electric compass, GPS route, and system integration modules. To obtain cyclists' real-time information when cycling, a bicycle-based real-time information feedback system was built and divided into three modules based on function. The three modules were the reed switch, real-time information display, and Bluetooth transmission modules. Through the event data recorder, this study aimed to integrate various types of real-time information and provide them to cyclists when they cycled to help them achieve their desired exercise results. In addition, the technology developed in this study enables cyclists to view cycling-related information through software analysis after they completed cycling. This information includes the cycling routes taken, total cycling distance, average speed, and total calories burned. The event data recorder also saves cycling route-related information such as slope changes and road conditions. Such information is useful for cyclists who have not cycled along the route before. By analyzing the recorded information, cyclists not only gain insight into their exercise results but can also share cycling-related information through the Internet. In developing the bicycle-based event data recorder, this study aimed to provide cyclists with accurate real-time information, enabling them to enjoy a consummate cycling environment.

2. System Design

This study introduced a bicycle-based event data recorder that combined a smartphone with an embedded system to record and provide cyclists with exercise-related information when they cycled. The event data recorder comprised two parts, which were a “smartphone-based event data recorder” and “bicycle-based real-time information feedback system”. Detailed information on the two parts is provided in the following sections.

2.1 Smartphone-Based Event Data Recorder

The smartphone-based event data recorder consisted of five modules, which were the accelerometer, gyroscope, electric compass, GPS route, and system integration modules. Detailed descriptions of the modules are presented as following.

2.1.1 Accelerometer Module

For the accelerometer module, this study used the three-dimensional (3D) accelerometers of smartphones to examine cyclists’ acceleration direction. Fig. 1(a) shows a diagram of the acceleration direction. Acceleration data can be used to analyze cycling habits and road conditions as well as prevent theft. Accelerometer functioning is based on the use of the heat conduction observed in heat convection. In other words, when an object accelerates in a direction, it creates disturbances in heat conduction, creating differences in the temperature of thermoelectric voltages measured from four directions; the output voltages also differ. The differences in electric potential can subsequently be used to determine the directions of acceleration because the differences in electric potential and direction of acceleration are directly proportional to each other.

2.1.2 Gyroscope Module

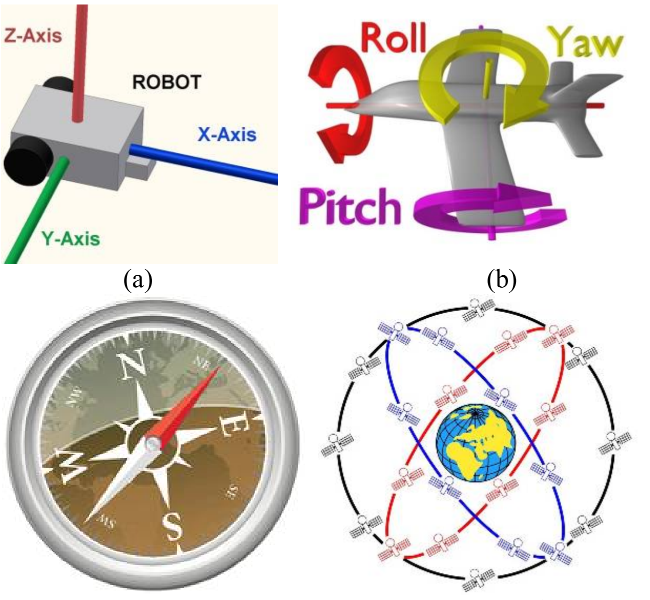
The 3D gyroscopes built in smartphones were used to determine cyclists’ angles of rotation. Fig. 1(b) illustrates the angles of rotation. This data can be used to determine whether cyclists are balanced, fatigued, or have poor cycling habits as well as whether their bicycles have overturned. Electronic gyroscopes, also called microelectromechanical gyroscopes, are semiconductor chips. These chips contain miniature magnetic material and detect the direction of movement during rotation.

2.1.3 Electric Compass Module

The 3D electric compasses of smartphones were used to determine cycling direction. Fig. 1(c) provides a diagram of the cycling direction as shown on a compass. This information can be used to determine whether cyclists are cycling along the correct routes to travel to their destinations. Information about local wind direction can also be obtained through the Internet to determine whether cyclists are cycling downwind or upwind. Electric compasses, similar to traditional compasses, distinguish the North and South Poles by sensing the Earth’s magnetic fields. Electric and traditional compasses are distinct because electric compasses use magnetoresistive sensors rather than magnetic needles. Additionally, electric compasses apply the principle of Hall effect to sense direction, using the direction of electron deviation in electric currents to calculate changes in voltage from which the directions of north and south can be identified.

2.1.4 GPS Route Module

For the GPS route module, the GPS function of smartphones was used to determine cyclist coordinates. Fig. 1(d) shows a diagram of GPS coordinates. GPS data can be used to record cyclists’ coordinates when they are cycling. Cyclists may also share route maps generated from recorded data with other cyclists through the Internet. GPS relies on satellite triangulation by which distance is calculated by measuring the transmission time of radio signals; the calculated distance is subsequently used to determine the location of a satellite in space. The GPS method is an observation method that involves high orbit and precise positioning.



(a) (b)

(c) (d)

Fig. 1. Module function diagram: (a) direction of acceleration; (b) angle of rotation; (c) directions on a compass; (d) GPS coordinates

2.2 System Integration Module

In this study, the system integration module read and organized the information provided by the aforementioned modules. The information, which was displayed in real-time on smartphone screens, was also stored in smartphones' memories. In addition, the system integration module used the built-in Bluetooth function of smartphones to connect to the Bluetooth transmission module of the bicycle-based real-time information feedback system to collect information. This information can be used to calculate and produce statistical results regarding cyclists' real-time speed, average speed, total distance traveled, and calories burned; these data are simultaneously displayed on and stored in smartphones. Through the system integration module, all software and hardware information can be integrated to produce data with optimal accuracy and stability and develop a bicycle-based event data recorder that provides accurate real-time information. Regarding the design of the smartphone screen display, this study divided the system integration module interface into six parts, as shown in Fig. 2. Descriptions of each of these items are as follows:

A. Positioning and tagging of the routes taken,
B. State of connection between the smartphone and Bluetooth module,
C. Cycling direction indicated by the electric compass module, D. Real-time bicycle speed information relayed by the bicycle-based real-time information feedback system,
E. Information regarding total distance traveled relayed by the feedback system,
F. Weight of the cyclists, which is used to calculate calories burned, and
G. Total time engaged in cycling.

藍芽狀態：已連結
行進方向：東南
單車時速：0km/hr
移動距離：0km640m
100
執行時間：0:3:31

Fig. 2. System integration module interface

2.3 Bicycle-Based Real-Time Information Feedback System

The bicycle-based real-time information feedback system contained three modules: the reed switch, real-time information display, and Bluetooth transmission modules. The Arduino UNO (as shown in Fig. 2) was used as the basis for designing the bicycle-based real-time information feedback system in this study. An image of the hardware is shown in Fig. 3. The system first reads information provided by the reed switch module by using the Arduino while displaying related cycling information on the real-time information display module. Next, the system sent real-time cycling information back to smartphones through the Bluetooth transmission module.

Fig. 2. Arduino UNO [13]

Fig.3. Actual hardware image

2.3.1 Reed Switch Module

A reed switch was used to measure the number of wheel rotations and time required for wheels to complete one rotation. Reed switches function using reed tubes, which serve as the primary parts of devices that convert mechanical movement into electrical signals. When magnets approach the magnetic switches of devices, they cause the reed switches inside the magnetic switches to sense changes in the magnetic field. The reed switch contact point subsequently closes, thus completing the electric circuits. In this study, reed switches were installed on bicycle wheels. The module was contacted once each time that a wheel completed one rotation, as shown in Fig. 4. To prevent the module from being triggered more than once upon contact, the reed used the positive-edge trigger method as its method of judgment. When no contact is made (thus no trigger) for more than 15 s, the bicycle was determined to be at rest. According to the time interval between each trigger and number of times that the module was triggered, the real-time speed and mileage were determined. The formulas for calculating the two variables are shown as follows:

$$speed = \frac{length/1000}{time/(1000 \times 60 \times 60)} = 3600 \times \frac{length}{time} \quad (1)$$

$$distance = \frac{count \times length}{1000} \quad (2)$$

where *speed* is the real-time speed (*km/h*) of the bicycle, *length* is the wheel circumference (*m*), *time* is the time interval between each wheel rotation (*ms*), *distance* is the mileage (*km*), and *count* is the number of wheel rotations.

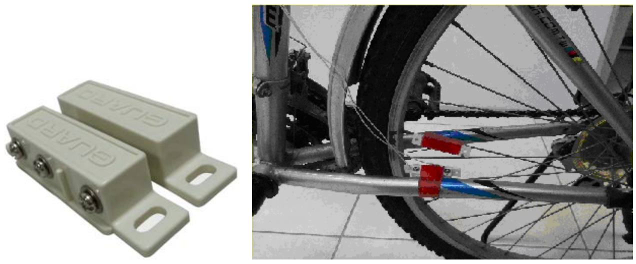


Fig. 4. Image of reed switch installation

2.3.2 Real-Time Information Display Module

Information (e.g., speed and accumulated mileage) derived from the reed switch was displayed using the real-time information display module, as shown in Fig. 5. This information was sent back to the smartphone-based event data recorder (i.e., the smartphone on the bicycle) through the Bluetooth transmission module. Accurate real-time exercise-related information was then calculated by the smartphone by using the calculation programs, and the information was displayed for cyclists. Furthermore, the information was recorded and saved by the smartphone, enabling cyclists to share their cycling information online.

Fig. 5. Real-time information display module interface

2.3.3 Bluetooth Transmission Module

The DF Bluetooth V3 [14] manufactured by DFRobot (as shown in Fig. 6) was used as the system module in this study. This module establishes a connection with the Bluetooth device built in the smartphone. The real-time information calculated by the reed switch module was then transmitted to the smartphone-based event data recorder, as shown in Fig. 13.

Fig. 6. Bluetooth transmission module [14]

3. Experimental Results

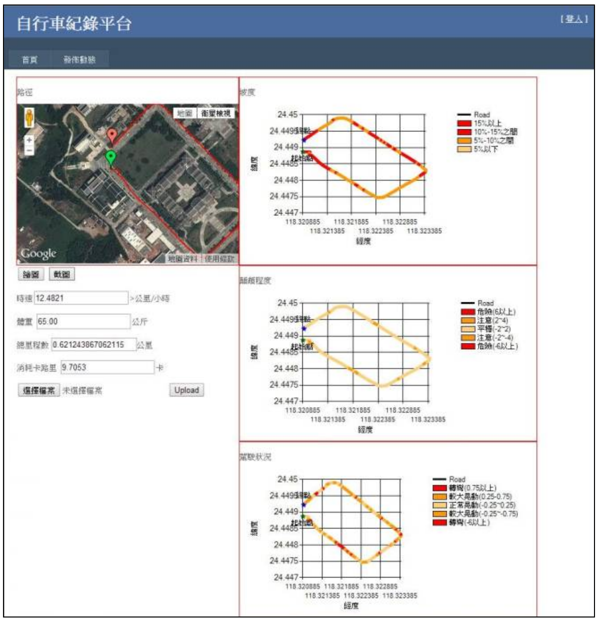
3.1 System Parts

The bicycle-based event data recorder introduced in this study contained a “smartphone-based event data recorder” and “bicycle-based real-time information feedback system.” An image of the entire hardware model is shown in Fig. 7.

Fig. 7. Image of the bicycle-based event data recorder

3.2 Recording Platform

After cycling, information recorded in the smartphone-based event data recorder was saved in a recording platform through the Internet; this information was subsequently shared online. The cloud recording platform designed by ASP.NET was used to design the recording platform. The recorded information was converted to useful information and displayed on a webpage for user access. Cycling information was divided into five categories on the recording platform, namely route taken, cycling information, slope conditions, road conditions, and riding conditions, as shown in Fig. 8. Detailed information on the five categories is provided as follows.



時速 12.4821 >公里/小時
體重 65.00 公斤
總里程數 0.621243867062115 公里
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Fig. 8. Recording platform interface

3.3 Route Taken

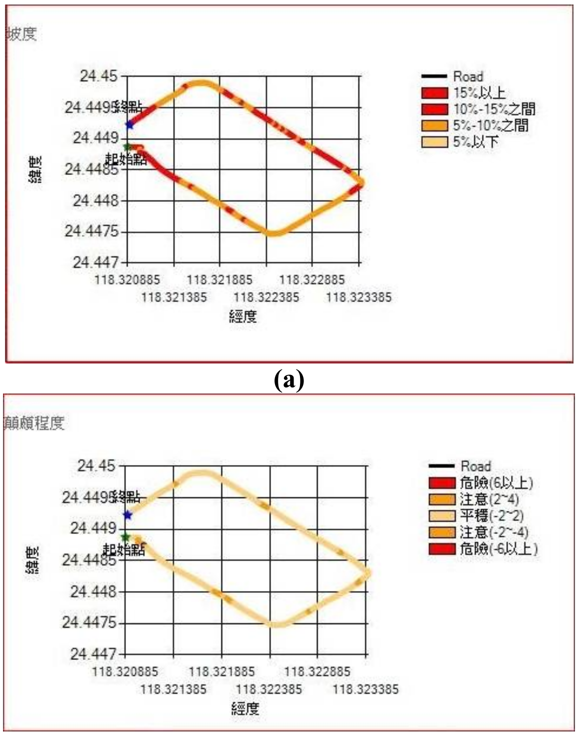
Regarding information on route taken, coordinates of the routes taken recorded by the GPS route module in the smartphone-based event data recorder were plotted on the Google Map accordingly, as shown in Fig. 9.

Fig. 9. Routes taken

3.4 Slope Conditions and Road Conditions

Information on slope conditions showed the changes in slope for the cycling routes taken. Slope conditions were determined using the altitudes of the recording points obtained by the GPS route module to calculate the horizontal distances between the recording points. Next, (3) was employed to calculate the slope changes, as shown in Fig. 10(a). Road conditions referred to the bumpiness of the cycling routes taken. Data recorded by the accelerometer module were calculated and converted to simple information, as shown in Fig. 10(b).

$$\text{Slope} = \frac{\text{Changes in altitude}}{\text{Changes in horizontal distance}} \tag{3}$$



(a)

(b)

Fig. 10. (a) Slope changes; (b) Road conditions.

4. Conclusion

This study developed a smartphone-based real-time information feedback system for bicycles, providing cyclists with information while they are cycling. Smartphones were used for information display and calculation. To use the system introduced in this study, cyclists are only required to install the aforementioned modules and copy these programs to their smartphones. This system is expected to provide cyclists with more complete exercise-related information. Just as how a coach instructs professional cyclists, this system provides cyclists with information about the effectiveness of their exercise when cycling, helping cyclists to achieve their exercise goals. In addition, the proposed system allows cyclists to share cycling information online. This information is useful for other cyclists who have not travelled along the route before. Overall, this study attempted to develop a bicycle-based event data recorder that can provide cyclists with accurate real-time information, thus enabling cyclists to enjoy a well-equipped cycling environment.

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