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IoT Based Location Alert and Controlling System for Animal Belts via Mobile Devices

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Abstract: Traditional pet control methods like leashes are often cumbersome and ineffective in ensuring pets remain within designated areas, presenting a challenge for pet owners. The primary goal of this research is to empower pet owners with control over their pets' movements and whereabouts. This paper presents Animal Belt with a system that employs geofencing technology to monitor pets' locations relative to predefined boundaries. Upon breaching the geofence, the belt initiates vibration, triggers prerecorded voice commands, and notifies the owner via a mobile application with a Google Maps link pinpointing the pet's location. Testing revealed the system's reliability with a geofence radius of 300 meters, consistently activating when pets exceeded the boundary. Empirical data confirmed the system's effectiveness, with it remaining inactive within the boundary and activating when breached. Notable results included accurate geofence enforcement and effective vibration feedback prompting pets' return. The system demonstrated a significant enhancement in pet safety and control, replacing traditional leashes with customizable settings tailored to pets' specific needs. The pet belt system effectively ensures pets remain within designated boundaries, utilizing vibration feedback and prerecorded voice commands. This system provides convenience and peace of mind for pet owners, reducing the need for constant monitoring and enhancing pet safety during outings. Future improvements may include solar-powered components and real-time health monitoring for optimized performance and sustainability.

Keywords: Geofence, vibration, GPS, Blynk App, IoT

1. Introduction

Over the past 15 years, heightened environmental degradation has emphasized the critical need for enhanced wildlife monitoring and protection. Animal tracking systems play a crucial role in studying behavior, migration patterns, and ecosystem dynamics, as each species uniquely contributes to its environment, underscoring the importance of safeguarding biodiversity. However, escalating challenges such as accidents, injuries, and disease outbreaks significantly threaten animal populations, particularly in vast and remote wilderness areas where pinpointing injured animals is challenging [1]. Additionally, animals face risks like theft, especially at night when vigilance is reduced, necessitating advanced monitoring solutions [2]. Current animal tracking systems incorporate technologies such as GPS, GPRS, RFID, and sensors. Studies by Khor TM reveal low awareness and high costs as significant barriers to adoption in Malaysia. Technologies like microchips and tattoos, while beneficial for pet recovery, lack real-time tracking capabilities. GPS, widely integrated into smartphones, uses geofencing to create virtual boundaries for pet monitoring [3]. Research by S.-H. Kim et al. explored the use of GPS and RFID in zoological gardens, proposing an intelligent monitoring service with sensor nodes and web interfaces but noted limitations due to reliance on outdated technology platforms, potentially hindering scalability and compatibility with modern systems. Nonetheless, the prototype offers benefits such as remote access via web-based open APIs [4]. Similarly, M. Gor et al. developed the GATA system, integrating Wireless Sensor Networks (WSN) and GPS for wildlife monitoring with an emphasis on real-time tracking. While GATA provides straightforward real-time animal monitoring compared to traditional methods like radio tracking and picture identification, it faces challenges related to labor and high monitoring costs due to insufficient research on power-

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efficient microcontroller-based monitoring modules [5]. V. R. Jain et al. investigated wildlife monitoring using an automated WSN system, improving energy efficiency and positional accuracy with enhanced collar designs. Despite their promise, these studies encounter obstacles such as high costs, significant energy consumption, and dependence on outdated technology platforms [6]. Despite advancements, there is a scarcity of research and services employing GPS, RFID, and sensors in zoological settings. Existing systems are hindered by high costs, energy consumption, and the need for more efficient power management, highlighting a gap in developing cost-effective, energy-efficient, and scalable animal tracking solutions compatible with contemporary technology platforms. The objective of this study is to develop a comprehensive and cost-effective real-time animal tracking and monitoring system leveraging geofencing and mobile device integration to enhance animal safety and security, addressing the limitations of current methods.

This study addresses critical gaps in existing animal tracking systems by integrating modern technologies for real-time monitoring, improving energy efficiency, and reducing costs. The proposed system aims to provide a scalable solution compatible with contemporary technology platforms. The contributions of this study include the development of a cost-effective, real-time animal tracking and monitoring system leveraging geofencing and mobile devices; enhanced energy efficiency and positional accuracy through improved design and technology integration; provision of real-time information to users via web interfaces, ensuring remote access and monitoring; and improved safety and security for animals, addressing risks such as theft and injury through advanced tracking and monitoring techniques.

2. METHODOLOGY

This section provides a comprehensive explanation of the system diagram, detailing the components utilized and their operational flow. It is divided into two subsections, as illustrated in Fig. 1, which highlights the features of the belt.

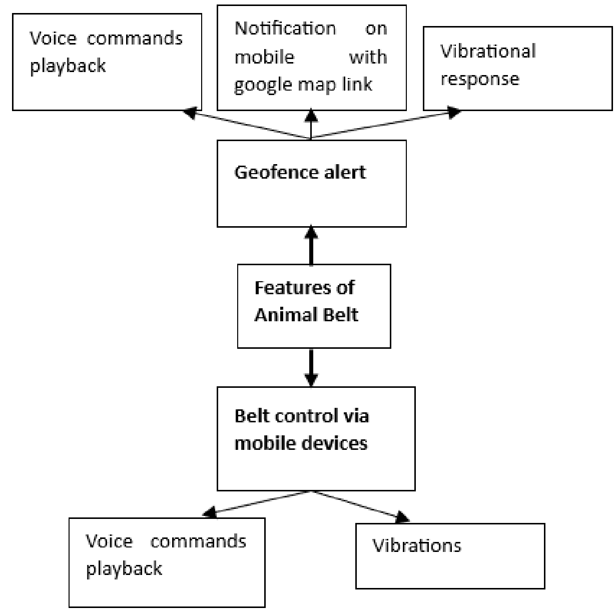


Figure 1 Features of Animal belt

A. System overview

This section includes overview of 2 systems. One system is for a geofence alert system, integrating a pancake vibration sensor, Neo 6M GPS, APR33A3, and SIM800L GSM modules with an Arduino Uno. This system provides automated auditory commands and vibration feedback through a belt mechanism when a pet breaches a predefined geofenced area [7].

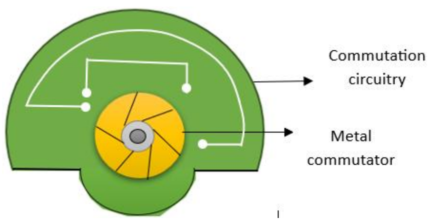
And another system shows the integration of the APR33A3 module and pancake vibration module with a Node-MCU, utilizing IoT technology to induce belt vibrations and deliver audible commands to a pet. The system is controlled via the Blynk app on mobile devices [8].

B. Hardware

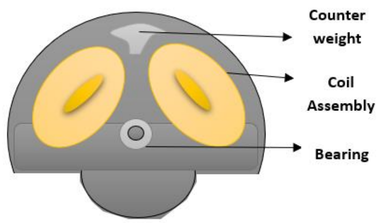
The section presents the description of the following components used in system.

1) Pancake vibration module

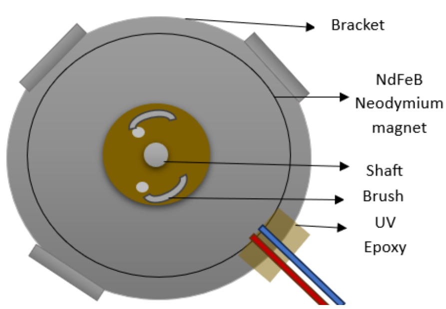
A coin vibration motor, commonly used in smartwatches and fitness trackers, employs Eccentric Rotating Mass (ERM) technology. This involves a flat PCB with a 3-pole commutation circuit around an internal shaft as shown in Fig. 2(a). The motor rotor, consisting of two voice coils and a lightweight mass on a plastic disc, is attached to the shaft via a central bearing as shown in Fig. 2(b). Electrical power is supplied through brushes contacting the PCB commutation pads. Upon activation, the voice coils generate a magnetic field, interacting with a disc magnet in the motor chassis as shown in Fig. 2(c). The commutation circuit reverses the magnetic field in the voice coils, engaging with the neodymium magnet's poles, causing the off-centered mass to rotate and induce vibration. The commutator, with six segments linked to two coils, allows for six distinct magnetic orientations, configuring the motor as a six-pole machine. Brush resistance varies throughout the rotation cycle [9, 10].



(a) Functional layer (backside)



(b) Functional layer (frontside)



(c) Base-layer

Figure 2 Pancake vibration module (internal structure)

2) *Neo 6M GPS module*

The NEO-6M GPS module is a highly efficient GPS receiver with an integrated 25 x 25 x 4mm ceramic antenna for robust satellite acquisition. It synchronizes with signals from a constellation of 24 satellites to determine precise location coordinates (latitude, longitude, and altitude) using trilateration. Analyzing the travel time of microwave signals from at least three satellites, the module calculates its position [11, 12].

The NEO-6M features an LED indicator for 'Position Fix' status:

- No blinking: Searching for satellites.
- Blinking every 1 second: Position Fix is found (sufficient satellites detected).

3) *Sim800l GSM module*

The SIM800L is a compact cellular module operating on the 900 MHz and 1800 MHz bands, supporting GPRS, SMS, voice calls, internet connectivity, and FM reception. It communicates with microcontrollers via UART and responds to AT commands for tasks like signal strength checks, SIM card details, network status, battery monitoring, text handling, and call management. Operating at 3.4V to 4.4V, it's suitable for direct LiPo battery use and requires an external antenna soldered to its PCB [13, 14]. The module features an LED indicator:

- Blink every 1 second: Module running, awaiting network connection.
- Blink every 2 seconds: Active GPRS data connection established.
- Blink every 3 seconds: Connected to a cellular network for voice calls and SMS.

4) *Power supply*

Li-Po batteries have a voltage range of 3.7V to 4.2V – perfect for a SIM800L module. Any Li-Po battery with a capacity of 1200 mAh or higher should work, as these batteries can withstand current spikes up to 2 A while maintaining usable voltage [15].

The 9V battery is a rectangular dry cell classified by its 48.5mm x 26.5mm x 17.5mm dimensions and one-sided clasp terminals. They hold mid-range capacities upwards of 1,200mAh [16].

5) *Arduino uno*

Arduino Uno is a microcontroller board based on the Atmga328P. It was 14 digital input/output pins (of which 6 can be used as PWM output), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button [17, 18].

6) *APR33A3 voice module*

APR33A3 Voice Recorder and Playback Module is designed for easy recording and playback of audio files. It features a built-in microphone, supports various audio formats, and includes a 3.5mm headphone jack for direct audio output. Key functionalities are enabled by the APR33A series IC, integrating advanced audio processing, ADC, and DAC capabilities [19,20]. The module operates in modes for recording, playback, resetting, messaging, PWM (Pulse Width Modulation), erasing, and voice input. In 7-message mode, recording starts when the /REC pin is low (VIL) and a tact switch (M0 to M6) is pressed. Playback begins in the VIH state, triggered by pressing a tact switch. PWM mode drives a speaker via VOUT1 and VOUT2, and standby mode reduces power until initialization via the RSTB pin. Erasing data is initiated by setting the M7 pin low, confirmed by LED. Modifications are made by holding M7 low and pressing the M pin, indicated by LED. The APR33A3 module provides reliable voice recording, playback, PWM output, and erasing capabilities for various applications.

7) Node MCU

Node MCU is an open-source IoT (Internet of Things) platform based on the ESP8266 Wi-Fi module. It is used to control various electronic devices and make them communicate with each other over a network [21,22].

C. Software

1) Blynk app

Blynk app is an IoT platform for iOS and Android smartphones, enabling remote control and monitoring of Arduino, Raspberry Pi, and Node MCU devices over the internet. It allows users to create GUIs using widgets like buttons and sliders [23,24].
Key components:

- Blynk App: Mobile app for designing and configuring interfaces.
- Blynk Server: Manages communication between smartphones and devices, can be cloud-based or local.
- Blynk Libraries: Facilitate integration with hardware, ensuring smooth data exchange and command synchronization.

Blynk supports IoT applications in the monitoring, control, and prototyping stages of projects.

2) ThingSpeak IoT platform

ThingSpeak is an IoT analytics platform that enables data collection, storage, analysis, and visualization from IoT devices. It supports real-time data streaming and integrates with MATLAB for advanced data processing, making it ideal for monitoring, analytics, and actionable insights in various IoT applications.

3. WORKING

This section provides comprehensive details on the features, divided into two sub-features as shown in Figure 1. Each sub-feature is further divided into three parts: technology used, steps for setting up the devices, and operational flow.

A. Geofence alert

Geo-fencing technology uses GPS and/or Wi-Fi to create virtual perimeters, called "geofences," around specific geographic areas on digital maps. When a location-tracking device crosses these boundaries, predefined actions or notifications are triggered via the GSM module. In this implementation, GPS signals determine the location and boundaries, using a circular geofence defined by the latitude and longitude of the area's center. This method is straightforward, involving inputting the coordinates into the microcontroller [25].

The Haversine formula is given by:

$$d = 2r \arcsin\left(\sqrt{sin^2\left(\frac{\phi_2-\phi_1}{2}\right) + \cos(\phi_1)\cos(\phi_2)sin^2\left(\frac{\lambda_2-\lambda_1}{2}\right)}\right) \quad (1)$$

Equation 1 presents the calculation of the distance 'd' between two points on the Earth's surface using the haversine formula.

This formula, represented in (1), utilizes differences in latitude (Δφ) and longitude (Δλ) to compute haversine values, with 'R' denoting the Earth's radius (6371 km). The resulting distance 'd' is expressed in kilometers, matching the Earth's radius units [26].

Unlike the Euclidean distance formula applicable to flat surfaces, the haversine formula is ideal for spherical Earth calculations due to its accurate handling of spherical geometry. It is derived from the spherical law of cosines, optimized for precision in determining distances over large areas.

Below are the steps for configuring the animal belt device for a desired location:

1. Use Google Maps to locate and mark the desired area for the geofence (as shown in Fig. 3).
2. Select the specific region on the map to define the boundaries of the geofence (illustrated in Fig. 4).
3. Plot the point within the chosen area and obtain latitude and longitude coordinates from a popup message. Determine the radius (r) of the circular geofence, as demonstrated in Fig. 5 and 6, and input these details into the microcontroller.

Here, coordinates 48.06706010314518, 11.305574622256353 are extracted while testing.

The accompanying figures visually demonstrate the step-by-step procedure using Google Maps.

Figure 3 Location finding on Google map

Figure 4 Selecting region for Geofencing

Figure 5 Plotting a point on selected region

Figure 6 Setting the radius of Geofence circle

Fig. 7 illustrates the operational workflow of the entire system following the establishment of connections between modules and the development board.

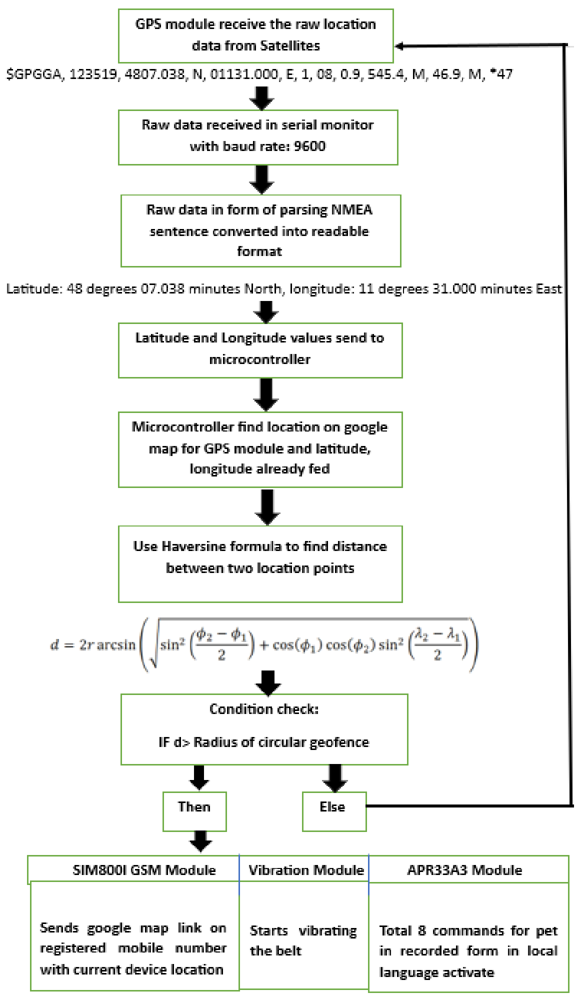


Figure 7 Workflow of Geofence alert system

Initially, the Neo6M GPS module receives raw GPS data and communicates serially using Software Serial. This data is transmitted in the NMEA standard language to the serial monitor. In microcontroller applications, parsing NMEA sentences is essential to extract relevant data segments and transform them into a user-friendly format [27].

An obtained NMEA sentence is: "$GPGGA, 123519, 4807.038, N, 01131.000, E, 1, 08, 0.9, 545.4, M, 46.9, M, *47." The structure of this NMEA sentence is analyzed and detailed in table I.

TABLE I. NMEA MESSAGE STRUCTURE

Field value	Description
$	Starting of NMEA sentence.
GPGGA	Global Positioning System Fix Data
123519	Current time in UTC – 12:35:19
4807.038, N	Latitude 48 degrees 07.038′ N
01131.000, E	Longitude 11 degrees 31.000′ E
1	GPS fix
08	Number of satellites being tracked
0.9	Horizontal dilution of position
545.4, M	Altitude in Meters (above mean sea level)
46.9, M	Height of geoid (mean sea level)
(empty field)	Time in seconds since last DGPS update
(empty field)	DGPS station ID number
*47	The checksum data always begins with *

From table I, the device's location is identified as latitude 48 degrees 07.038 minutes North and longitude 11 degrees 31.000 minutes East.

To find the distance using the haversine formula, need to compute the values for Δφ and Δλ:

Let,
Latitude1 as lat1: 48.070380
Latitude2 as lat2: 48.073023604601474
Longitude1 as long1: 11.310000
Longitude2 as long2: 11.31542538591539

For Δφ:
$\Delta\varphi = (lat2 * \pi/180) - (lat1 * \pi/180)$
$\Delta\varphi = (48.073023604601474 * \pi/180) - (48.070380 * \pi/180)$
$\Delta\varphi \approx 0.00005$ radians

For Δλ:
$\Delta\lambda = (long2 * \pi/180) - (long1 * \pi/180)$
$\Delta\lambda = (11.31542538591539 * \pi/180) - (11.310000 * \pi/180)$
$\Delta\lambda \approx 0.00009$ radians

Now, plug these values in (1):

$\sin^2(\Delta\varphi/2) \approx \sin^2(0.000025)$
≈ 0.000000000625
$\cos(\varphi 2) \approx \cos(0.83944)$
≈ 0.670
$\cos(\varphi 1) \approx \cos(0.83939)$
≈ 0.671
$\sin^2(\Delta\lambda/2) \approx \sin^2(0.000045)$
≈ 0.000000002025

$a = \sin^2(\Delta\varphi/2) + \cos(\varphi 1) * \cos(\varphi 2) * \sin^2(\Delta\lambda/2)$

$a \approx 000000000625 + (0.671 * 0.670 * 0.000000002025)$
≈ 0.000000001545

Now, compute the distance:
$distance = 2 * 6371 * \arcsin(\sqrt{a})$

≈ 6371 * 2 * arcsin(0.000038)
≈ 6371 * 0.000076
≈ 0.484196 km

So, the approximate distance between the two points is about 484 meters.

Upon evaluation of (1), which calculates the distance (d) between the device and the geofence center, two conditions emerge:

Condition 1: If $d < r$, indicating that the device is within the geofence region.
Condition 2: If $d > r$, indicating that the device is outside the geofence region.

When condition 2 is met:

- The system activates the Sim800l GSM module to send SMS messages and make calls, transmitting the device's location via a Google Maps link.
- The APR33A3 voice module plays recorded instructions to the pet in the owner's voice, typically in the local language.
- Vibrations generate in the belt continuously.

B. Vibration and voice commands controlled via mobile devices

The system utilizes a Node-MCU, Blynk application, and various hardware components to enable remote control of a pet belt. Commands issued via the Blynk mobile app are sent to the Blynk Cloud server and then transmitted to the Node-MCU for processing [28].

For device setup, the Node-MCU is configured to interface with vibration modules and the APR33A3 voice module, ensuring it can control these components based on received commands [29].

Operationally, commands from the Blynk app are relayed through the Blynk Cloud server to the Node-MCU [30]. The Node-MCU processes these commands, activating or deactivating the vibration modules and playing voice instructions via the APR33A3 module, facilitating remote pet training and communication [8].

4. Belt Prototype and Application

This section details the prototypes, practical applications of the pet belt, and specialty. Fig. 8 presents the prototype belt featuring three key components in separate enclosures: the central box houses the geofencing system, optimized for GPS signal transmission, while the other two boxes contain the vibration feedback and recording playback modules. Fig. 9 illustrates the proper placement of the elastic belt on the pet, which is worn from the rear by lifting the hind legs due to the absence of hooks or buttons.

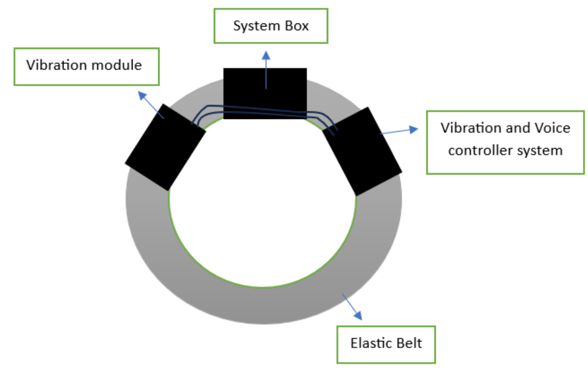


Figure 8 Prototype of Animal belt

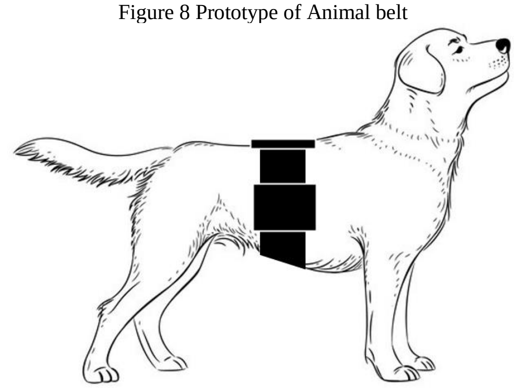


Figure 9 Application of belt

The belt includes a feature to assist in case of pet loss. If the pet strays beyond 1 kilometer from the geofence center and exceeds a set speed threshold, specific voice commands are activated to aid in rescue during potential kidnapping scenarios. These commands are:

1. "This animal is under military-trained surveillance."
2. "This pet is subject to real-time GPS location tracking."
3. "Law enforcement authorities have accessed the pet's current location and are actively pursuing it."

The elastic belt's design, lacking hooks or buttons, makes removal difficult for kidnappers. It is secured tightly and must be worn by passing it through the pet's back legs. The belt also emits vibrations every 10 seconds to hinder quick removal. Users can customize these voice commands to suit regional languages, ensuring clear communication across diverse linguistic backgrounds.

5. RESULT

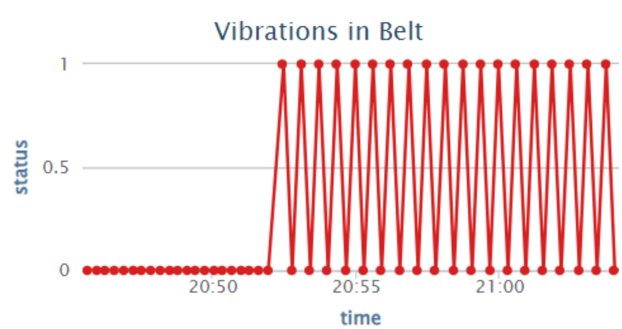
The testing phase produced notable results regarding the system's performance, particularly during geofence assessment. With the geofence radius set at 300 meters, the system consistently demonstrated reliable operation. Table II summarizes the empirical analysis, confirming the system's effectiveness in accurately defining and enforcing spatial boundaries for pet mobility.

TABLE II. GEOFENCE ALERT SYSTEM PERFORMANCE

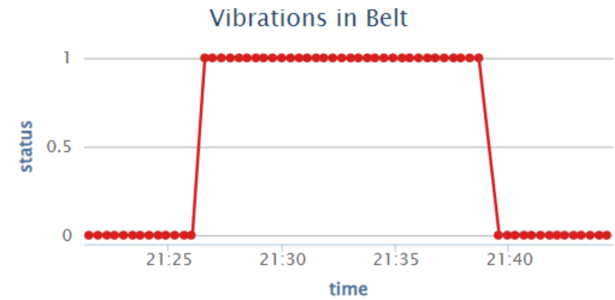
No. of Attempts	Pet distance from Geofence center in meters(m)	System status (Vibration and Audible commands)
1.	440m	ON
2.	210m	OFF
3.	755m	ON
4.	179m	OFF
5.	620m	ON
6.	2207m	ON
7.	1405m	ON

The data illustrates that the system remained inactive when the pet was within the 300-meter radius, as seen in attempts 2, and 4. Conversely, the system activated when the pet exceeded the geofence boundary, as evidenced in attempts 1, 3, 5, 6, and 7.

The following graphs illustrate the system's performance fig.10(a) depicted the operational status of the vibration module before and after breaching the geofence boundary and subsequently moving 1 km from the center. The module activated a vibration every 10 seconds once the predefined condition is met. Fig.10(b) demonstrated the vibration behavior when the pet is within the designated region, initiates continuous vibration upon exiting the region, and ceases vibrating once the pet returns to the owner inside the geofence boundary.



(a) Graph of vibration module status- for 1km boundary



(b) Graph of vibration module status- for 300m boundary

Figure 10 Vibration status in belt

DISCUSSION

The development of the pet belt system, incorporating advanced geo-fencing technology and mobile app management, signifies a substantial leap in pet safety and control. Utilizing vibration feedback for guiding pets within predefined boundaries, the system exhibited high reliability within a 300-meter radius during testing. Customizable settings enhance training efficacy and boundary enforcement, catering to diverse pet behaviors and temperaments, thus providing a tailored and humane management approach. The integrated location tracking feature enhances safety during outings, mitigating concerns regarding pet loss and kidnapping. However, the system faces challenges, primarily due to the high power consumption associated with GPS technology, necessitating frequent recharging. Additionally, the initial cost may exceed that of traditional solutions, potentially limiting accessibility. Dependence on mobile app management could also present usability challenges for non-tech-savvy individuals or those without compatible smartphones. When compared to other pet tracking studies, the GPS integration in the pet belt system is noteworthy for its superior accuracy and unlimited range, unlike RFID and Wi-Fi technologies, which are less effective outdoors. The design judiciously balances the advantages of GPS for outdoor tracking with the challenges of power consumption. The implications of this study are significant. The pet belt system offers a modern, tech-driven solution for pet safety, establishing a new standard for training and management. Future enhancements, such as solar-powered components and real-time health monitoring, could further optimize performance and sustainability, potentially inspiring similar innovations in animal monitoring.

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CONCLUSION

The innovative pet belt system, utilizing advanced geo-fencing technology and a user-friendly mobile app interface, represents a substantial advancement in pet management solutions. By automating boundary control and eliminating the necessity for traditional leashes, the system significantly enhances pet safety and owner convenience. The integration of customizable vibration feedback and voice command playback through the app further augments control and communication between pet owners and their animals. This system offers distinct advantages over traditional rope belts and existing monitoring solutions, including precise boundary control and reduced human effort. Potential applications extend beyond pet management to wildlife conservation and elderly care, demonstrating its versatility and broad impact. These extensions could help mitigate human-wildlife conflicts, ensure the safety of cognitively impaired individuals, and provide advanced safety solutions.Future research should focus on improving the accuracy of geo-fencing technology and enhancing the responsiveness of the vibration feedback mechanism. Current studies are exploring AI-driven behavioral analysis and the integration of biometric sensors, aiming to adapt the system to individual pets' habits and monitor their health in real-time. These advancements will enhance the system's functionality and reliability, unlocking new possibilities for automated boundary control applications across various fields.

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