ISSN 2616-5767 Vol.8, Issue 5: 107-112, DOI: 10.25236/AJETS.2025.080515

Design of an Intelligent Pet Wearable Device Based on STM32

Luo Shunan[1,a,*], Deng Yun[1,b], Zhang Yucheng[1,c]

[1]University of Science and Technology Liaoning, Anshan, China
[a]1026485105@qq.com, [b]3091576143@qq.com, [c]1066965502@qq.com
**Corresponding author*

Abstract: *Aiming at the problems of fragmented data, singlea functionality, and insufficient real-time performance in current pet health management, an intelligent pet wearable device based on STM32 is designed. The system uses the STM32F103C8T6 microcontroller as the core, integrates multi-sensor and Internet of Things (IoT) communication modules, and constructs an integrated pet health management platform of "perception-analysis-warning-interaction." At the hardware level, a modular design is adopted to realize functions such as GPS positioning, heart rate and blood oxygen monitoring, and motion behavior recognition. At the software level, through embedded algorithms and cloud collaboration, data fusion, health assessment, and remote interaction are completed. Test results show that the system positioning error is ≤5 meters, heart rate monitoring accuracy is ≥95%, motion recognition accuracy is ≥90%, and response delay is ≤1 second, demonstrating good reliability and practicality. It can provide pet owners with all-weather, comprehensive pet health monitoring services.*

Keywords: *STM32; Pet health monitoring; GPS positioning; Internet of Things; Multi-sensor fusion*

1. Introduction

With the development of the social economy and changes in family structure, pets have gradually become important emotional companions and family members[1]. However, issues such as pets getting lost outdoors, health abnormalities being difficult to detect promptly, and the single functionality and data isolation of existing smart devices are becoming increasingly prominent. Pet owners have a growing urgent demand for intelligent, integrated health management devices[2]. Currently, most pet wearable devices on the market focus on a single function like positioning or health monitoring, lacking data linkage and comprehensive analysis capabilities, and cannot achieve true "preventive" health management[3]. To this end, this paper designs an intelligent pet wearable device based on STM32. By integrating multiple functions such as GPS/BeiDou positioning, heart rate and blood oxygen monitoring, motion sensing, and voice interaction, and utilizing IoT technology to achieve cloud synchronization of data and mobile terminal visualization, it constructs a complete solution from data collection, intelligent analysis to remote monitoring, aiming to enhance the intelligence level and user experience of pet health management[4].

2. Hardware System Design

This hardware system adopts a layered modular architecture design. It uses the low-power STM32L431CBT6 as the main control core, integrating from top to bottom the perception layer (GPS/BeiDou positioning, heart rate and body temperature monitoring, motion posture recognition modules), the control layer (data processing and command decision unit), the communication layer (NB-IoT + Bluetooth BLE dual-mode transmission), the power layer (low-power supply and charging management), and the interaction layer (status indication and simple control modules). Standardized interfaces enable module linkage and flexible expansion. The system is centered on "lightweight, long battery life, and high reliability," integrating integrated functions such as positioning and tracking, health monitoring, and two-way interaction. It constructs a full-chain closed loop of "collection-processing-transmission-feedback," solving the pain points of traditional pet devices such as functional fragmentation and limited application scenarios, providing accurate and stable hardware support for pet health management across all scenarios. The Hardware System Layered Architecture Design is shown in Figure 1.

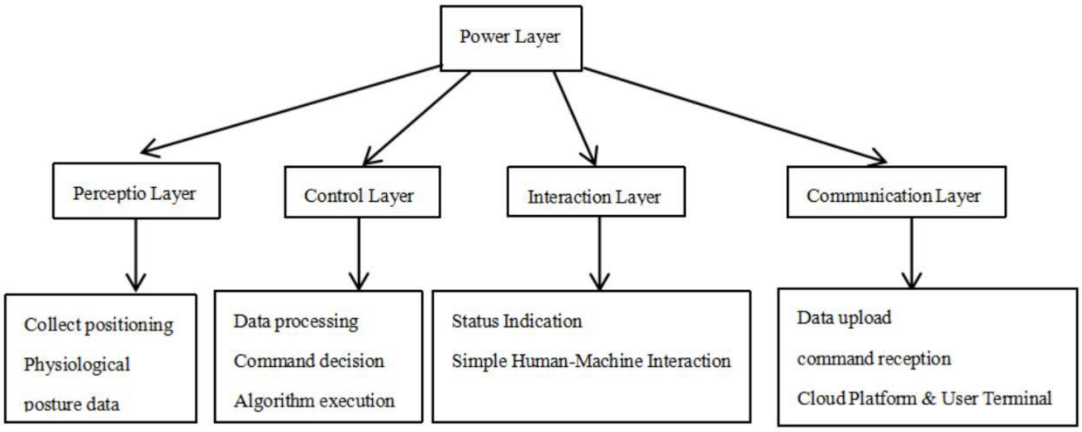

Figure 1: Hardware System Layered Architecture Design

2.1. Main Control Module

The main control chip is the STM32F103C8T6, based on the ARM Cortex-M3 core, featuring a 72MHz main frequency, 64KB Flash, and 20KB SRAM. It supports rich peripheral interfaces, meeting the needs of multi-sensor data fusion and real-time processing. The power module uses the TP4056 charging management chip paired with an 18650 lithium battery, achieving USB-C fast charging and overcharge/over-discharge protection. Stable voltage is supplied to each module through DC-DC step-down and LDO voltage regulation circuits, with a system battery life of ≥48 hours.

2.2. Perception Layer Modules

To achieve comprehensive and accurate perception of pet location, physiological state, and motion behavior, this system's perception layer integrates three core sub-modules: the GPS/BeiDou dual-mode positioning module for outdoor full-scenario tracking (e.g., walking in residential areas, retrieving from underground garages); the heart rate and body temperature monitoring module responsible for real-time physiological health data collection (e.g., resting heart rate, body temperature fluctuations); and the motion posture and behavior perception module for recognizing motion postures and abnormal behaviors (e.g., running, excessive barking).

GPS/BeiDou Positioning Sub-module: The core components are the GPS+BeiDou dual-mode positioning module and the MPU6050 posture sensor. The dual-mode positioning module can cover location signal collection in complex outdoor scenes such as residential areas, tree-lined paths, and underground garages, outputting precise longitude and latitude information. The MPU6050 simultaneously collects pet acceleration, angular velocity, and other motion posture data. After being transmitted to the main control module, this data provides the basis for dynamic calibration of positioning data, effectively reducing positioning drift caused by rapid pet movement and urban multipath effects, thereby improving positioning accuracy. It provides core location data for functions such as anti-lost tracking, electronic fence alerts, and motion trajectory recording, meeting the positioning needs for outdoor pet walking across all scenarios[5].

Heart Rate and Body Temperature Monitoring Sub-module: The core components are a high-precision contact heart rate sensor and an environment temperature-compensated body temperature sensor. The sensors adhere closely to the pet's skin to collect raw heart rate and body temperature signals in real time. At the hardware level, a preliminary filtering circuit is built-in to reduce interference from ambient temperature and pet fur. The raw data is transmitted to the main control module for further calibration via software algorithms, ensuring a heart rate measurement error of ≤±3 bpm and a body temperature measurement error of ≤±0.3°C. It can stably capture physiological data changes during pet rest and activity states, providing accurate physiological data support for pet health warnings (e.g., fever, abnormal heart rate), daily health trend analysis, and sleep quality assessment.

Motion Posture Recognition Sub-module: The core components are a triaxial accelerometer, a vibration sensor, and a high-sensitivity microphone. The triaxial accelerometer and vibration sensor work together to collect pet activity levels and motion posture data such as walking, running, lying down, and agitation. The main control module uses this to determine the pet's motion state and

ISSN 2616-5767 Vol.8, Issue 5: 107-112, DOI: 10.25236/AJETS.2025.080515

behavior patterns. The microphone captures sound signals such as barking and licking, assisting in the identification of behaviors like excessive barking and abnormal agitation, providing a data basis for pet behavior management. It enables pet activity statistics and abnormal behavior warnings (e.g., continuous agitation indicating stress response), meeting the behavior monitoring needs for scenarios like staying home alone and outdoor activities[6].

3. Software System Design

This software system relies on the STM32CubeMX development platform, following the design philosophy of "modular collaboration, multi-terminal linkage, reuse + incremental development." It builds a full-chain software architecture covering the collar end, base station end, and APP end. The system uses the low-power STM32 microcontroller as the local computing core, transplants mature communication protocol stacks and control logic, and incrementally develops core algorithm modules such as positioning calibration, health data analysis, and anomaly identification. It realizes the closed-loop management of "data collection - processing - transmission - feedback - iteration." The software overall supports four core functions: positioning and tracking, health monitoring, interactive companionship, and behavior management, effectively solving the pain points of traditional pet software such as data fragmentation, insufficient accuracy, and poor multi-terminal coordination, providing efficient and stable software support for pet health management across all scenarios. The Software System Layered Architecture and Core Functions Diagram is shown in Figure 2.

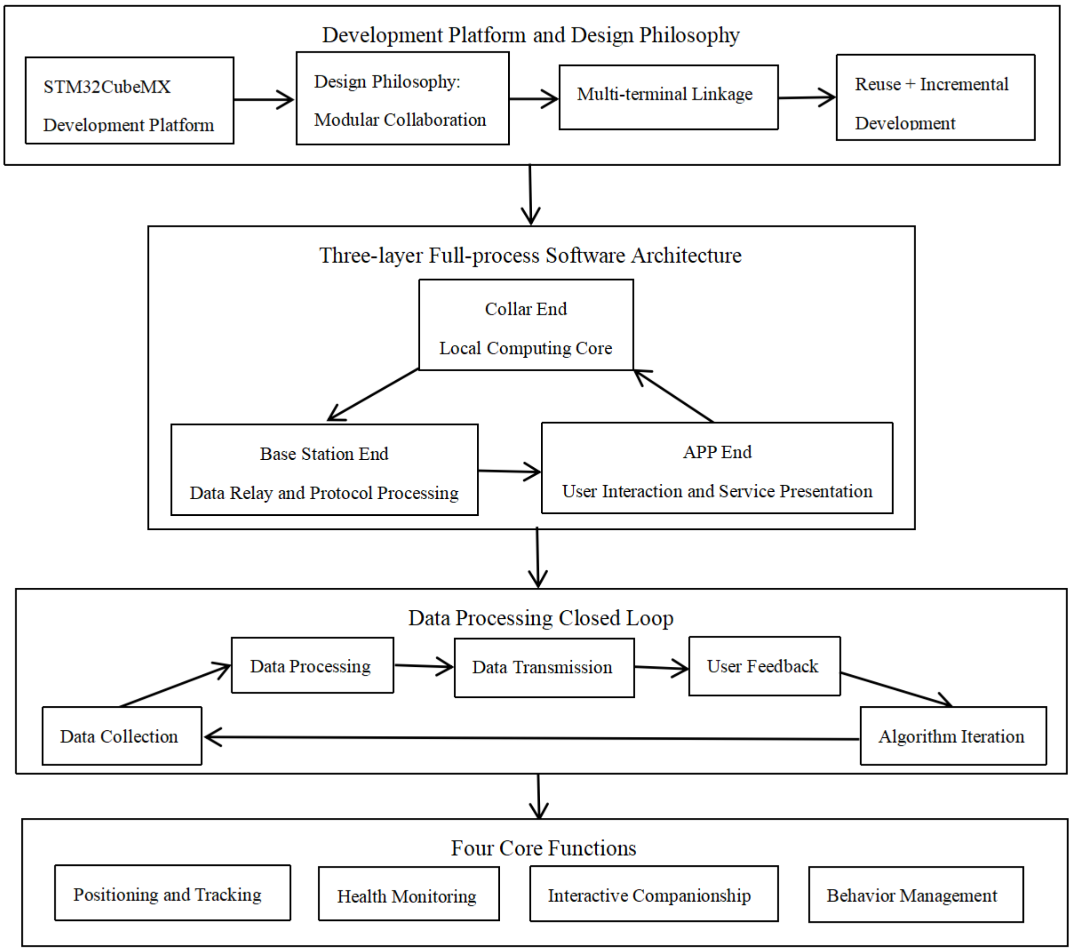

Figure 2: Software System Layered Architecture and Core Functions Diagram

3.1. Core Control and Scheduling Module

Based on the STM32CubeMX development environment, the core control and scheduling module reuses existing mature modules such as WiFi communication, MQTT protocol stack, and voice recognition control, and adds a new OTA remote upgrade sub-module. As the "central dispatch center" of the software system, its core functions include: coordinating hardware resource scheduling at the collar end, intelligently switching between low-power sleep mode and full-feature operation mode based on the pet's motion state (stationary/active), and cooperating with hardware power management to achieve a battery life of up to 7 days; managing protocol stack operation to ensure the stability and compatibility of multi-terminal data transmission, while supporting remote iteration of software functions through the OTA upgrade module, allowing algorithm optimization and function expansion without disassembling the device; coordinating task scheduling among various software sub-modules to ensure orderly progression of processes such as data processing, command execution, and alarm triggering, reducing latency in multi-module coordination. This module reduces development risk and debugging costs through technology reuse and enhances system operation stability and lifecycle through intelligent scheduling and remote upgrade capabilities, meeting the needs for pet use in all-weather and all-scenario environments.

3.2. Data Processing and Algorithm Design

The adaptive Kalman filter algorithm uses the motion amplitude collected by the MPU6050 posture sensor as the dynamic noise coefficient, optimizing the traditional Kalman filter model. Aiming at the positioning drift problem caused by urban multipath effects and rapid pet movement, it dynamically adjusts filtering parameters to calibrate GPS/BeiDou dual-mode positioning data in real-time, reducing positioning drift by 70% and significantly improving positioning accuracy in complex outdoor scenarios such as community squares, tree-lined paths, and underground garages. It provides reliable data support for functions like electronic fences and trajectory query, effectively solving the problem of poor adaptability of traditional positioning algorithms and meeting the precise needs for pet outdoor dynamic positioning.

The health data calibration algorithm employs a three-step method of "moving average, peak detection, and outlier removal" to process heart rate data, combined with an ambient temperature compensation model to correct body temperature data. This algorithm performs noise reduction and calibration on the raw signals collected by the heart rate sensor and body temperature sensor, effectively mitigating interference from factors such as ambient temperature and pet fur. It ensures heart rate measurement errors within ≤±3 bpm and body temperature measurement errors within ≤±0.3°C, enabling stable capture of physiological data changes in pets across various states such as rest, activity, and sleep. This technology provides a high-precision data foundation for health warnings, daily health trend analysis, and sleep quality assessment, robustly supporting the system's capability for "preventive" health management.

The motion and behavioral state judgment algorithm builds a multi-source data fusion model based on a triaxial accelerometer, a vibration sensor, and a microphone. By comprehensively analyzing pet activity levels, movement postures (such as walking, running, lying down, agitation) and related sound signals (including barking, licking, etc.), it intelligently identifies abnormal behaviors such as excessive barking, frequent agitation, and abnormal licking. Simultaneously, it accurately counts daily activity levels and sleep duration to form an individualized behavioral profile. This algorithm provides reliable decision-making support for behavior management and health assessment, supports real-time alerts for abnormal behaviors, and effectively adapts to the behavioral monitoring needs of pets in various scenarios such as staying home alone or engaging in outdoor activities.

3.3. Multi-terminal Collaborative Communication Module

The multi-terminal collaborative communication module adopts the MQTT communication protocol and integrates both WiFi and short-range communication protocols to establish a bidirectional data transmission channel connecting the collar end, base station end, and application end. On one hand, this module is responsible for encrypting data such as positioning information, health data, behavioral records, and anomaly alerts collected by the collar end, uploading it in real-time to the base station and cloud, and synchronously pushing it to the user's application. On the other hand, it can receive and parse control commands from the application end (such as setting electronic fences, adjusting collection frequencies, or sending voice commands) and transmit them to the core control module to drive the hardware to perform corresponding operations. At the same time, the base station serves as a data relay hub, effectively optimizing communication links in complex environments and significantly enhancing overall transmission stability. This module breaks down the data barriers between the collar and user terminals, realizing a multi-terminal collaborative system of "local data collection, cloud synchronization, and remote management control," providing reliable support for core functional scenarios such as remote monitoring, command issuance, and instant alerting.

3.4. Functional Application Implementation Module

The Functional Application Implementation Module serves as the core interface for interaction between the software system and users. It aims to transform underlying technologies and data processing results into intuitive, actionable services[7]. Centered around four core functionalities—positioning and tracking, health monitoring, interactive companionship, and behavior management—it provides users with a comprehensive pet care solution through a mobile application (APP). This effectively addresses practical pain points such as pet loss, unknown health status, abnormal behavior, and lack of companionship, enabling all-weather, intelligent remote care and management of pets.

The Positioning and Tracking Application Module supports GPS and BeiDou dual-mode positioning. By integrating a map engine into the APP, it enables real-time visual display of the pet's precise location. Users can customize electronic fence areas. When a pet crosses the boundary, the system immediately sends an alert via the APP and triggers a buzzer warning on the collar. Simultaneously, the module automatically records and stores historical movement trajectories, supporting filtering and export by time period. This module effectively addresses the pain point of difficulty in locating lost pets and is particularly suitable for scenarios such as outdoor walks and continuous monitoring of pets prone to getting lost.

The Health Monitoring Application Module is dedicated to transforming calibrated, high-precision physiological data into intuitive and actionable health insights. Within the APP, it clearly displays daily and weekly trends in the pet's heart rate and body temperature through visual forms such as line charts and trend curves. When the system detects abnormal heart rate, excessive body temperature, or sleep disturbances, it automatically triggers highlighted reminders and pushes warning notifications to the user. Furthermore, based on long-term monitoring data, the module generates detailed sleep quality reports, analyzing the duration and proportion of deep and light sleep, thereby enabling a scientific assessment of the pet's sleep state. This function helps pet owners grasp their pet's health status in real-time and with precision, providing reliable data support especially for the daily health management and long-term monitoring of elderly or ill pets.

The Interactive Companionship Application Module aims to break through spatial and temporal limitations by leveraging two core functionalities—remote two-way voice interaction and laser play control—to enrich the emotional bond between pets and their owners. Users can send voice messages via the APP, which are transmitted through the communication module to be played on the collar's speaker. Meanwhile, the collar's microphone can capture sounds from the pet's surroundings and transmit them back to the APP, enabling real-time two-way communication. Additionally, users can remotely issue commands via the APP to control the collar to trigger laser play actions, simulating interactive games. This module effectively alleviates pets' loneliness when their owners are away or when they are left alone, making it particularly suitable for scenarios such as business trips or extended absences, ensuring care and companionship are always within reach.

The Behavior Management Application Module enables intelligent management of pet behavior through three core functions: abnormal behavior alerts, behavior data statistics, and mode switching control. When the system algorithm identifies abnormal behaviors such as excessive barking or frequent agitation, the APP immediately pushes detailed alert information, specifying the behavior type and occurrence time. Concurrently, the module automatically tracks key metrics like daily activity levels and barking frequency, generating visual behavior reports[8]. Moreover, it supports linkage between the collar and smart pet crates. Users can remotely switch modes and issue commands via the APP, triggering collaborative operations such as automatic feeding or environmental adjustment in the pet crate. This module effectively helps owners promptly detect signs of pet discomfort or anxiety, achieving all-weather, refined control over pet behavior. It is fully adaptable to pet monitoring needs across various scenarios, including home and outdoor environments.

4. Conclusion

The intelligent pet wearable device based on STM32 designed in this paper is primarily suitable for pet care scenarios that require outdoor activity monitoring, health risk warnings, and remote interactive companionship, such as daily pet walking, home care for elderly or sick pets, and pets staying alone while their owners are away. In practical applications, the device collects real-time data on the pet's location, heart rate, body temperature, and behavior through multi-sensor fusion. After processing and analysis by embedded algorithms, it achieves precise positioning and tracking, alerts for abnormal physiological indicators, behavior state recognition, remote voice interaction, and other functions[9]. Through the mobile app, it provides intuitive data visualization and alarm notifications. This design offers pet owners an all-weather, intelligent, and integrated health management solution, effectively addressing common pain points such as the risk of pets getting lost, difficulty in monitoring health status, and separation anxiety[10]. It enhances the refinement and proactive prevention capabilities of pet care and demonstrates considerable practical value and application prospects in promoting pet health and well-being as well as improving human-pet interaction experiences.

References

[1] Zhao L ,Cui M ,Fu F Z .Focus on pet diseases[J].Animal Diseases,2024,4(1):25.

[2] Qu Y ,Wang H ,Liu H , et al. Smart Wearable Devices for Exhaled Breath Condensate Harvesting and Health Monitoring.[J].FASEB journal : official publication of the Federation of American Societies for Experimental Biology,2025,39(20):e71102.

[3] Zhao P ,Gao D ,Zhou Y , et al. Multifunctional integrated flexible triboelectric nanogenerator based on collagen fibers for smart wearable devices[J].Chemical Engineering Journal, 2025, 522167693-167693.

[4] Trotz-Williams L ,Gradoni L .Disease risks for the travelling pet: Leishmaniasis[J].In Practice, 2003, 25(4):190-197.

[5] Levina A , Varyukhin V, Kaplun D, et al. A Case Study Exploring Side-Channel Attacks On Pet Wearables[J].IAENG International Journal of Computer Science,2021,48.0(4.0).

[6] Linden D V D ,Edwards M ,Hadar I , et al. Pets without PETs: on pet owners' under-estimation of privacy concerns in pet wearables[J].Proceedings on Privacy Enhancing Technologies, 2020, 2020(1):143-164.

[7] Qinhu Z ,Zonglin D ,Jiajun T , et al.Analysis of the Effectiveness and User Acceptance of Smart Wearable Devices in the Management of Chronic Diseases in the Elderly[J].International Journal of General Practice Nursing,2025,3(1):1-9.

[8] Goda S A M A ,Mohammady Y E ,Aboseif M A , et al. Comparative socioeconomic, environmental and technical analysis of conventional versus smart sustainable integrated multi-trophic aquaponics systems[J].Scientific Reports,2025,15(1):39414.

[9] Bijoy H M ,Fuad M ,Kawsar N H , et al. Embedded machine learning framework for respiratory disease detection[J].Biomedical Signal Processing and Control,2026,113(PC):109132.

[10] Aqueveque P ,Davidson P P ,Ramos E , et al. Real-Time Detection of Industrial Respirator Fit Using Embedded Breath Sensors and Machine Learning Algorithms[J].Biosensors,2025,15(11).