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Design of Intelligent Bicycle Anti-theft System Based on Internet of Things and Computer Technology

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Abstract: With the acceleration of urbanization, bicycles are widely favored as a green travel mode, but their anti-theft problems are becoming more and more prominent. This study aims to design an intelligent bicycle anti-theft system based on Internet of Things and computer technology to enhance the efficiency and safety of bicycle theft prevention. The system realizes remote monitoring, real-time positioning and intelligent alarm by integrating sensor, wireless communication and cloud computing technologies. The hardware design covers the main control and sensor module, communication module, etc., while the software design includes embedded software and mobile application. The system is equipped with key functions such as real-time positioning display, alarm information receiving and pushing, remote control, etc., and adopts a multi-layer security protection mechanism to ensure the safety of user data. This study not only promotes the wide application of IoT technology in the field of anti-theft, but also provides a useful reference for the research and development of intelligent bicycle anti-theft system.

Keywords: Internet of things technology; Computer technology; Smart bicycle; Anti-theft system.

1. Introduction

With the return of bicycles in the city and the high willingness to ride, it has prompted a significant increase in their use. In Beijing, for example, the number of shared bicycle rides reached 1.088 billion in 2023, and the average daily riding volume increased by 12.79% year-on-year. However, the surge in the number of bicycles has also brought about an intensification of the problem of theft, bringing economic losses and psychological distress to owners. Traditional anti-theft measures such as mechanical locks and alarms, due to their simple structure and low cost, have limited anti-theft effects and are easy to be cracked, while the high rate of false alarms and slow response time make it difficult to effectively respond to theft.

The application of Internet of Things (IoT) technology in the field of bicycle anti-theft gradually highlights the advantages of the integration of sensors, wireless communications and cloud computing technology, to achieve remote monitoring, real-time positioning and intelligent alarm, significantly improving the anti-theft effect [1]. Intelligent bicycle anti-theft system utilizes GPS positioning technology to track the location of the bicycle in real time, and the owner can obtain the location information and alarm instantly through the cell phone APP, which effectively improves the chances of retrieval.

The research and development of intelligent bicycle anti-theft system based on the Internet of Things and computer technology is of great significance to safeguard the safety of bicycles and improve the efficiency of anti-theft [2]. The system not only provides convenient and efficient anti-theft services for the owner, reducing the risk of theft, but also provides clues for public security organs to solve the case, helping to improve the detection rate of theft cases and maintain social security stability. The development of this system promotes the wide application of Internet of Things (IoT) technology in the field of anti-theft and promotes the innovative development of related industries [3]. Although progress has been made in this field both at home and abroad, there is still room for improvement in the technical level and market application in China, and it is necessary to further reduce the cost and improve the cost-effectiveness of the IoT anti-theft system.

2. Overall System Design

2.1. System Requirements Analysis

The research and development of intelligent bicycle anti-theft system aims to meet the core needs of users for real-time positioning, remote alarm, evidence collection and so on. With the acceleration of urbanization, bicycles are widely favored as a green mode of travel, but their anti-theft problem has become a major nuisance for users. Users expect the system to have real-time positioning function, so as to grasp the location of the bicycle at any time, and once the vehicle is stolen, it can be quickly located and retrieved; remote alarm function requires the system to send alarm information to the users cell phone immediately when the vehicle moves abnormally or is illegally unlocked, so as to realize instant response; evidence collection function needs to record key data before and after the vehicle is stolen, such as location information, time stamps and so on, to provide strong evidence for subsequent recovery and compensation [1]. The evidence collection function needs to record key data before and after the theft of the vehicle, such as location information and time stamps, to provide strong evidence for the subsequent recovery and compensation [4]. Based on user requirements, the system functional requirements are clearly defined as remote alarm, real-time localization, evidence collection, low-power design, fast response and long-distance communication. The system needs to send real-time alarm information through wireless communication technologies such as GSM/GPRS, realize real-time tracking and display of vehicle location using satellite navigation systems such as GPS/BeiDou, record key information such as vehicle status, position change, operation records, and support remote download and local storage of data. In terms of performance requirements, the system needs to have low power consumption, fast response, long-distance communication, high reliability and anti-jamming ability to ensure stable work in complex environments. Reliability and security requirements require the system to adopt high-reliability hardware and software design, the use of high-quality electronic components, the use of modular design, improve code readability and maintainability. In terms of security, the system needs to adopt multi-layer security protection mechanisms, including data encryption, access control, identity authentication, etc., to ensure user data security and privacy protection, and at the same time, it has self-detection and fault warning functions to detect and repair potential problems in a timely manner.

2.2. System Architecture Design

The architecture design of the smart bicycle anti-theft system covers hardware, software and application layers, aiming to build an efficient, stable and user-friendly system (see Figure 1). The hardware layer integrates acceleration sensors, GPS, etc., which is responsible for collecting real-time bicycle status and location information and transmitting it to the software layer through wireless technologies such as ZigBee, LoRa, etc. The software layer relies on an embedded operating system (e.g. FreeBee). The software layer relies on an embedded operating system (e.g., FreeRTOS) to analyze and process the collected data and realize intelligent decision-making. The application layer provides user interaction and remote control, supporting mobile APP and web access [5].

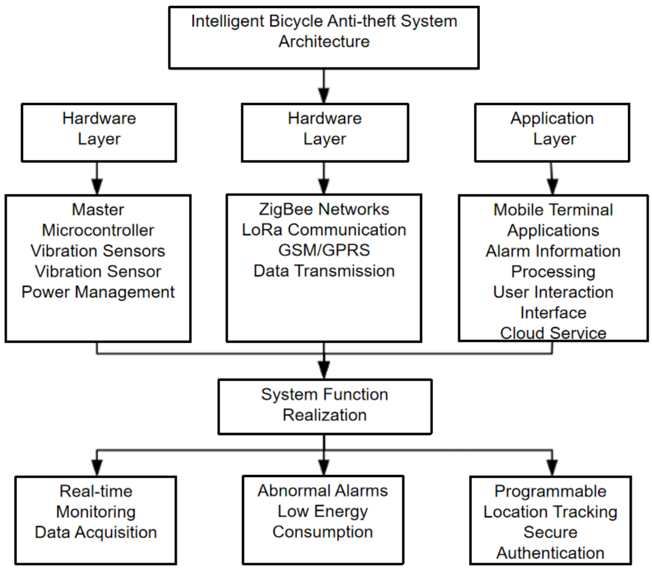

Figure 1. Core Architecture of Intelligent Bicycle Anti-theft System

The system adopts star and mesh hybrid network topology to adapt to the complex communication environment in the city. The sensor network utilizes ZigBee and LoRa technologies to transmit data to the gateway, which then connects to the Internet via 4G/5G and Wi-Fi and uploads to the cloud server. The cloud adopts distributed architecture and big data processing to analyze the data in real time and push it to the user terminals, ensuring real-time data sharing and high reliability of the system.

The system is divided into four modules: sensor, communication, control, and application. The sensor module monitors the bicycle status; the communication module realizes efficient data transmission; the control module is based on embedded system with C/C++ programming to process data and make decisions; the application module provides user interaction interface and supports remote control. The modules work together through standard interfaces to jointly realize the system functions.

In terms of workflow, after the system starts, the sensor collects data in real time and transmits it to the control module, which analyzes the data to determine the bike status. If abnormalities are detected (e.g. illegal movement), an alarm is triggered, which is sent to the user via the communication module and uploaded to the cloud. Users can instantly check the status of the bike and control it remotely, ensuring efficient and stable operation of the system in various environments.

3. System Hardware Design

3.1. Main Control and Sensor Module Design

In the hardware design of the intelligent bicycle anti-theft system, the main control module selects STM32 microcontroller, which meets the system data processing and control requirements by virtue of its powerful processing capability and rich peripheral resources. The peripheral circuit design includes key reset, crystal clock and serial communication to ensure stable operation of the microcontroller and realize efficient data interaction [6]. The vibration/piezoelectric sensor module adopts piezoelectric ceramic sensors, which can accurately sense the small vibration of the bicycle, and when abnormal vibration generates an electric signal that is transmitted to the main control chip through the conditioning circuit, triggering an alarm and notifying the user, which improves the sensitivity and response speed of the system. The positioning module integrates GPS and BeiDou dual-mode technology to achieve all-weather high-precision positioning, real-time calculation of the bike position and transmission to the main control chip through the serial port, supporting historical track playback and optimizing the user experience. The power supply module is based on lithium battery, equipped with intelligent charging management chip and voltage regulator and filter circuit to ensure stable power supply of the system, and designed with easy-to-replace battery compartment to prolong the service life of the system.

3.2. Communication Module Design

In the intelligent bicycle anti-theft system, the design of communication module needs to take into account the technical characteristics and system requirements. zigBee technology, with its low power consumption, short-range communication and self-organizing network capability, is suitable for close-range data transmission within the sensor network, to ensure the real-time and accuracy of the bicycle status information. loRa technology, with its long-range and low-power consumption characteristics, has become an ideal choice for remote data transmission, and can stably transmit sensor data to the monitoring center or user terminal. gsm/GPRS technology, with its wide coverage, high speed and mature network foundation, can realize the system and alarm notification. LoRa technology, with its long range and low power consumption, is the ideal choice for remote data transmission, and can stably transmit sensor data to the monitoring center or user terminals, while GSM/GPRS technology, with its wide coverage, high speed, and mature network infrastructure, meets the demand for remote communication and alarm notification, and realizes a seamless connection between the system and the users cell phone.

Based on the above analysis, this system adopts a communication scheme that combines ZigBee, LoRa and GSM/GPRS technologies. the ZigBee communication module takes CC2530 chip as the core, integrates enhanced 8051 microcontroller and RF transceiver, and supports a variety of network topologies to ensure efficient communication within the sensor network. the LoRa communication module relies on SX1278 chip, and applies LoRa spread-spectrum communication technology. The LoRa communication module relies on the SX1278 chip and applies the LoRa spread spectrum modulation technology to realize long-distance and low-power remote communication, which improves the system endurance and reduces the cost, while the GSM/GPRS communication module utilizes the mature network technology to support the SMS and data communication, which meets the needs of the alarm notification and remote query.

In order to realize efficient operation of the system, the design of multi-mode communication working mechanism, through intelligent scheduling algorithms, to achieve seamless switching and cooperation between ZigBee, LoRa and GSM/GPRS. Within the sensor network, ZigBee is used to ensure real-time data transmission; for remote communication, LoRa or GSM/GPRS is selected according to the requirements to realize long-distance, low-power data transmission and alarm notification, providing owners with a full range of bicycle safety monitoring services.

3.3. Mechanical Dynamics Analysis and Modeling

The core performance of bicycle anti-theft system depends on the accurate modeling of mechanical dynamic characteristics. As a nonholonomic restraint system, the bicycle needs to meet the static balance of gravity, support force and friction force at rest; In motion, the dynamic coupling of inertial force, gyro effect and air resistance should be considered. The six-degree-of-freedom dynamic model based on Lagrange equation provides a theoretical basis for system design.

$$M(q)\ddot{q} + C(q,\dot{q})\dot{q} + \quad (q) = t$$

Among them, the mass matrix $M(q)$ describes the mass distribution of the frame, the Coriolis force $C(q,\dot{q})$ term reflects the energy dissipation during the movement, and the gravity term $\quad (q)$ determines the static equilibrium position. Through this model, the vibration mode of the frame under lateral impact can be deduced, which provides key parameters for sensor arrangement. For example, the transverse vibration frequency of the head pipe can be calculated by equivalent stiffness k and mass m:

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

In the aspect of sensor dynamic response optimization, the least square method is used to fuse the data of triaxial acceleration sensor:

$$a_{est} = (H^T R^{-1} H)^{-1} H^T R^{-1} z$$

4. System Software Design

4.1. Embedded Software Design

The embedded software design of the smart bicycle anti-theft system adopts a layered architecture, covering the operating system layer, driver layer and application layer. The operating system layer utilizes a real-time operating system (RTOS), such as FreeRTOS, for resource management and task scheduling; the driver layer controls the hardware devices, including RFID, GPS, and wireless communication modules; the application layer provides a user interaction interface to support monitoring the status of the bicycle and receiving alarm information via cell phone APP. The main control microcontroller program flow includes initialization setting, data acquisition and processing, alarm triggering and wireless communication implementation. The initialization stage completes port configuration, interrupt setting and timer initialization. In the data acquisition and processing session, the sensor data is collected by ADC and Kalman filtering algorithm is applied to remove noise and improve data accuracy. After abnormal vibration or illegal movement detection, the system triggers the alarm mechanism and sends alarm information to the user through LoRa or NB-IoT technology. Sensor data acquisition and processing uses high-precision acceleration sensors (e.g., ADXL345) to monitor bicycle vibration, process the signal through amplification circuit and ADC conversion, and reduce the false alarm rate through the adaptive threshold adjustment function. The GPS positioning module (e.g., U-blox NEO-M8N) receives satellite signals, calculates and transmits the precise positional information to the microcontroller to realize real-time bicycle positioning and tracking. The alarm function is realized by sound and light alarms and remote alarms to ensure timely notification to the user in abnormal situations (see Figure 2). The low power consumption management strategy adopts dynamic power management technology, which automatically adjusts the power supply according to the system operation status and enters into sleep mode to reduce power consumption, and monitors the battery voltage through the power management chip to ensure the safe operation of the battery and prolong the service life of the system.

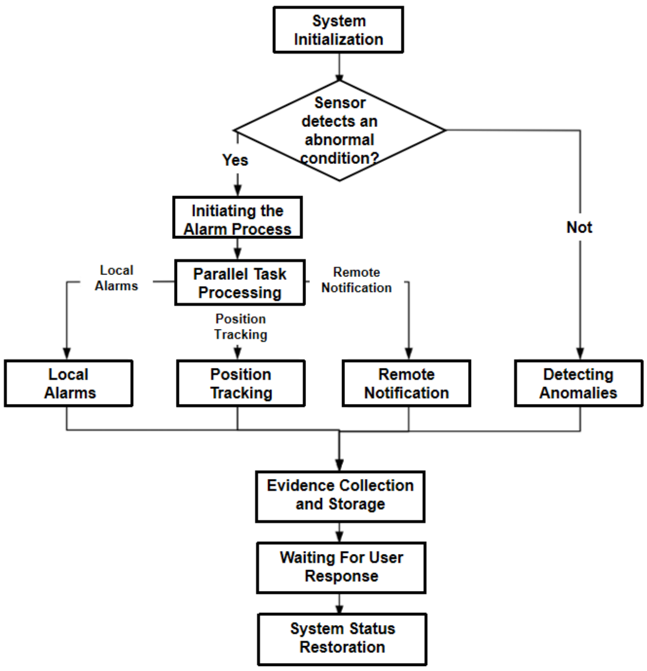

Figure 2. System software flow

4.2. Mobile Application Design

In order to optimize the user experience of the smart bicycle anti-theft system, the mobile application design adopts a layered architecture, covering the user interface layer, business logic layer and data access layer. The interface layer is presented in flat design, highlighting real-time positioning, alarm reception and remote control functions, with intuitive icons and simple menus to help users operate efficiently. The business logic layer focuses on user request processing, data validation and alarm condition judgment, and the modular design ensures functional independence and scalability. The data access layer follows the RESTful API standard and efficiently transfers and shares data in JSON format.

The real-time positioning function is realized with the help of third-party map service SDK. The system regularly acquires GPS data and updates the location information, so that users can view the real-time location and trajectory of bicycles. Alarm reception and push function ensures that when abnormal vibration or theft occurs, the sensor trigger signal is uploaded to the server and the user is instantly notified of the alarm details via push service. The remote control function allows users to adjust alarm sensitivity and set security zones through the app, enhancing system flexibility.

In terms of security, the system adopts SSL/TLS encrypted data transmission and AES algorithm encrypted storage of user data, while setting up a rights management mechanism to restrict data access and operation rights of different users. Regular security audits and vulnerability scans further protect system security and privacy (see Figure 3).

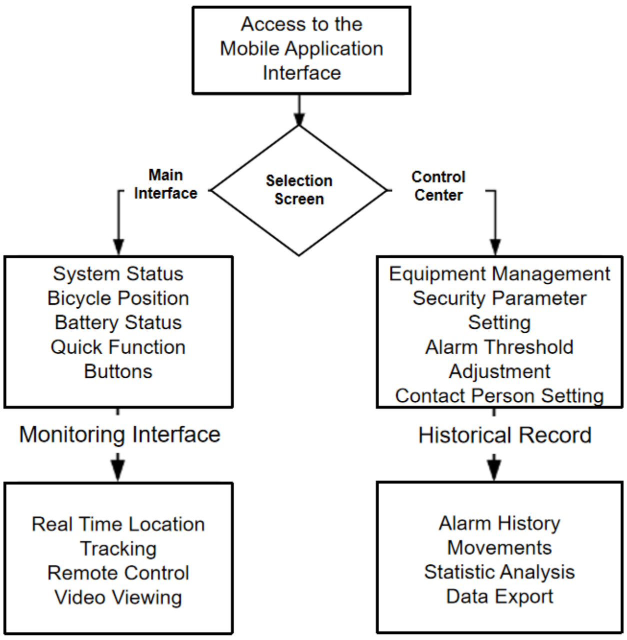

Figure 3. Mobile application interface structure

5. Conclusion

In the design study of intelligent bicycle anti-theft system based on IoT and computer technology, this project realizes a number of key functions and innovation points. The system is equipped with core functions such as real-time localization, remote alarm, evidence collection, low-power management, etc., and works together through multiple communication methods to improve the overall performance of the system. Comprehensive testing and analysis covering functional, performance and reliability tests verified the feasibility and effectiveness of the system. However, the system still has limitations, such as power management strategies and security and privacy mechanisms to be optimized. Improvement measures are proposed to address these issues, including further reducing system power consumption and enhancing data security protection. Looking ahead, the research direction will focus on exploring advanced IoT technologies and algorithms to improve system performance and reliability, as well as strengthening cross-disciplinary cooperation to promote the widespread application and development of smart bicycle anti-theft technologies.

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