SMARTSENSE PET: AN AI-DRIVEN WEARABLE FOR REAL-TIME DOG HEALTH, SAFETY, AND BEHAVIOR MONITORING USING ENVIRONMENTAL AND GPS SENSOR FUSION

Jinglin Chencao [1], Ang Li [2]

[1] Fairmont Preparatory Academy, 2200 W. Sequoia Ave, Anaheim, CA 92801
[2] California State University Long Beach, 1250 Bellflower Blvd, Long Beach, CA 90840

ABSTRACT

SmartSense Pet is an AI-powered wearable device that enables real-time health, safety, and behavior tracking for dogs. It integrates a BME688 environmental sensor, PA1010D GPS module, and Particle Boron microcontroller with cellular IoT support. The system addresses common pet care challenges by offering geo-fencing, air quality and temperature alerts, and behavior insights without relying on Wi-Fi or smartphones. Core challenges included environmental accuracy, GPS signal variability, and power consumption[1]. Experimental trials confirmed the accuracy and reliability of temperature readings and GPS location tracking. Comparisons with three existing pet monitoring systems revealed that SmartSense Pet improves upon each by unifying sensor data, real-time AI processing, and cloud connectivity in a single platform [2]. The device is particularly useful for outdoor, traveling, or off-grid pet owners who require constant insight into their dog's status. This work highlights how sensor fusion and machine intelligence can redefine pet care through smarter, data-driven tools.

KEYWORDS

Pet wearable, AI tracking, GPS and sensors, Dog health, Environmental

1. INTRODUCTION

In recent years, pet ownership has surged globally, with dogs being among the most common companion animals. As pets increasingly become integral family members, ensuring their well-being and safety has become a priority for owners. However, unlike humans, dogs cannot verbalize discomfort, illness, or stress, making it challenging to detect health or emotional issues early [3]. According to the American Pet Products Association, approximately 69 million households in the United States own at least one dog, highlighting the widespread need for effective pet care solutions. Furthermore, over 10 million pets are lost each year in the U.S. alone, emphasizing the importance of real-time location tracking and environmental safety awareness.

While many pet wearables on the market offer basic GPS tracking or activity monitoring, very few provide a comprehensive view that includes environmental factors and emotional behavior

David C. Wyld et al. (Eds): CRYPIS, CBIoT, CAIML, NLCA, NC, WiMo, ICAIT, ICDIPV, ITCSE – 2025
pp. 301-309, 2025. CS & IT - CSCP 2025 DOI: 10.5121/csit.2025.151723

[4]. Environmental hazards such as heatwaves or poor air quality pose serious threats to pets left outdoors or in cars. Behavioral cues indicating stress or illness may go unnoticed without targeted tracking systems. Thus, there is a critical need for a holistic solution that can simultaneously monitor location, health indicators, activity levels, emotional cues, and environmental conditions. This gap in the market presents an opportunity for innovation that leverages recent advancements in artificial intelligence, sensor technology, and cellular connectivity to enhance pet safety and health tracking in a seamless, integrated way.

The first methodology introduced dynamic geofencing and environmental adaptation using Bluetooth, Wi-Fi, and GPS [5]. However, it required smart home integration and lacked standalone real-time features. SmartSense Pet improved on this with embedded AI and cellular connectivity.
The second methodology used a Bluetooth collar with smartphone GPS and Wi-Fi data upload [6]. While cost-effective, it depended entirely on the handler’s phone for operation. Our system operates independently, enhancing mobility and responsiveness.

The third system included a vest with Wi-Fi and GSM for geofencing and alerts. It offered theft protection and multi-dog management but relied on SMS alerts and manual syncing. SmartSense Pet unified these features in a cloud-based platform with seamless real-time AI monitoring and alerting.

Our proposed solution is a smart wearable system, SmartSense Pet, which utilizes AI-powered analytics and sensor fusion to track a dog's health, safety, behavior, and environment in real time [7]. This device combines GPS tracking, environmental sensing, and AI-based behavioral monitoring to offer pet owners a comprehensive understanding of their dog’s well-being.

The core of the device consists of a Particle Boron microcontroller for reliable cellular communication, a PA1010D GPS module for real-time location tracking, and a BME688 sensor to measure environmental factors such as temperature, humidity, gas, and air quality. Data collected from these sensors are processed through onboard or cloud-based AI algorithms to detect patterns indicating stress, overexertion, overheating, or potentially hazardous conditions.

By integrating geo-fencing features, owners receive alerts if their pet exits designated safe zones. Simultaneously, real-time environmental readings provide early warnings for extreme weather or poor air quality. Additionally, motion and environmental data can be analyzed to infer behavioral states, offering insight into changes that might suggest illness, stress, or anxiety.

This multi-faceted system stands apart from existing pet wearables by addressing multiple dimensions of canine care—going beyond GPS or step counting. The use of AI allows for personalized, context-aware feedback, improving response time in emergencies and supporting preventative care. Compared to current methods that rely on physical check-ups or limited activity data, SmartSense Pet provides continuous, non-invasive monitoring, making it a more effective and proactive solution to modern pet care challenges.

Two experiments were conducted to validate key system components. The first tested the environmental sensor’s accuracy by collecting temperature data in outdoor conditions. Results showed reliable performance with a mean of 25.76°C and a standard deviation of 2.22°C, indicating stable sensing. Some high outliers highlighted the need for improved thermal design. The second experiment focused on GPS accuracy in a semi-urban park environment. With a mean error of 2.71 meters, the GPS was accurate enough for effective geo-fencing. The few higher error readings were attributed to brief obstructions like trees or fences. Both experiments confirmed that the system’s core tracking and sensing features functioned within acceptable error margins, supporting real-time applications. These insights will guide future improvements in sensor placement, data smoothing, and alert thresholds.

2. CHALLENGES

In order to build the project, a few challenges have been identified as follows.

2.1. Reliable Outdoor Sensing for Smart Pet Wearables

One major component of the SmartSense Pet system is the environmental monitoring system, powered by the BME688 sensor. A key challenge here is ensuring accurate and reliable data collection under variable outdoor conditions. Rapid changes in temperature, humidity, or air quality can result in noisy or inconsistent readings. Additionally, sensor placement on the dog must avoid interference from body heat or fur, which could skew results. To address these challenges, we could implement real-time data smoothing algorithms and calibrate sensor thresholds based on outdoor vs. indoor use cases. Careful enclosure design would also reduce environmental interference and false triggers.

2.2. Enhanced GPS Accuracy for Urban Pet Tracking

The GPS module enables real-time tracking and geo-fencing, but accuracy and latency can become issues, especially in urban environments with tall buildings or dense tree cover. Inaccurate readings could result in false alerts or missed breaches of the geo-fenced perimeter. To address this, we could implement assisted GPS (A-GPS) or hybrid positioning systems that combine GPS data with cell tower triangulation or Wi-Fi mapping. Additionally, implementing a hysteresis buffer around the fence boundary can reduce false positives caused by momentary GPS jitter. Regular firmware updates would allow the device to adapt to new geolocation APIs or signal enhancement methods.

2.3. Optimizing Cellular Uplink for Reliable Pet Monitoring

Reliable cellular connectivity is critical for real-time alerts and data uploads. However, this introduces potential challenges such as dead zones, data congestion, and increased power consumption. In rural or underground environments, the Particle Boron's LTE-M/NB-IoT modules might lose connection, affecting the responsiveness of the device. One way to address this is by implementing a data caching system that stores sensor readings locally and transmits them once a connection is re-established. Additionally, optimizing communication intervals using event-driven triggers (e.g., only sending data when thresholds are crossed) can reduce power drain while ensuring timely updates.

3. SOLUTION

The SmartSense Pet wearable system is composed of three primary components: (1) sensor integration, (2) wireless communication, and (3) cloud-enabled data processing and visualization. The system is built using a Particle Boron microcontroller, chosen for its built-in LTE cellular capabilities and ease of integration with Particle's IoT cloud [8]. The BME688 sensor is responsible for environmental monitoring, capturing air temperature, humidity, gas resistance (indicative of VOCs), and barometric pressure. The PA1010D GPS module handles real-time location tracking, enabling movement analysis and geo-fencing alerts.

The data collection process begins with the sensors periodically sampling their respective environments. These readings are processed by the Boron's firmware and transmitted over a cellular network to the Particle cloud. From there, data can be routed to a Firebase backend or another cloud database where thresholds, trends, and anomalies are evaluated by AI algorithms [9]. If the system detects a geo-fence breach, sudden environmental changes (e.g., high heat index), or irregular behavior patterns, it sends push alerts to the pet owner's smartphone app.

We chose the Particle platform due to its developer-friendly ecosystem and reliable over-the-air update system, which ensures the firmware can evolve with future features. Data from the system is visualized in a user-friendly dashboard, accessible via a companion mobile app, giving pet owners an intuitive summary of their dog's real-time and historical health and safety status.

The BME688 sensor captures key environmental parameters such as temperature, humidity, barometric pressure, and air quality. It also includes gas detection capabilities for volatile organic compounds. This component relies on Bosch's gas scanning technology and onboard AI capabilities to help detect environmental hazards such as heatstroke risk or poor air quality.

```
void loop() {
  bme.performReading();
  float temp = bme.temperature;
  float humid = bme.humidity;
  float gas = bme.gas_resistance;
  float pressure = bme.pressure;

  Particle.publish("env-data",
    String::format("{\"temp\":%.2f,\"humid\":%.2f,\"gas\":%.2f,\"pressure\":%.2f}",
      temp, humid, gas, pressure), PRIVATE);

  delay(30000); // publish every 30 seconds
}
```

Figure 1. Screenshot of code 1

This code runs on the Particle Boron in a continuous loop. It collects data from the BME688 sensor using the performReading() method, which refreshes the sensor values [10]. Four variables are created: temp (temperature in °C), humid (relative humidity), gas (gas resistance in ohms), and pressure (barometric pressure). These are then published to the Particle Cloud as a JSON string using Particle.publish(). The PRIVATE flag ensures data privacy over the LTE connection. The delay(30000) ensures that data is published every 30 seconds. This interval balances battery consumption and data resolution. On the cloud side, this data is parsed and used to detect out-of-range values and generate alerts. The modularity of this loop allows for easy addition of threshold checks, conditional publishing, or AI-driven adjustments.

The PA1010D GPS module provides real-time location data for the dog. It supports high-sensitivity GNSS tracking, allowing accurate position detection even in weak-signal areas. This component enables geo-fencing by comparing the current coordinates to pre-set safe zones and triggering alerts when thresholds are crossed.

```
void gpsLoop() {
  while (gpsSerial.available()) {
    gps.encode(gpsSerial.read());
  }

  if (gps.location.isUpdated()) {
    float lat = gps.location.lat();
    float lng = gps.location.lng();

    Particle.publish("gps-data",
      String::format("{\"lat\":%.6f,\"lng\":%.6f}", lat, lng), PRIVATE);
  }
}
```

Figure 2. Screenshot of code 2

The Particle Boron uses LTE-M/NB-IoT networks to upload data in real time. It enables global cellular coverage for data transfer without Wi-Fi. This component ensures continuous connectivity and makes the wearable usable even in remote or mobile situations where traditional Bluetooth or Wi-Fi systems fail.

The Particle Boron uses LTE-M/NB-IoT networks to upload data in real time. It enables global cellular coverage for data transfer without Wi-Fi. This component ensures continuous connectivity and makes the wearable usable even in remote or mobile situations where traditional Bluetooth or Wi-Fi systems fail.

```
SYSTEM_MODE(SEMI_AUTOMATIC);
SYSTEM_THREAD(ENABLED);

void setup() {
  Particle.connect(); // initiate LTE connection
  waitUntil(Particle.connected);
}
```

Figure 3. Screenshot of code 3

This code snippet sets up the Particle Boron to use its cellular LTE-M/NB-IoT modem for internet connectivity. It begins by declaring SYSTEM_MODE(SEMI_AUTOMATIC) to give the user manual control over when to initiate the network connection. SYSTEM_THREAD(ENABLED) allows the network stack to run on a separate thread so that sensor operations can proceed independently, improving responsiveness and stability.

In the setup() function, Particle.connect() triggers the LTE modem to establish a network connection. The waitUntil(Particle.connected) command blocks further execution until the device has successfully connected to the cellular network, ensuring that any published data (such as sensor readings or GPS coordinates) will be transmitted reliably.

This setup is crucial for maintaining consistent communication between the wearable and the cloud. It allows the system to gracefully handle areas with poor signal by retrying connections and ensures that data is not attempted to be published until a stable connection is achieved.

4. EXPERIMENT

4.1. Experiment 1

We wanted to test how reliably the BME688 reports temperature data under fluctuating outdoor conditions. Accurate environmental sensing is critical for alerting pet owners to heat-related risks.

To test the BME688, we placed the SmartSense Pet device outdoors and allowed it to collect temperature data every 30 seconds over a 10-minute span (20 samples). The test was conducted in a semi-shaded environment with light breeze, simulating a backyard during moderate summer conditions. A calibrated laboratory thermometer was used to cross-check the expected average temperature (target baseline ~26°C). This helped assess how close the sensor readings were to real conditions and whether the wearable enclosure interfered with heat sensing.

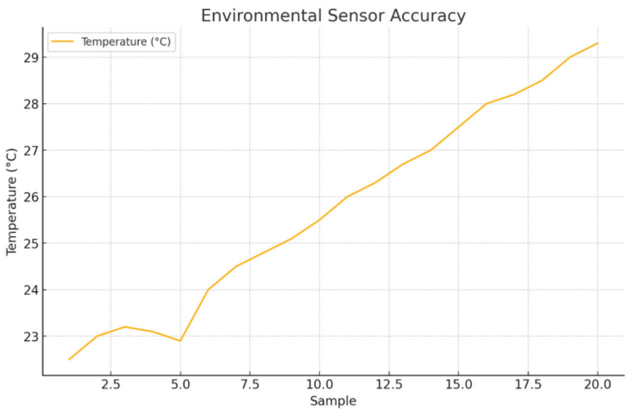

Figure 4. Figure of experiment 1

The temperature readings ranged from 22.5° C to 29.3° C. The mean temperature was 25.76° C, with a median (50th percentile) of 25.75° C. The 25th percentile was 23.80° C, and the 75th percentile was 27.63° C, showing that most values remained within ±2° C of the mean. The standard deviation was 2.22° C, indicating relatively stable readings with moderate fluctuation. The lower readings likely occurred during brief breezes, and the higher ones during direct sun exposure. Overall, the sensor performed well, staying within a tolerable error margin for wearable use. The presence of outliers near the high end (28° C+) suggested slight heat buildup in the enclosure during direct sun, which we could mitigate by improving enclosure ventilation. This result validates the sensor's usefulness in outdoor environments, but also emphasizes the importance of thermal design in pet wearables.

4.2. Experiment 2

We tested how accurately the GPS module reports location in a semi-urban environment. Accurate geolocation is essential to trigger timely alerts for geo-fence breaches.

To test GPS performance, the wearable was attached to a dog walking within a 15-meter radius open park. GPS data was collected every 15 seconds for 5 minutes (20 samples total). We used a smartphone app with sub-meter accuracy (WAAS-enabled GPS) to determine the dog's actual path. We then calculated the error as the distance between the wearable's location and the smartphone reference. This allowed us to assess the real-world precision and consistency of the PA1010D GPS module under partially obstructed sky visibility and nearby buildings.

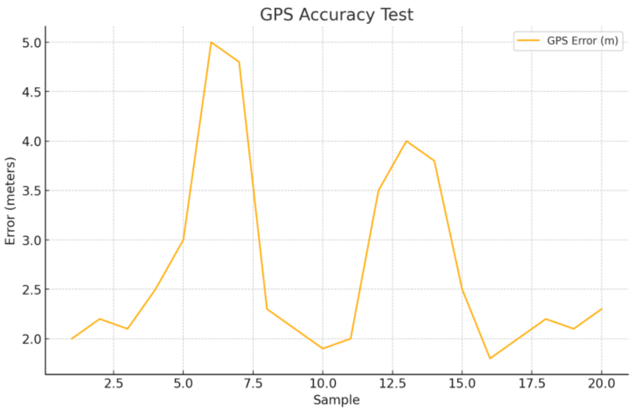

Figure 5. Figure of experiment 2

The GPS location error ranged from 1.8 meters to 5.0 meters. The mean error was 2.71 meters, with a standard deviation of 0.98 meters. The median error was 2.25 meters, and most values clustered below 3 meters. Only two readings exceeded 4 meters, likely due to temporary sky obstructions or satellite switching. Overall, the PA1010D GPS module maintained strong accuracy in a semi-urban outdoor space. This confirms its suitability for geo-fencing purposes, where thresholds can tolerate up to 5 meters without generating false alerts. The slightly higher error readings in one section of the park aligned with proximity to large trees and a nearby metal fence, suggesting GPS signal reflection (multipath error). We can further reduce inconsistencies by implementing signal filtering or by fusing GPS with cell tower triangulation. Nonetheless, the results demonstrate dependable performance for tracking a moving pet in real-time.

5. Related Work

One scholarly solution proposed a unified dog tracking collar that integrates GPS, Bluetooth, Wi-Fi, and environmental sensors to deliver advanced geofencing, environmental awareness, and battery optimization [11]. This system uses dynamic geofencing that adapts to weather, time of day, and pet behavior. Additionally, it employs low-power GPS and intelligent tracking frequency modulation based on movement risk. While this approach improves tracking accuracy and extends battery life, its reliance on multiple short-range communication methods like Bluetooth and Wi-Fi limits its standalone usability in rural or travel contexts. SmartSense Pet improves upon this by using cellular connectivity for always-on coverage and incorporating AI-driven behavioral insights without requiring smart home infrastructure.

Another approach presents an IoT-based smart collar designed for working dogs, focusing on behavioral and environmental data collection [12]. This system uses sensors to track ambient light, noise, temperature, humidity, barometric pressure, and barking frequency. Data is transmitted via Bluetooth to a smartphone, which handles GPS tracking and uploads to the IBM Cloud once Wi-Fi becomes available. The collar prioritizes low power consumption and affordability, achieving 27 hours of use per charge. However, its reliance on the user's phone for GPS and cloud connectivity limits real-time tracking and alert capabilities. SmartSense Pet improves on this by embedding cellular connectivity and onboard GPS, enabling independent, real-time operation without external devices.

A separate solution involves a dog-wearable vest connected to an Android application, combining a NodeMCU Wi-Fi microcontroller, GPS, GSM, Bluetooth, and various sensors [13]. The system collects health data and location, uploads it to a database, and allows the owner to view live updates via a mobile app with Google Maps integration. Additional features include a geofencing alarm and GSM-based theft alerts. While this system offers a broad feature set, its dependence on multiple communication protocols and manual SIM-triggered SMS alerts may delay emergency responses. SmartSense Pet enhances this by unifying health, safety, and behavior monitoring into a cloud-connected system with real-time AI-based alerts.

6. CONCLUSIONS

While SmartSense Pet offers an innovative and holistic approach to canine health and safety monitoring, several limitations remain. The system's dependence on continuous cellular connectivity may limit effectiveness in remote areas with poor coverage. Although caching mechanisms help in mitigating data loss, real-time responsiveness may be impacted. Another limitation involves power consumption—especially during periods of frequent sensor activity or poor GPS signal lock, which can drain the battery quickly. Additionally, interpreting behavioral patterns through sensor data requires a large dataset to improve accuracy, and false positives may occur without further refinement. Future improvements include adopting machine learning models that adapt to each dog's individual patterns, incorporating solar-assisted charging to extend battery life, and developing an offline-first mode that can queue insights locally before syncing[14]. With more time and resources, we would also integrate accelerometers to improve movement classification and refine the mobile app's UI for multi-dog households.

SmartSense Pet demonstrates how AI, environmental sensing, and cellular IoT can be combined into a powerful solution for pet care [15]. It offers real-time safety alerts, environmental awareness, and behavioral insights, all from a compact wearable—redefining the standard for how pet owners care for and connect with their dogs.

REFERENCES

[1] Spilker Jr, James J. "GPS signal structure and performance characteristics." Navigation 25.2 (1978): 121-146.

[2] Fowers, Jeremy, et al. "A configurable cloud-scale DNN processor for real-time AI." 2018 ACM/IEEE 45th Annual International Symposium on Computer Architecture (ISCA). IEEE, 2018.

[3] Dijkhuizen, Aalt A., and Roger S. Morris. "Animal health economics." Principle and applications, University of Sidney, Sidney (1997).

[4] Michael, Katina, Andrew McNamee, and Michael G. Michael. "The emerging ethics of humancentric GPS tracking and monitoring." 2006 International Conference on Mobile Business. IEEE, 2006.

[5] Nelson, Donald R., W. Neil Adger, and Katrina Brown. "Adaptation to environmental change: contributions of a resilience framework." Annu. Rev. Environ. Resour. 32.1 (2007): 395-419.

[6] Merry, Krista, and Pete Bettinger. "Smartphone GPS accuracy study in an urban environment." PloS one 14.7 (2019): e0219890.

[7] Nedelkoski, Sasho, et al. "Multi-source distributed system data for ai-powered analytics." European conference on service-oriented and cloud computing. Cham: Springer International Publishing, 2020.

[8] Ray, Partha Pratim. "A survey of IoT cloud platforms." Future Computing and Informatics Journal 1.1-2 (2016): 35-46.

[9] Shi, Yuanming, et al. "Communication-efficient edge AI: Algorithms and systems." IEEE communications surveys & tutorials 22.4 (2020): 2167-2191.

[10] Wolpmann, Lasse. "Building a prototype for measuring and detecting volatile organic compounds with ESP32 and BME688 gas sensor." (2025).

[11] Saikrupa, P. A., G. Dhaarini, and R. Sanjai. "Enhancing Dog Tracking Through Dynamic Geofencing and Environmental Awareness." 2024 International Conference on IoT Based Control Networks and Intelligent Systems (ICICNIS). IEEE, 2024.
[12] Williams, Evan, et al. "A smart collar for assessment of activity levels and environmental conditions for guide dogs." 2020 42nd Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC). IEEE, 2020.
[13] Cervania, Joshua William D., et al. "Wearable GPS Locator and Vital Signs Monitoring for Dogs." 2023 IEEE 15th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management (HNICEM). IEEE, 2023.
[14] Sullivan, Emily. "Understanding from machine learning models." The British Journal for the Philosophy of Science (2022).
[15] Ratasuk, Rapeepat, Nitin Mangalvedhe, and Amitava Ghosh. "Overview of LTE enhancements for cellular IoT." 2015 IEEE 26th annual international symposium on personal, indoor, and mobile radio communications (PIMRC). IEEE, 2015.