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Article

Pedestrian Safety and Early Warning System Based on Green Energy

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Abstract: In Taiwan, pedestrians are run over by vehicles often in many intersectionsdue to poor lighting or lack of traffic lights. Thus, we developed a green energy-driven automatic warning system to ensure the safety of drivers and pedestrians. A variety of sensing modules, such as Hall sensors and coil loops, were used in the system to detect approachingvehicles. When an approaching vehicle was detected, the LED warning light warned pedestrians and drivers. In addition, according to data released by the government, sensors or detectors were set up at a sufficient distance from the crosswalk to ensure that the vehicle could stop before it reached the sidewalk. In the system, green energy was used to ensure that the entire system was operated for a long time and reduced energy consumption. It was verified that the proposed system could be used in various environments such as suburbs or remote intersections to improve safety.

Keywords: Sensors, Safety, Pedestrians, Green energy

1. Introduction

Recently, pedestrian safety is an important issue in transportation [1,2]. The Taiwanese government increased the fines for drivers of cars and motorcycles who didnot respect pedestrian priority [3]. According to pedestrian habits in the past ten years, using handheld devices or mobile phones caused pedestrians not to pay attention to traffic or environmental dangers [4,5]. Therefore, various methods to ensure pedestrian safety have been proposed, such as 3D crosswalks [6] and special road visual features [7] to provide adequate warning and reduce speed [8] for drivers and pedestrians.However, to provide useful warning systems for drivers and pedestrians, the attentiveness of drivers and pedestrians must be considered. Recently, to avoid traffic accidents, many ideas using artificial intelligence (AI), Internet of Things (IoT) sensors, or image recognition technology have been proposed [9,10]. Through active sensing technology, AI, and passive visual assistance, the safety of road users can be ensured. In other words, how to warn drivers or pedestrians or perform hazard detection was an important issue.

In the design of the warning system, the system's robustness (system stability and anti-interference ability) needs to be considered to operate in diverse environments. For example, different weather conditions and various ambient lighting levels affect the accuracy of object recognition in AI systems. At the same time, how to supply energy for actual system operation also needs to be considered. Rather than relying on complex computer programs to provide advanced security services, a more feasible solution needs to be designed. The operation of the system must be based on stable physical laws instead of introducing too many sensing devices and artificial programming to reduce costs.In this study, we used the data of the braking distance for different asphalt road conditions. In applications, the condition of the asphalt pavement must be considered to determine the system deployment location.The roads built a long time ago require longer braking distances. Therefore, in developing a system, universal physical principles need to be considered to detect the approaching status of vehicles precisely to warn vehicle drivers and pedestrians.

In the proposed system of this study, IoT sensors were used to automatically detect vehicles. The status of coming vehicles on the road was monitored without manual operation and excessive programming. Compared with systems with many programming, sensing, and calculations, the system was direct and stable. The proposed system estimated vehicle speed and braking distance and inferredthe possibility of accidents based on the assessment and calculation. Using an unbiased assessment approach, the system provided sufficient time and distance to prevent driving and pedestrian hazards.To continuously provide security services, the system operated independently and was connected to any third-party services. The system was powered independently based on green energy. In addition, the developed system did not need to rely on the assistance of other infrastructures, so it was less affected by other systems and had better robustness.

In this article, Section 2 introduces the relevant systems and the physical phenomena used.Section 3 introduces the system and implementation methods. Section 4 presents the simulated system, and conclusions were drawn in Section 5.

2. Related Systems and Physical Property

Various ideas to improve pedestrian safety have been proposed in the past for passive warnings and active detection. Active sensing methods were used to find potential dangers. Based on the active sensing method, warning messages were put forward for passers-by to notice. In a passive method, signs and markings were used to allow passers-by to passively change their original traffic behavior patterns when entering this safe area.In recent years, autonomous driving based on AI and various IoT sensors has been developed [9,10]. IoT devices such as ultrasonic sensors, infrared sensors, or cameras are used for image recognition. However, since sound waves or infrared rays are interfered with by the environment and result in reduced accuracy, vehicles on the road are misidentified causing car accidents [11]. With diverse environmental factors, the robustness of the active detection system is affected by effects that cannot be controlled. When people, vehicles, and objects in front of the vehicle are not correctly identified, unexpected results occur. Autonomous vehicles cause traffic accidents and even casualties due to identification errors. This type of active sensing and identification method requires IoT sensing components, identification systems, and services to perform multiple detection and identification to reduce misjudgments in a single system. However, this results in a long recognition time for additional repeated detection and judgment execution.

3D stereo vision in the crosswalkis used to warn driving[6]. When a vehicle approaches a crosswalk, the three-dimensional illusion is shown to avoid crushing or colliding with objects on the road. Zigzag lane markings or unique road markings are used, too [7]. Drivers reduce their speed due to the illusion that the road is narrow and uneven. This type of approach is to passively warn drivers by designing the illusion of road markings or sidewalk markings. However, when it is not bright enough due to weather, or when the road has been used for a long time, the effect of this method is not significant. Therefore, in this study, we proposed a system based on physical phenomena for warning [12]. In the system, it was assumed that all vehicles had metal equipment or engines. Then, metal coils were buried under the road. The pavement material served as the magnetic core. following Faraday's law of electromagnetic induction was used for the coil to provide power to the sensor,

$$\varepsilon = -N\frac{d\varphi_B}{dt} \tag{1}$$

where ε was the electromotive force, N represented the number of turns of the coil, and φ_B represented the magnetic flux passing through one turn of the coil. When a vehicle passed or stayed on the coil, the inductance of the coil loop decreased, and a pulsed wave or signal was sent to the control box as a basis for detecting the presence or passing of the vehicle. In other words, when a vehicle with a large amount of metal came close to an operating coil, it sentthe signal. Using two independent coils at a fixed distance apart, the vehicle's driving speed was measured by measuring the time difference between the signals that triggered the two coils. Many speed cameras were based on the application of this technical method. According to the extension of Eq. (1), in the magnetic flux extended into the relationship between the magnetic field B and the tiny unit area a, the magnetic flux was defined as follows.

$$\varphi_B = \int \vec{B} \cdot d\vec{a} \tag{2}$$

Then, Eq. (1) forms Eq. (2).

$$\varepsilon = -N\frac{d}{dt}\int \vec{B} \cdot d\vec{a} \tag{3}$$

Therefore, in addition to a changing magnetic field, an electric field was produced. If the induction range (area) of the coil becomes larger, or the total number of coil turns increases, the induction effect and intensity difference will increase. If an oscillation circuit is used to emit a fixed-intensity magnetic field to sense approaching vehicles, the magnetic field affected by the vehicle metal changes, increasing the number of sensors to detect moving objects. This increasesthe sensing area and the number of coils. Therefore, sensors are used to detect changes in electromagnetic induction and identify the approach of vehicles and other objects. There are many speed-sensing traffic violation cameras currently on the market that are used in this approach. With more coils, a larger range can be covered to generate enough signals to determine whether the vehicle is approaching or not.Therefore, it is necessary to consider the speed of travel and the expected distance over which the vehicle needs to slow down and stop. Taking into account the impact of weather on system robustness, worst-case scenarios (nighttime, rain, and slippery roads) were simulated to find out whether the induction coil had to be buried so that the warning system could have sufficient time for the vehicle to stop.

3. Proposed System and Implementation Method

Assuming that most pedestrians were using crosswalks to cross the road, the proposed system needed to allow vehicle drivers to stop the vehicle before reaching or approaching the crosswalk. The assessments and estimates show that after an average driver detects a warning signal, it takes about 1.6 sduring the day and about 2.5 sat night to brake a vehicle [13]. In other words, before braking, the vehicle moves toward the crosswalk at its original speed. Therefore, the distance traveled during the driver's reaction time delay must also be calculated for the distance to completely decelerate and stop a vehicle.In addition to the reaction time of the vehicle driver, the friction coefficient of the asphalt road surface needed to be taken into account [14]. The coefficient of friction of a new asphalt pavement was greater than that of an asphalt pavement that was 1 to 3 years old. In addition, different states of asphalt pavement, such as wet or dry grounds, have different friction coefficients. According to the hypothesis [15], the friction coefficient of asphalt pavements with different years of use and different conditions was defined as showin in Table 1.

Table 1. Friction coefficient of asphalt road.

Asphalt Road	Year of Use after Installation	Friction Coefficient
dry conditions	Brand new road	0.85
	Used for one to three years	0.75
	More than three years of new road surface	0.7
wet conditions	More than three years of new road surface	0.8
	Use for one to three years	0.65
	greater than three years	0.6

Considering the different speeds and friction coefficients of each passing vehicle, faster vehicles require a longer distance to stop. The required braking distance (in m) corresponds to the condition and age of the asphalt pavement as shown in Table 2.

Table 2. The distance for vehicle breaking corresponds to the state and year of the asphalt road.

Distance for Vehicle Breaking corresponding to State and Year of Asphalt Road														
State of Road	Friction Corfficie	Speed												
		20	25	30	35	40	45	50	55	60	65	70	75	80
Dry														
New	0.85	1.8	2.3	4.2	5.6	7.4	9.3	11.5	14.0	16.6	19.9	23.0	26.2	30.0
1~3 Years	0.75	2.0	3.2	4.6	6.4	8.4	10.5	13.0	16.0	18.0	22.8	26.0	30.0	34.0
> 3 Years	0.70	2.2	3.4	5.0	6.9	9.0	11.5	14.1	17.0	20.2	24.0	27.9	32.0	36.0
Wet														

New	0.80	1.9	3.2	4.4	6.0	8.8	10.0	12.2	15.0	17.9	21.0	24.5	28.0	32.0
1~3 Years	0.65	2.4	3.7	5.4	7.4	9.5	12.2	15.4	18.4	22.0	26.0	30.0	35.0	37.0
> 3 Years	0.6	2.6	4.1	5.9	8.0	10.5	13.4	16.5	20.0	24.0	28.5	32.2	37.0	41.0

Considering the worst possible situation when a vehicle brakes, we proposed a limiting function to estimate the distance required for braking as follows.

$$D(L) = v(L) \times t_r + d(\mu(y), v(L)) \quad (4)$$

where *v* was the maximum allowable speed corresponding to a specific road L (illegal speeding was not considered in this study). *t* was the reaction time known from the reference literature, which corresponded to 1.6 s during the day and 2.5 s at night. In addition, according to Table 2, when a specific road surface L was used for y, its corresponding asphalt friction coefficient $\mu$was calculated. Finally, based on the maximum allowable speed limit *v*, the corresponding braking distance d was determined. Finally, adding the original speed movement distance of the vehicle caused by the driving reaction time, the required driving distance D corresponding to the asphalt pavement L was estimated.

However, inpractical use, the induced coils were not deployed dynamically and were not removed at will. Therefore, the worst case corresponding to the required distance of the asphalt road L was considered. In this study, under the worst-case condition (irrelevant violation), it was assumed that the friction coefficient of the asphalt pavement due to age was 0.6. When the road was wet, it was assumed that the slowest reaction time for driving at night from seeing the warning to starting to brake was 2.5 s. Finally, in this study, to evaluate the distance the vehicle needs to stop, the formula was as follows.

$$D(L) = v(L) \times 2.5 + d(0.6, v(L)) \quad (5)$$

Based on this, we calculated the required distance from the position of the coil to the position of the crossing pedestrian or the position of the crosswalk to deploy the pedestrian warning system on roads at different speed limits. Fig.1 shows the required braking distance corresponding to the friction coefficient of the asphalt road surface and the speed of the vehicle. The best situation (Best) was that the reaction time of Eq. (4) was 1.6 s, and the shortest path was found on the dried newly paved asphalt road. On the contrary, the worst case was the result calculated by Eq. (5). When the vehicle moved at a speed of 80 km/h, the distance of the worst scenario was 96.5 m, while that of the best scenario was 65.5 m. Therefore, the coils used in sensing must be arranged based on the braking distance in the worst-case scenarios to secure sufficient stopping distance and warning time.

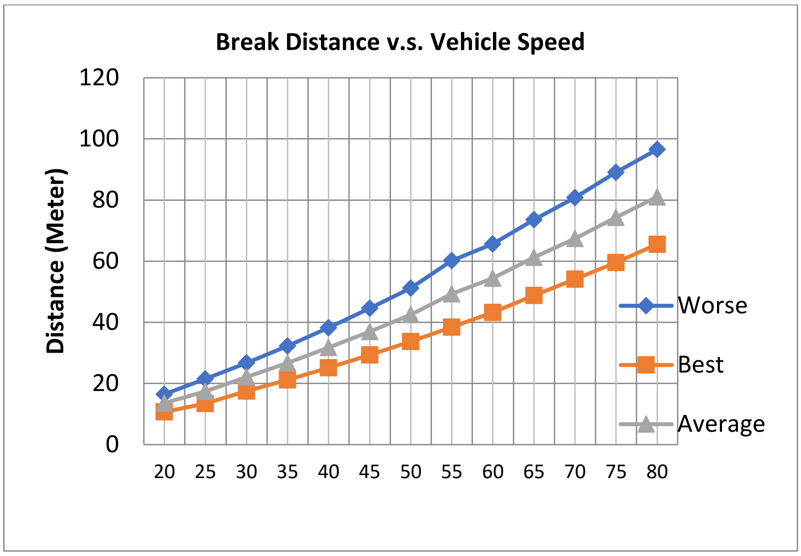


Fig. 1. The required distance for stopping the vehicle corresponds to the worst case and best case.

Based on the estimated distance, the module of the induction coil and IoT sensor was placed at a sufficient distance from the intersection crosswalk. The sensed signal was used to trigger the alarm system. If manual processing or program calculation was required, delayed time occurred, so the distance calculated by Eq. (5) became insufficient. In other words, longer distances were needed to gain safe time and distance. Therefore, in this study, to avoid over-extending the distance and uncontrollable program calculation delays, the physical electromagnetic induction method was used to detect the approaching vehicle. To effectively warn drivers and pedestrians day and night, LED lights were better than sounds or signs. When the sensor sensed a vehicle, the control box that received the signal flashed the LED lights on the asphalt road next to the crosswalk. By flashing the LED light for at least 2.5 s, the driver was warned to stop a vehicle at enough distance before approaching the crosswalk. The LED light flashed to warn pedestrians of approaching vehicles on the crosswalk. To have a sufficient effect, the LED flashing lasted for more than 2.5 s to allow the driver to have sufficient reaction time. When approaching a crosswalk, the driver could confirm the road status and ensure the safety of pedestrians.

When pedestrians crossed the road, the warning lights flashing alerted them for approaching vehicles. At this time, pedestrians can crossthe road quickly. On the contrary, pedestrians did not cross the road until vehicles passed. Even users of handheld devices could be aware of the danger due to sudden light changes of LEDs. Compared with sound warnings, the LED could be sufficient stimulation to warn pedestrians without being affected by the ambient noise. In the warning system proposed, IoT sensors, control boxes, and batteries were used. The control box received signals from the coil or IoT sensor module. The control box controlled the LED light. For the sensor to detect and generate electromagnetic waves, an oscillation circuit was embedded in the control box. The concept of the system is shown in Fig.2.

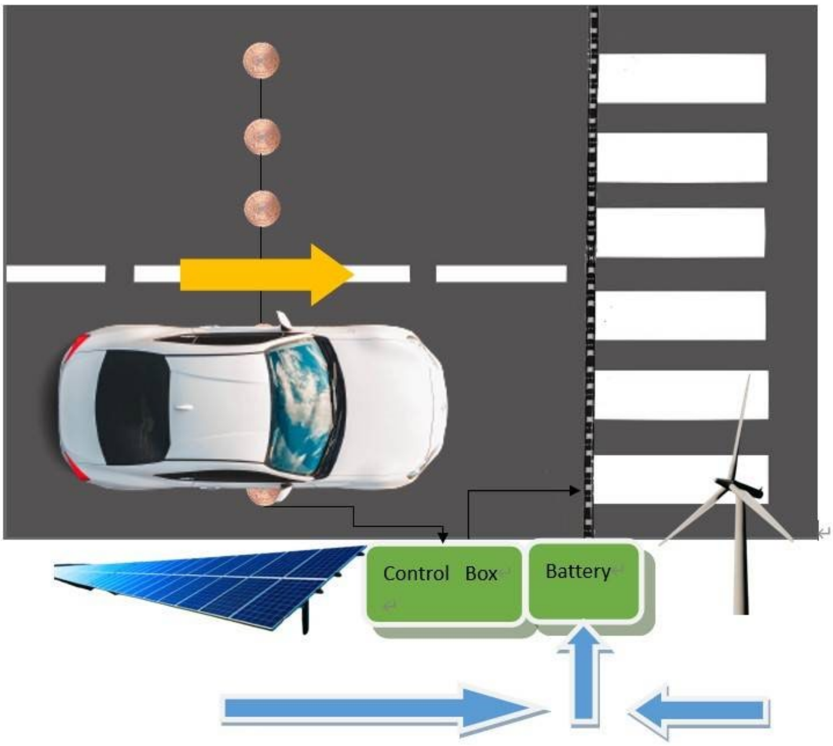


Fig. 2. The concept of the proposed system.

Most intersections in the city center were close to each other. In addition, there were many intersections with traffic light control, and the speed of vehicles was not high. Thus, deploying the proposed system at every intersection easily caused false alarms. On the contrary, the vehicle speed and traffic volume in the night were opposite. The dense traffic lights at each intersection make vehicles have frequent decelerations and stops. Therefore, the proposed system was suitable for suburban areas or areas with fewer traffic lights, providing pedestrians with safety. How to provide power in suburban areas with less lighting at night is also an important issue.Therefore, in this system, green energy was used as the power source. A variety of green energy sources was connected to generate electricity and charge the battery. Solar panels and wind turbines were connected in parallel or in series to obtain optimal efficiency. With batteries, the system operated independently. With or without wired power, the system worked independently based on the green power source.

4. Simulation Result

To verify the system's operation, we simulated the system. In the simulation, the system used a Hall module to replace the original coil as toy cars did not have enough metal to cause changes in the electromagnetic field. In the simulation, we did not realistically deploy large induction coils. Therefore, a single Hall module was used to sense the toy car, rather than multiple coils connected to the control box. To use the Hall module, the electromagnetic field needed to be changed to trigger and drive the Hall module to generate signals. Therefore, we placed a magnet in the engine room of the toy car. When the toy vehicle approached the Hall module, the magnet initiated the Hall module.The ESP32 embedded system was placed in the control box as the main controller because ESP32 used most existing IoT modules. In addition to the Hall module and relay module, a controller was used to extend the connection to the camera module and wireless network module. In addition, the input and output control pins of ESP32 were used to drive the relay. The LED light was connected to the relay, so the ESP32 used the relay switch to control the number and time of the LED flashes. Fig.3 shows the general system wiring and architecture in the control box, considering that multi-room vehicle driving was more sensitive to police car lights. We used two colors of LEDs (blue and red) to allow vehicle drivers and pedestrians to detect and avoid danger by flashing LED lights for a while.

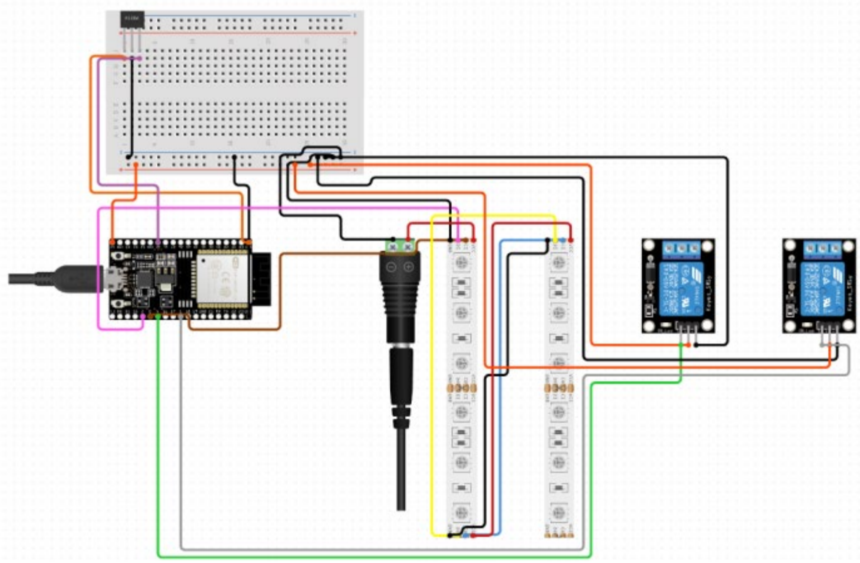
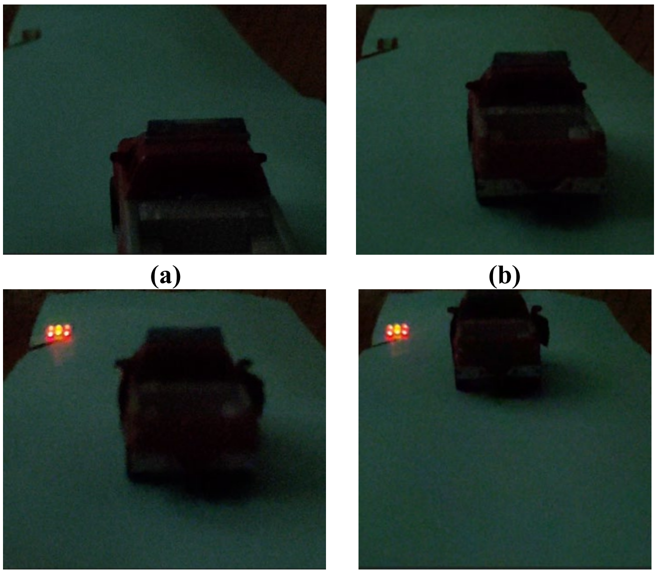


Fig. 3. Theconcept of the proposed system based on ESP32 with relay, LED, Hall Module, and power source.

As green energy power generation sources, solar and wind power generation were used. Using the previous pivoting method [16–18], different green energy power sources were connected to provide power through series and parallel circuits. In this way, there was no need for the excessive singleness of the power source and the increase in the instability of the power source due to weather effects. As shown in Fig.4, the wind turbine and the solar panel provided power to the LED lights on the power supply circuit (right side of the figure). Solar panels can be used in areas with normal sunshine, while wind turbines can be used in better locations where wind is strong. The proportion of green energy was controlled to continuously provide power to the battery, and the power was supplied to the control box and LED as shown in Fig. 4.

Fig. 4. The emulation result of the pivoting green energy power.

When a simulated car with a magnet approached the Hall module, a signal was emitted and sent to the control box. Then, through the relay module, the LED light turned on and flashed, making it visible to drivers and pedestrians. Fig.5 shows the simulation when the ambient brightness was insufficient. Flashing LED lights improved safety for drivers and pedestrians. In the beginning, the vehicle was at the lighting position of the simulation environment as shown in Fig.5a. The Hall module in the darkness is shown in Fig.5b. Fig.5c shows that when the Hall module sensed the magnetic field-induced change caused by the magnet in the engine room of the simulated car, the signal activated the relay and lighted the LED. In the worst-case scenario of 80 km/h, the final braking speed was 0. The distance required from the start of braking to the stop was 41 m. In the longest required distance, the deceleration of the vehicle was estimated to be 6 m/s^2. In other words, it took about 4 s to stop. Therefore, the system needed to display for at least 6.5 s, allowing the vehicle driver to have 2.5 sto react and more than 4 sto brake after seeing the LED lights. Fig.5d shows that after the LED light started to flash by the controller, even if the simulated vehicle continued to move forward and decelerated away from the position of the Hall module, it continued to flash, which verified that this system was feasible and operated normally.



(a) (b) (c) (d)

Fig. 5. The simulation result of the proposed system. (**a**) initial state of proposed system; (**b**) vehicle approaches the Hall module; (**c**) the Hall module is triggered and LED light flashes with long enough distance ; (**d**) LED light keeps flashing.

5. Conclusions

The warning system was developed with green energy to use in suburban or remote areas. Corresponding to the vehicle speed limit and braking distance, the coil sensor was provided an early warning at the appropriate position so that the driver had enough time to stop. Considering the relative road conditions and driving speed, the induction coil was buried 96.5 mfrom the crosswalk, at least an average of 80 m to stop a vehicle in about 6 s. Pedestrians and drivers required at least 4 sto react to avoid accidents.

Author Contributions: conceptualization, S.-J.Jian and M.-S. Jian;methodology, S.-J.Jian and M.-S. Jian;software,S.-J.Jian, Y.-L. Chen and Y.-Z. Liao; validation,S.-J.Jian, Y.-L. Chen and Y.-Z. Liao; formal analysis,H.-T. Liu and P.-L. Sung; investigation,H.-T. Liu and P.-L. Sung; Resources, M.-S. Jian; data curation,M.-S. Jian, H.-T. Liu, and P.-L. Sung; writing—original draft preparation, S.-J.Jian and M.-S. Jian;writing—review and editing,S.-J.Jian and M.-S. Jian;visualization, All; supervision, M.-S. Jian. All authors have read and agreed to the published version of the manuscript.

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