RESEARCH ON CYCLING POWER ESTIMATION AND PROTOTYPE OF A GPS BIKE COMPUTER BASED ON SYSTEM-ON-CHIP PLATFORM

Huynh Viet Thang*, Vu Van Thanh
The University of Danang – University of Science and Technology, Vietnam
*Corresponding author: thanghv@dut.udn.vn

(Received: January 05, 2024; Revised: February 25, 2024; Accepted: February 26, 2024)

Abstract - A GPS (Global Positioning System) bike computer is a specialized electronic device that allows for recording the traveled trajectory and training parameters of cycling activities. Current GPS bike computer devices on the market often do not provide cycling power parameter to support the riders. This paper presents a method to efficiently estimate cycling power based on the ground speed and altitude variation of the bike. The suggested method can be applied in the design and implementation of bike computers on embedded systems. The paper also presents the design and implementation of a GPS bike computer prototype based on a System-on-Chip platform.

Key words - GPS bike computer; cycling power; system-on-chip

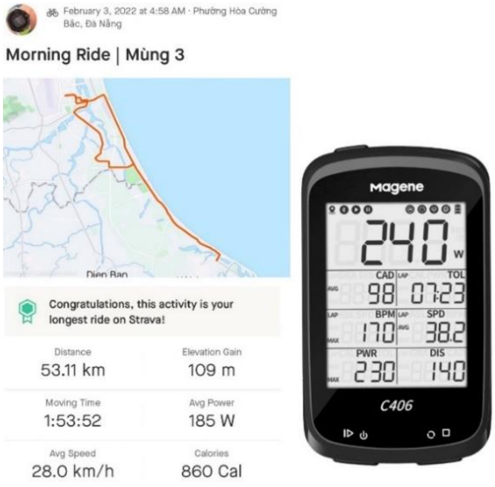
1. Introduction

Cycling is a sport activity that brings a lot of health benefits. Cycling regularly every day has many beneficial effects on the musculo-skeletal system, respiratory system, cardiovascular activity, and helps to relieve stress, and also brings many other benefits. Currently in Vietnam, the number of people riding bike is increasing significantly, especially in the context of post Covid-19 era, making people more and more conscious of exercising to improve their health. Cycling is a sport chosen by majority of people because cycling has many different levels, making it easy for people to choose a type of workout suitable for their health and needs.

There are many types of equipment to assist cyclists, from simple to advanced equipment, for common trainers to semi-professional athletes and even for professional athletes. A bike computer is a specialized electronic device that records the training journey, along with training parameters such as distance, time, speed, elevation, and in combination with other add-on devices, it is possible to measure heart rate, cadence (pedaling speed), and cycling power. Figure 1 illustrates an example of a Magene C406 bike computer [1] and the corresponding trip recorded by the device. The use of cycling training devices will help cyclists monitor their own training process, training parameters, tracklogs and thereby helping them to improve their training activity quality and fitness score. Cycling-aid devices are, therefore, essential pieces of equipment for cyclists.

Currently, the bicycle navigation devices available on the market are often quite expensive. Low-cost bike computers often offer poor positioning quality, simple and inaccurate trip and parameters measurement, and low durability. The other high-end bicycle navigation devices, although very expensive, only support measuring common training parameters such as distance, speed, and slope; just a few high-end devices, like the Garmin Edge devices, could provide an estimated cycling power by installing another third-party app [2], which is not so convenient and accurate as using a real cycling power-meter.

There are few studies on cycling power output and the factors that affect the cycling workout. An evaluation of aerodynamic and rolling resistances in mountain-bike field conditions is studied in [3], showing that rolling resistance in mountain biking is a major performance determinant during mountain bike races and more important than in road cycling. Estimation of rolling resistances during cycling for electric bicycles is investigated in [4], in which the aim of the research is to better estimate the residual range of electric bicycles for increasing their operational distance. Another use of bike computers for the evaluation of electric bicycles is presented in [5]. Recently, the physical characteristics and resistance parameters of urban cyclists are studied in [6]. The results in [6] provide representative distributions of physical parameters for real-world urban cyclists that can be used in bicycle performance modelling. A visual illustration of the relationship between cycling power and bicycle ground speed is presented in [7].


February 3, 2022 at 4:58 AM · Phường Hòa Cường Bắc, Đà Nẵng

Morning Ride | Mùng 3

Congratulations, this activity is your longest ride on Strava!

Distance 53.11 km
Elevation Gain 109 m
Moving Time 1:53:52
Avg Power 185 W
Avg Speed 28.0 km/h
Calories 860 Cal

Figure 1. *Example of a cycling tracklog on Strava and the bike computer Magene C406*

Hardware implementations of some bike computer devices and platforms can be found in [8-9]. By combining a Raspberry Pi and a Kindle, one can build a GPS bike computer, as shown in [8]. In [9], the authors used smart phone as a central monitoring device for the bicycle and the wifi network as a communication channel between the smart phone and the sensors to monitor the trajectory of the bicycle. Those hardware implementations are, however, not power-efficient.

In this paper, we aim to study the cycling power output model and suggest a method for cycling power estimation on embedded processors. In addition, we present the design and development of a GPS (Global Positioning System) bike computer device based on an embedded system platform, a device that allows to accurately record cycling tracklog and training parameters with functions equivalent to other bike navigation devices currently on the market.

2. Cycling Power Estimation Model

There are three primary forces that affect to the cyclist: gravity, rolling resistance and aerodynamic drag. In order to move forward at a constant ground speed *V*, the cyclist has to pedal the bike to generate a cycling power for overcoming the three above force components.

In the absence of wind and mechanical drivetrain losses, cycling power *P* (watts) can be modelled as [6]

$$P = mgGV + mgC_{rr}V + 0.5C_d A\rho V^3 \qquad (1)$$

where *m* (kg) is the total weight of the rider and the bicycle, *g* (m/s^2) is the gravitational force constant, *G* is the road grade (unitless), *V* (m/s) is the ground speed of the bicycle, C_{rr} (unitless) is the coefficient of rolling resistance, ρ (kg/m^3) is the air density, *A* (m^2) and C_d (unitless) are the frontal area and the drag coefficient of the bicycle.

For the sake of calculation convenience, the road grade *G* can be caculated by dividing the altitude variation over the traveled distance of the bicycle. Let Δh (m) be the altitude variation of the bicycle corresponding to the traveled distance Δd (m) over the sampling period, the road grade can be caculated as follows

$$G = \frac{\Delta h}{\Delta d}, \qquad (2)$$

and the computational model for cycling power P can be rewritten as follows

$$P = mg\frac{\Delta h}{\Delta d}V + mgC_{rr}V + 0.5C_d A\rho V^3 \qquad (3)$$

Equation (3) gives detail about the three power components generated by the cyclist to maintain a ground speed *V*. The first power component $P_{gravity}$, related to gravity force, depends on the steepness of the road as well as the total weight of rider and bicycle. For the convenience in calculation, especially when performing calculations on embedded microprocessor chips, the ground speed *V* and the altitude change Δh are recorded periodically with a sampling period Δt. Assuming that the sampling period is properly chosen as small enough, the ground speed *V* can be considered as constant over this sampling time, and the travelled distance can be computed as

$$\Delta d = V \cdot \Delta t \qquad (4)$$

or

$$\frac{V}{\Delta d} = \frac{1}{\Delta t} \qquad (5)$$

Therefore, the first cycling power component $P_{gravity}$ is then estimated as

$$P_{gravity} = mg\frac{\Delta h}{\Delta d}V = mg\frac{\Delta h}{\Delta t} \qquad (6)$$

The cycling power in Equation (3) is then calculated as shown in Equation (7)

$$P = mg\frac{\Delta h}{\Delta t} + mgC_{rr}V + 0.5C_d A\rho V^3 \qquad (7)$$

Since the ground speed *V* and the altitude Δh vary over time while the other terms in Equation (7) are constants during a cycling activity, we can further reduce the number of computations by defining the three new parameters as follows

$$M_1 = mg \qquad (8)$$

$$M_2 = mgC_{rr} = M_1Crr \qquad (9)$$

$$C = 0.5C_d A\rho \qquad (10)$$

The cycling power model for efficient implementation on an embedded microprocessor is rewritten as

$$P = M_1\frac{\Delta h}{\Delta t} + M_2V + CV^3 \qquad (11)$$

In this project, we choose the sampling period $\Delta t = 1$ second, the ground speed and the altitude of the bicycle the will be recorded every second. Our selection of sampling period is also consistent with the sampling period of other GPS devices currently in the market, for example, the Magene C406 [1].

Table 1 presents the typical values of some parameters related to the cycling power estimation model [6]. Given the weights of rider and bicycle, the three parameters M_1, M_2 and *C* can be calculated once and saved in flash memory of the microprocessor. The ground speed and altitude of the bicycle are regularly updated every second for the estimation of cycling power shown in Equation (11).

Table 1. *Typical values of rolling resistance parameters related to cycling power model*

Parameter	Value	Unit
g	9.8067	m/s^2
C_{rr}	0.0077	-
C_d	0.63	-
A	0.509	m^2
ρ	1.226	kg/m^3

3. Cycling Power Evaluation Results

This section presents the evaluation results of cycling power with data extracted from practical cycling activities. We compare the cycling power estimated by our suggested method with the cycling power provided by GPS bike computer C406 of Magene.

3.1. Experimental setup

We compute the cycling power of eight practical outdoor cycling activities performed in Danang city in the two years 2021 and 2022. The cycling tracklogs were recorded with a GPS bike computer C406 of Magene. The Magene C406 bike computer recorded all the related parameters of the cycling activity at every second and saved the tracklog as a.FIT (Flexible and Interoperable Data Transfer) file. The datafields stored in the FIT file include the GPS coordinates, travel distance, ground speed, altitude, and the estimated cycling power.

We extracted the ground speed and the altitude parameters from the FIT file to estimate the cycling power using Equations (7) to (11). We then compare our estimated cycling power data with the estimated cycling power data provided by the Magene C406. In our experiments, our bike is a touring Giant Fastroad SL2, the weight of the bike is 11kg, the weight of the cyclist is 55kg, the other parameters are chosen from Table 1.

3.2. Results

Table 2 presents the cycling power estimated by our method in comparison to the cycling power provided by the bike computer Magene C406. In this table, the activities are sorted in ascending order of total gain achieved. The data in Table 2 clearly suggests that the higher the elevation gain of the road is, the more average power the rider needs to put on pedals. In terms of bicycle speed, riding faster will consume more power.

The cycling power estimated by our method is very close to the cycling power measured by the Magene C406 device. The relative difference between the two methods is less than 5%, in which our estimated power values are slightly smaller than the values computed by the Magene C406 device. Experimental results obviously show that our suggested method for cycling power estimation gives similar caculated results compared to results of the reference device.

Table 2. *Cycling power estimation results*

Cycling activity	Distance (km)	Total Gain (m)	Average speed (km/h) (km/h)	Average power by our method (W)	Average power by Magene C406 (W)	Difference (%)
1	6.50	8	15.7	69	72	-4.17
2	41.05	46	27.6	143	149	-4.03
3	20.52	53	26.6	128	131	-2.29
4	20.17	54	26.5	158	163	-3.07
5	34.04	61	26.9	146	152	-3.95
6	30.08	103	27.0	165	170	-2.94
7	53.11	109	28.0	179	185	-3.24
8	32.04	116	27.3	178	183	-2.73

4. Prototype of a Bike Computer

4.1. General idea

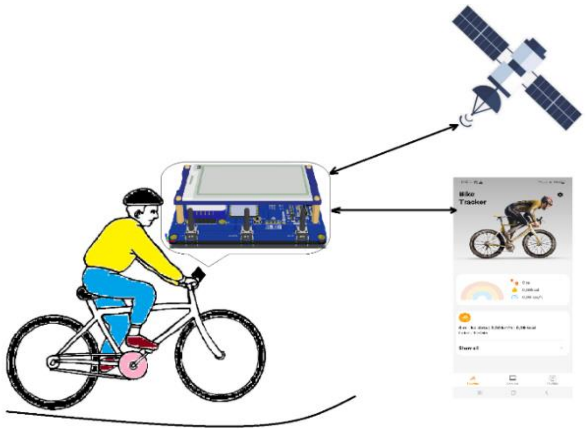


Figure 2. *General diagram of the bike computer solution*

In this section, we present the design and prototype of a bike computer based on the ESP32 low-cost and low-power System-on-Chip microcontroller. Figure 2 gives the general diagram of the bike computer solution for recording cycling activities. The bike computer device is mounted on the bicycle and receive GPS signals from satellites to record the cycling trip. The information received from satellites includes the coordinates and altitude of the bicycle, the ground speed, distance and time traveled. All these information are sampled every second and displayed on the bike computer's screen. The cyclists, therefore, can easily monitor the workout status during their activity. After finishing the cycling workout, cyclists can synchronize the data recorded by the bike computer with the cycling tracking application on their smartphone.

4.2. Circuit design and implementation

Figure 3 presents the functional block diagram for the circuit of the bike computer. The circuit includes the following blocks: battery charging and management block, DC-DC lowdropout voltage regulator block, micro-controller unit (MCU) block, bluetooth communication block, LCD display block, data storage with micro-SD card, GPS module, and setting button block.

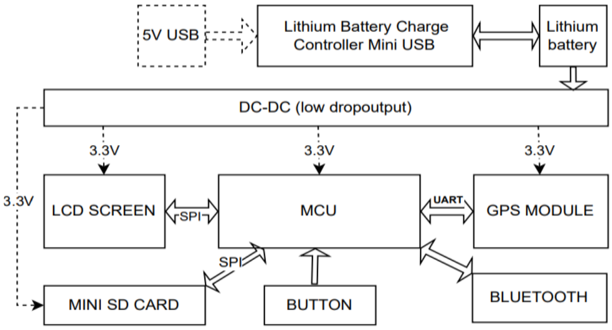


Figure 3. *Functional block diagram of the bike computer*

In our design, we choose to use lithium battery because of its high durability, water resistance capability, compactness, large storage capacity and good explosion resistance. The lithium battery is selected as a 1-cell type, when fully charged, with a voltage of 4.2V and a current of 4000mAh. The GPS block only works when training mode is selected, thus we use a separate DC-DC lowdropout voltage regulator that can be controlled in an ON-OFF mode via the MCU. In training mode, the bike computer starts the GPS module, reads data and saves them to the SD memory card and displays necessary information on the LCD. For power saving, the LCD paper screen is chosen. This LCD paper screen consumes extremely low power consumption with a maximum of about 5mA when operating. A 2.9-inch screen is chosen to ensure adequate display of training information including: speed, altitude, distance, and training time.

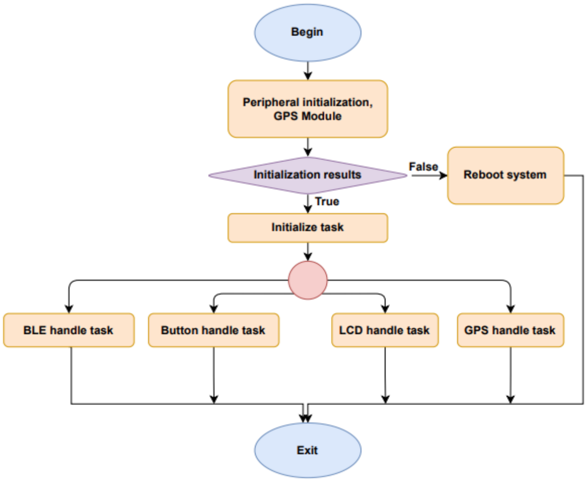


Figure 4. *Software flow chart of the bike computer*

For the embedded software development, we employ a Real-Time Operating System (RTOS) on the ESP32 microcontroller with four independent tasks that can operate at the same time for the bike computer: Bluetooth communication (BLE handle task), button communication (Button handle task), LCD display (LCD handle task) and GPS connection (GPS handle task) for receiving GPS data and saving data to memory card. The flowchart of the software is illustrated in Figure 4.

4.3. Bike computer specifications

The prototype of our bike computer is presented in Figure 5. The weight of the device is 135g, and its dimensions are 10cm x 6cm x 2.5cm. In training mode, the total maximum current consumption of the bike computer is about 235mA, so the device can operate continuously in training mode for about 17 hours. In the sleeping mode, i.e. there is no training activity, the maximum current is about 20mA and the device's battery can last for about 16 days.

Figure 5. *Practical prototype of bike computer*

Due to the limitations of time, the cycling power estimation function has not implemented onto the GPS bike computer prototype device yet. This function is planned to deploy for future versions of the device.

Figure 6. *Trajectory comparison*

For testing the accuracy of the GPS function of the device, we performed a 30km cycling activity. Our bike computer prototype recorded a traveled distance of 29.9km with an average speed of 32.9 (km/h) while the Magene C406 saved a tracklog of 30km with an average speed of 33.4 (km/h). Figure 6 presents the trajectory recorded by our device in comparison with the trajectory recorded by Magene C406 bike computer for the same route of 30km. As can be seen, the two trajectories are very similar. The difference between the recorded distances and speeds of the two tracklogs may be due to different GPS chips implemented on the two devices.

5. Conclusion

This paper have presented a method for cycling power estimation that can be applied in the design and implementation of smart bike computers on embedded devices. The cycling power evaluation with practical data showed that our suggested method provides similar results compared to results of the reference device. The paper also presents the design and implementation of a GPS bike computer based on a System-on-Chip platform. Incoporating cycling power estimation function to the bike computer prototype is an open research issue for future work.

Acknowledgement: This work was supported by The Murata Science Foundation and The University of Danang, University of Science and Technology, code number of Project: T2022-02-04MSF.

REFERENCES

[1] Magene, "C406 GPS Bike Computer", *www.magene.com*, 2024. [Online]. Available: https://www.magene.com/bike-computers/51-c406-gps-bike-computer.html [Accessed 25/02/2024].

[2] Garmin, "edgePower - Estimated Power Meter for Cycling", *https://apps.garmin.com*, 2024. [Online]. Available: https://apps.garmin.com/en-US/apps/0f0c518e-9145-42cf-aac0-49a87fba793c [Accessed 25/02/2024].

[3] W. M. Bertucci, S. Rogier, and R. F. Reiser, "Evaluation of aerodynamic and rolling resistances in mountain-bike field conditions", *Journal of Sports Sciences*, vol. 31, no. 14, pp. 1606-1613, 2013. https://doi.org/10.1080/02640414.2013.792945

[4] D. Meyer, G. Kloss, and V. Senner, "What is slowing me down? Estimation of rolling resistances during cycling", *Procedia Engineering*, vol. 147, pp. 526-531, 2016. https://doi.org/10.1016/j.proeng.2016.06.232

[5] A. Bouillod, G. Soto-Romero, F. Grappe, W. M. Bertucci, E. Brunet, and J. Cassirame, "Caveats and recommendations to assess the validity and reliability of cycling power meters: a systematic scoping review", *Sensors*, vol. 22, no. 1, pp. 386-417, 2022. https://doi.org/10.3390/s22010386

[6] S. Tengattini and A. Y. Bigazzi, "Physical characteristics and resistance parameters of typical urban cyclists", *Journal of Sports Sciences*, vol. 36, no. 20, pp. 2383-2391, 2018. https://doi.org/10.1080/02640414.2018.1458587

[7] S. Gribble, "The computational cyclist", *www.gribble.org*, 2024 [online]. Available: https://www.gribble.org/cycling/power_v_speed.html [Accessed 25/02/2024].

[8] D. Schneider, "Take your Pi for a ride [spinning up a Raspberry Pi-based cycling computer]", *IEEE Spectrum*, vol. 52, no. 8, pp. 24-25, 2015. https://doi.org/10.1109/MSPEC.2015.7164394

[9] Y. Lee and J. Jeong, "Design and Implementation of Monitoring System Architecture for Smart Bicycle Platform", *Procedia Computer Science*, vol. 134, pp. 464-469, 2018. https://doi.org/10.1016/j.procs.2018.07.182