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1. Introduction to Pet Care Challenges in the 21st Century

The evolution of society has brought about changes in the relationship between people and animals. Animals are no longer just pets; they are now accepted as members of the family. Surveys by the American Pet Products Association (APPA, 2023) state that about 67% of U.S. households own a pet and that this trend is more or less the same the world over. Such a change in perception has led to an ever-increasing demand for health, safety, and lifestyle solutions for pets. But despite the phenomenal increase in care and responsibility of pet owners toward pets, there are still several sore, unresolved challenges:

- Safety issues concerning pets (lost or stolen pets),
- Unrecognized health issues owing to continuous monitoring deficiency,
- Communication gap between veterinarians and pet owners, and
- Lack of awareness on pattern activity and behaviour in pets.

A traditional collar only gives identification and leash-attachment functionality and does little else; it cannot indicate a pet's state or whereabouts beyond the mere fact of being physically near. Conversely, as urbanization progresses and more and more people live in apartment complexes and busy cities, these environments have been posing a threat to the unsupervised pets. That is where technology comes in with yet another appealing answer!

1.1 Rise of IoT and Wearable Technology

The Internet of Things (IoT) is a completely changed world that impacts human interference with the same. The principle is that devices can connect directly to each other, collect data, and share it with other devices and analyze it. Similar devices are available for homes-smart thermostats and connected insulin pumps for backsliding in healthcare. IoT has almost touched every industry sector. Of all the branches of IoT, fitness and health have probably been the most profitable. This has helped make personal health monitoring accessible to many humans. Fitness bands, health monitors, and smartphones that keep track of things like sleep, heart rate, movement, and all those healthy stats are no longer only found in the elite segment of society; they are being adopted by the larger public. Following in the same pattern is pet care. The global wearable pet technology market value in 2022 surpassed USD 2.5 billion and is projected to grow at the CAGR of greater than 12 percent till 2030 (Grand View Research, 2023). Several factors trigger this growth, such as increased awareness about pet health, disposable income, and fast-growing development of sensors, cloud computing, and mobile applications.

1.2 Evolution of Pet Monitoring Solutions

Throughout the years, pet monitoring has progressed from basic radio-frequency identification (RFID) chips to GPS-enabled tags and automated feeders. The shift to real-time pet wearables marks the next phase in this progression. These wearables not only track a pet's location but also assess physiological indicators and environmental elements. Early models of smart collars primarily provided GPS tracking. However, advancements soon incorporated features such as activity monitoring, health tracking, and even awareness of environmental conditions (e.g., temperature detection). Despite this, many current market solutions still present disjointed features or lack real-time analytics, edge processing, and comprehensive data visualization. The Smart Pet Collar initiative seeks to remedy these shortcomings by delivering an all-encompassing, real-time monitoring system that includes:

- GPS tracking and geofencing.
- Health tracking (heart rate, temperature, and activity levels).
- Analysis of behavioural patterns .
- Emergency alert functionalities.
- User interfaces connected to mobile cloud platforms.

1.3 Importance of Data in Pet Health

In the same way that wearable devices assist people in detecting the early signs of illness and/or fatigue, data from smart collars can greatly contribute to pet diagnostics and management of health problems. Unfortunately, many pets suffer in silence, when symptoms can be pretty much unnoticed up to the point of severity. Regular vet visits are complemented by continuous monitoring devices that:

- Detect changes in activity levels.
- Identify abnormal heart rhythms or temperature spikes.
- Detect behaviour indicative of stress.
- Monitor historical trends in the condition.

Such evidence is significantly useful for veterinarians, who can analyze long-term trends in support of better diagnoses and treatment plans. Preventative care can offer less emergency room visits and improved quality of life for the pet.

1.4 Societal and Ethical Implications

As an ethical responsibility that comes along with pet ownership, you need to safeguard them. Most pet owners feel that guilt or anxiety when secluding their pets for longer hours. While some pet owners get emotionally traumatized once the pet disappears or faces an illness without notice. A solution that gives full peace of mind to both parties, complete transparency, and actionable insights is not merely a technological advancement; it is a social need. This is reinforced by the fact that the development of anti-theft features aligns the ever-increasing pet security concerns of cities, particularly pet theft (especially of high-value breeds). The combining of real-time location alerts with collar removal detection mechanisms has practical advantage.

1.5 Technological Opportunities and Constraints

The Smart Pet Collar Project combines the usage of embedded systems with sensors, mobile platforms, and cloud computing. The selected components are as effective as they are inexpensive, and these include the ESP32 microcontroller, the SIM800L GSM/GPRS module, heart rate and temperature sensors. This configuration in hardware supports the principle of edge computing by enabling the collar to process some data locally before being passed on to the cloud. Thus, latency, bandwidth, and emergency alerts (like overheating or fast heart rates) can all be done in nearly real-time without the need for external servers. However, battery life, data security, ruggedness (such as waterproofing), and the comfort of the animal are actively considered. The project examines trade-offs between size, weight, performance, and connectivity carefully with prototyping.

1.6 Educational and Developmental Purpose

The present project is also an academic exercise for software engineering students to apply theoretical concepts into the practical implementations of their projects. It is related to modules of IoT, cloud services, embedded systems, mobile development, and machine learning. The students are gaining hands-on experience through this project in:

- Hardware interfacing (sensors, microcontrollers),
- Software development (firmware and app),
- System architecture and API design,
- Data visualization and analysis,
- User-cantered design principles.

Such a balance between the look at theory and the look at applications in the real world is in keeping with the broader objectives of STEM education fostering innovation, collaboration, and problem-solving skills.

2. Objectives

The main objective from the Smart Pet Collar project is to design and realize a fully functional IoT-based real-time wearable device for pets in which the device is based on safety, health monitoring, and well-being. Including such a device as one of the anticipated projects is meant to make modern pet owners' needs very much in line with the traditional pet monitoring devices currently in use by using embedded systems, wireless communications, and analytics in the cloud.

This section outlines the general aim that has measurable, specific objectives to direct the development and evaluation of the system.

2.1 General Objective

To create a wearable IoT wisely for pets that foster location tracking in real-time, health monitoring, behavior analysis, and safety management, wirelessly through a mobile application interface.

2.2 Specific Objectives

1. Real-Time Sensor Integration

The objective is to integrate multiple sensors, such as a heart-rate sensor (PPG), a temperature sensor (DS18B20), GPS module (Neo-6M), into a compact collar design so that important information about the pet and its surroundings may be collected.

•Reason: Pets cannot verbally express when they are unwell. Monitoring vital signs and activity status helps in the early detection of health problems.

•Intent: The collar will track heart rate, temperature, and motion data in real time and continuously broadcast this information to both the cloud and the user's mobile application.

2. Embedded Computing with Edge Processing

Using ESP32 microcontroller for on-device computation and enabling real-time data processing and decision-making before cloud storage.

- Reason: Due to latency network issues, the event may be delayed, leading to failure in the emergency.

- Expected Outcome: Independent fly trigger warnings (such as high temperature or high heart rate) even when there is no stable internet connection, creating faster responses.

3. Wireless Communication via GSM/LTE and Wi-Fi

To guarantee unbroken cloud connectivity no matter where the pet is, SIM800L GSM/GPRS and Wi-Fi communication modules are implemented.

•Justification: Pets tend to wander outside or in places without Wi-Fi. GSM provides global coverage and real-time data transfer.

•Expected Outcome: Reliable streaming of sensor data to the cloud so that tracking and alerts can be done consistently in remote areas.

4. Mobile Application Interface using Blynk

To build a mobile dashboard on the Blynk IoT platform with capabilities such as:

•Real-time data visualization (maps, graphs, sensor values);

•Alerts and notifications;

•Justification: Most pet owners rely on mobile devices for information and communication, and so it is important to build with a mobile-first approach to enhance accessibility and user engagement.

•Expected Outcome: A responsive app with intuitive dashboards and control over device settings.

5. GPS-Based Location Tracking and Geofencing

Real-time GPS monitoring and geofenced safety zones have been established whereby users are notified when pets exit a predetermined area.

•Rationale: Loss of pets is a major concern; geofencing minimizes the danger by giving immediate alerts on unauthorized movement.

•Expected Outcome: Live map tracking, visual representation of safety zones, and alerts for exits from specified areas.

6. Data Analysis and Behavior Prediction

The intention of the project is to assess extended data trends in order to recognize unusual behaviors (e.g., lethargy, hyperactivity, temperature changes) for AI-based predictive diagnostics in later iterations.

- Justification: Trend observation will yield more information than snapshot readings; hence, they aid in preventive health care.
- Expected Outcome: The foundation for even more advanced behavior and health trend analysis.

7. Energy Efficiency and Battery Optimization

To keep the system completely functional for a period of 24-30 hours on a full charge while active monitoring of sensors and communication with the cloud.

• Justification - Owners cannot recharge their devices frequently. Energy-saving is also essential for real-world adoption.

• Expected Outcome - More Power-efficient firmware through sleeping modes, selective polling, and scheduled uploads of data.

2.3 Research and Innovation Objective

Investigating the capacity of joining wearable devices with edge computing and further cloud analytics in animal healthcare and behavior monitoring in adding to the knowledge in the veterinary area of IoT applications.

• Justification: Among the first student-developed IoT collars that will put together features of safety and wellness.

• Expected Outcome: A working prototype that will have practical significance for future research opportunities as well as commercialization endeavors.

3. Problem Statement

Pet ownership has significantly changed from being a simple companionship to an emotional attachment experience, sense of responsibility, and growing desire for intelligent care solutions in the past year or two. As pets are increasingly being viewed as members of the family, pet owners also become more concerned about their health, security, and happiness. Although this growing awareness is present, modern pet care is still plagued with serious limitations, especially in monitoring pet health, behavior, and whereabouts in real-time.

Among pet owners' most prevalent fears is losing their pets, either inadvertently or through theft. Approximately 10 million pets disappear annually in the United States alone, of which only a minute percentage is reunited with their families, the American Humane Association estimates. The traditional pet collar offers an ID tag or RFID chip, but these are passive systems no real-time location or immediate alert.

In addition to location safety, health issues in pets often go unnoticed until they become severe, as animals cannot verbally express discomfort or symptoms. Unlike humans, who have wearables like smartwatches to monitor their health 24/7, pets lack non-invasive tools that continuously track vital signs such as heart rate, temperature, and activity level. This creates a delay in diagnosis and intervention, potentially worsening the pet's condition or increasing veterinary costs.

Besides, pet behavioral changes are difficult to observe without the owner present. Subtle signs of illness, anxiety, or stress may be overlooked, especially in situations where pets are left alone at home during working hours or holidays. Behavioral abnormalities such as lethargy, restlessness, or hyperactivity are typically early signs of medical or environmental problems, but they cannot be observed without monitoring devices.

While there are products such as smart pet collars and trackers available, right now, they only provide infrequent, stand-alone features. Others focus more on either GPS tracking or activity tracking with a few having detailed health awareness. Many of these are missing:

- Real-time edge computing to make autonomous decisions,
- Internal heart rate and temperature sensors,
- Customizable geofencing alerts

Additionally, most products that are available are prohibitively expensive and not specifically designed for the local or regional user base. Some need paid subscriptions or costly third-party services to access essential features, making it difficult for regular pet owners, particularly in developing nations.

A second issue is that there is no unified platform for pet health management. It is typical for owners to struggle to keep vaccinations, vet visits, medication, and behavioral notes in one

location. The absence of a combined, intelligent system complicates communication between veterinary professionals and pet owners, reducing the quality of preventive care.

Keeping in mind these challenges, there is an immediate need for a cost-effective, scalable, and integrated solution that gives pet owners a reliable, real-time health-and-safety monitoring system with actionable information and accessibility through mobile platforms.

4. Project Outcome

The Smart Pet Collar project led to the successful implementation of an intelligent, real-time tracking system that improves the safety, health, and overall welfare of pets by utilizing advanced IoT technologies. The end product is a wearable collar with several sensors that monitor vital signs like heart rate, body temperature, and activity levels around the clock. These health parameters are crucial to detect early signs of disease or stress, especially since animals cannot communicate their discomfort verbally. Apart from health monitoring, the collar also has GPS-based location tracking that allows pet owners to know their pet's exact location at any time. The geofencing feature is provided, which enables users to create virtual safe zones, and upon the pet's exit from these zones, the system sends an automated notification to the owner's mobile phone. Both data processing and transmission are carried out using an ESP32 microcontroller and SIM800L GSM module in order to maintain stable performance even in outdoor settings where Wi-Fi may not be available. Implementation of Blynk as the smartphone app platform made it possible for a simple and intuitive user interface, where pet owners can monitor real-time data, receive notifications, and even manage pet profiles on their phone itself. Anti-theft capability is built in the collar that detects if the device is pulled out in a hurry and provides a notification to the user right away. Historical information is stored safely in the Firebase Realtime Database, so users can look back at past history and observe trends over time for their pet's activity and health. The device was put through many different conditions and proved stable, accurate, and reliable. Battery life is around 24 to 30 hours, and the collar is easily rechargeable. The design was maintained light and pet-friendly so that it is still comfortable and easy to use. Overall, the Smart Pet Collar succeeded in doing what it intended to do by offering a smart, affordable, and easy-to-use product that allows pet owners to care for their pets better using real-time information, preventive notifications, and mobile connectivity. Not only does this demonstrate technical success, but also how cautious engineering can make a difference in everyday life.

5. Project Solution

Smart Pet Collar presents a new paradigm to modern pet care challenges through the convergence of the strengths of Internet of Things (IoT) technologies, embedded systems, cloud computing, mobile interfaces, and data analysis into a wearable, portable product. This effort provides an all-encompassing, real-time health and safety tracking system beyond the usual pet collars.

Essentially, this device completes the communication loop between humans and animals by collecting, processing, transmitting, and displaying critical information. This enables pet owners to take proactive measures for safety, health, and behaviour control—thus boosting the welfare of pets and the serenity of human beings.

5.1 Overview of the Solution

The Smart Pet Collar is a wearable IoT device that will:

- Locate the pet in real-time through GPS.
- Monitor the pet's heart rate and body temperature through biomedical sensors.
- Detect motion patterns and behavioural trends through an accelerometer.
- Send geofencing warnings when the pet leaves a geofenced region.
- Send alerts to the mobile phone of the user through a specialized app.
- Store and report historical data analysis for extended health monitoring.
- Offer anti-theft protection via collar removal detection.
- Store all data in the cloud for access and analytics.
- Offer an easy-to-use mobile app for real-time monitoring and control.

These together create a solution that facilitates real-time intervention, predictive care, and data-driven pet health management.

5.2 Functional Components of the Solution

The Smart Pet Collar consists of the following key functional components:

A. Sensing and Monitoring Subsystem

This is the first point of interaction between the collar and the pet. It includes all physical sensors and modules for gathering real-world data:

- **PPG Heart Rate Sensor**: Constantly monitors the pulse of the pet. The Photoplethysmography (PPG) technology is not invasive, and it operates by measuring variations of blood flow with a light sensor. It is calibrated to function with varying types of fur and pet sizes.
- **Temperature Sensor (DS18B20)**: Measures environmental and body temperature. Body heat changes are used to detect fever or hypothermia. The sensor is accurate to ±0.5°C and is waterproof.
- **Neo-6M GPS Module**: Provides accurate real-time tracking. It communicates with satellites to triangulate the collar's location within 3–5 meters.

B. Embedded Processing and Control

The ESP32 microcontroller serves as the brain of the device. It is accountable for:

• Acquisition of data from sensors.

• Preprocessing of raw data.

• Detection of abnormality according to predefined thresholds.

• Handling communication with the cloud and mobile devices.

It supports edge computing, so minor decisions (like issuing an alert for an abnormal heartbeat) are taken locally, even without internet connectivity. This strategy reduces dependency on third-party services and offers quick response times.

C. Communication and Connectivity

Real-time data exchange necessitates communication. The solution supports dual-mode communication:

• Wi-Fi: Used where the pet is at home or within Wi-Fi-covered areas. Offers high-speed data synchronization and cloud communication.

• SIM800L GSM Module: Facilitates mobile LTE connectivity through a SIM card. It ensures smooth data transfer and location tracking, even at outdoor or remote sites lacking Wi-Fi.

Collectively, these modules allow the collar to stay in ongoing communication with the cloud and app infrastructure.

D. Power and Energy Management

The unit is powered by a 1500–2200mAh rechargeable lithium-ion battery, chosen for its balance between size, weight, and capacity.

• Maximizes battery life through:

- Sleeping sensors when not operational.
- Pushing data only at necessary intervals.
- Use of edge computing to reduce cloud dependency.

Battery life averages 24–30 hours, and users receive notification via the mobile app when battery levels are below 20%.

5.3 Key Functional Features

Each of the features in the Smart Pet Collar corresponds to a pain point of the user and is designed with functional use in mind.

1. Real-time GPS Tracking and Geofencing

• Users can set up a safe zone (e.g., backyard, park) via the app.

• The moment the pet exits the zone, the collar immediately notifies the owner.

• GPS updates every 30 seconds for ongoing accuracy without draining the battery too quickly.

Use Case: When the dog escapes through a gate, the owner is notified immediately and given a map pin of where the dog is.

1. Health Monitoring (Heart Rate + Temperature)

• The monitor records vitals at 10-second intervals.

• Thresholds are pre-set based on species and breed.

• Alerts are triggered if heart rate or temperature readings fall within critical ranges.

Use Case: When the pet develops a fever, for example, when the owner is away at work, the system detects the increase and alerts health right away.

2.Activity and Behavior Analysis

• The accelerometer measures motion intensity and posture.

• Behavior analytics track trends such as decreased playfulness or excessive rest, which are indicative of illness or stress.

• Users can see these patterns in the app in order to make a decision or visit a vet.

Use Case: A normally active pet that becomes inactive within a 48-hour timeframe can be exhibiting early warning signs of illness, which triggers early care.

3. Mobile Application and Customization

• The app serves as a command centre for the device.

• Owners can:

  o Create new geofencing zones.

  o Modify alert thresholds.

  o Receive updates even when on the road.

Use Case: A user can monitor their pet being looked after by a friend at home while on vacation and receive alerts in real time.

5.4 How the Solution Addresses the Problem

The Smart Pet Collar offers a multi-pronged solution to pet care challenges through:

- Avoiding loss of pets via live location tracking and alerts.
- Identifying early warning signs for health anomalies to avoid crises.
- Providing pet owners with peace of mind away from home.
- Aiding vets with comprehensive health histories.
- Providing preventive care through pattern identification.
- Offering anti-theft security in public and unattended areas.

Use Case : Each feature directly corresponds with a pain point of the user and uses technology to deliver real, actionable information instead of raw data.

5.5 Competitive Advantage and Uniqueness

Whereas there are a number of clever collars available, the Smart Pet Collar possesses the following novel features:

- Real-time alert prioritization using edge computing.
- Geofencing + health monitoring in a single low-cost unit.
- Cloud storage + trend analysis, not just real-time tracking.

In contrast to some items that address only location or fitness, the device provides a complete pet health and safety solution.

6. Approach and Methodology

Smart Pet Collar Design Development adhered to a systematic step-by-step approach to create accuracy, usability, functionality, and durability. There is absolute elaboration of the strategic process adopted by the development team step by step in every step from design to development and implementation and testing. The process incorporated elements of both V-Model lifecycle process to cover system design and Agile methods for increment refinement. A hybrid process facilitated rigorous hardware-software integration without compromising response to feedback and evolving requirements.

6.1 Requirement Analysis and Planning

The essence of any engineering project is well-defined problem space and user expectation. The initial phase was addressed by identifying the needs of the stakeholders and converting them into system specifications that could be executed.

Identifying Stakeholders and Use Cases

• Veterinarians, pet owners, and animal welfare experts were the stakeholders.

• Pet owners assigned escape of pets, disease acquisition without diagnosis, and absence of real-time status reports outside home.

• Physicians enjoyed the merit of real-time health monitoring information in informing clinical observations.

• Outcomes were utilized to inform use case development, such as:

"Pet owner wants alert when dog leaves secure area."

"Owner wants activity level monitoring so as to monitor pet weight."

"Vet wants presentation of long-term history of temperature and heart rate."

Technical Requirement Definition

Drawing from feedback, the team summarized:

• **Functional Requirements**: Real-time heart rate/temperature monitoring, recognition of behavior, real-time GPS location tracking, and mobile app integration.

• **Non-Functional Requirements**: Low energy consumption, user interface, data protection, cloud uptime reliability, and physical ruggedness.

These were detailed within a Requirements Traceability Matrix (RTM), which made it easy to follow up at regular intervals on progress toward defined goals.

6.2 System Design and Architecture

Having established the needs, the project then proceeded to system design. Smart Pet Collar architecture was defined in five conceptual layers each of which realized a block of functionality.

1. Perception Layer (Hardware/Sensor Input)

It gives input from pet or environment directly through sensors.

• **ESP32 Microcontroller:** Low-power, high-performance microcontroller with Bluetooth and Wi-Fi features. Manages all connected sensors' data and takes care of GSM and GPS communication as well.

• **PPG Heart Rate Sensor:** Tracks the animal's pulse through reflected light. Collar movement, color, and fur compensation.

• **DS18B20 Temperature Sensor:** Tracks body temperature of pet and room temperature. Water-proof and won't be damaged if put into pet accessories.

• **Neo-6M GPS Module:** Offers real-time positional data with 5-meter locational precision. GPS data is processed locally in order to implement geofencing.

• **SIM800L GSM Module:** Passes data over LTE networks in the event of no Wi-Fi connectivity while exchanging data via the cloud. Offers worldwide connectivity and is therefore convenient to use outdoors or remotely.

• **Battery Pack:** Lithium-ion battery 3.7V, capacity of 1500–2200mAh. Battery duration based on use, 24 to 30 hours.

2. Network Layer (Communication Handling)

Responsible for forwarding data between the collar and the backend server/cloud.

• **SIM800L/GPRS:** Utilized data over transmit when there was no Wi-Fi connection. Used low-bandwidth uploads via GSM.

3. Edge Processing Layer (On-device Computation)

To minimize latency and bandwidth, sensor data was locally processed by the ESP32 prior to cloud upload.

• Anomaly Detection: Utilized simple onboard logic to identify anomalies like:

- The heart rate is > 160 bpm or < 60 bpm.
- Sudden rise in temperature.
- Inactivity for an extended duration.

• Immediate Generation of Alerts: These anomalies triggered instantaneous alerts via GSM to the mobile app, before uploading data to the cloud.

• Fallback Memory: Data had been buffered and uploaded on reconnection following network failure.

4. Application Layer (UI and Mobile App)

Application Layer is the user-intelligent pet collar main point of interaction. It is where live visualizations of information collected by the device are viewed, alarms are received, and users also get to configure some of the settings. In our project, we have employed Blynk, an IoT platform with unlimited potential, which has the ability to support the fast development of mobile connected applications based on its drag-and-drop GUI and cloud integrations.

5. Use of Blynk in the Smart Pet Collar

Blynk let us create a clean but highly functional interface without the need to build a custom app from scratch. It provided us with an instant connection between the ESP32 microcontroller and the smartphone user using Blynk's cloud services. This approach significantly reduced the development time while giving us robust and reliable connectivity.

6. Key Features of the Blynk-Based Application

Cross-Platform Access: Blynk supports both Android and iOS and can be used easily on the most widely used mobile platforms. The users can download the Blynk app from the Play Store or App Store and use a secure token to authenticate.

Live Map for Real-Time Pet Location Tracking: A Map Widget displays the pet's real-time GPS location. It illustrates the pet's movement in real-time, including any designated safe zones (geofences). It provides reassurance, especially for pets outdoors or left alone.

Health and Activity Dashboards:

Heart Rate Monitoring: The pet's real-time pulse is displayed using a Value Display Widget or Gauge Widget.

Temperature Graphs: Live temperature graphs are displayed through Graph Widgets, allowing owners to monitor dips and rises.

Motion and Activity Levels: Accelerometer output is graphed as well, offering a report of how active or stationary the pet was throughout the day.

Alert Manager:

- Users may set alerts on heart rate, temperature, and other key parameters.
- Blynk provides push notification support, which we leveraged to inform users if a reading exceeds a critical level or if the pet moves out of the geofenced area.

7. Battery and Device Status Monitoring:

Battery status of the collar is tracked and shown on the dashboard to notify the user when it needs to be charged.

8. Benefits of Using Blynk

Rapid Prototyping: Enabled rapid setup and real-time testing without needing to write a lot of frontend code.

Real-Time Data Visualization: Reliable cloud connectivity introduced minimal latency between sensor readings and app update.

Scalable Architecture: As Blynk supports multiple widgets and virtual pins, adding future updates or feature extensions can be done easily.

Secure Connectivity: Each device uses a unique authentication token to securely connect to the user's phone.

6.3 Prototyping and Development Process

The prototyping was incremental and modular with chunks being written, tested, and added incrementally step by step.

Sensor Calibration

• All sensors tested against known equipment:

o Heart rate reading vs. veterinary monitors.

o GPS accuracy vs. smartphone GPS programs.

o Temperature reading vs. contact thermometers.

Firmware Development

• Written on Arduino IDE and C++.

Hardware Integration and the BLYNK

- Breadboarded initially for development.
- Enclosures water-proof, tightly packed for use in daily life conditions.
- 3D printed enclosures for integration of shockproof and ergonomic considerations.
- Blynk provided fast development of a responsive, user-friendly UI.

6.4 Testing and Evaluation

In the spirit of making the system work well and be as reliable as possible, proper multi-stage testing was carried out.

Unit Testing

- Individual testing of each module (GPS, sensors, GSM, app modules) was done.
- Sensor output was tested using serial monitors and logic analyzer.

Integration Testing

- Module-to-module as well as cloud interactions were tested.
- Synthetic network failures to test fallback data storage and resync.

Field Testing

- Adopted pets of various sizes and breed.
- Testing locations were homes, parks, and open fields.
- Alerts were triggered manually to verify notification timing and accuracy.

Performance Metrics

Metric	Observed Result
Heart rate accuracy	~95% (±5 bpm vs vet equipment)
GPS location precision	~5 meters
App alert delay	<1.2 seconds (MQTT real-time)
Battery life	24–30 hours based on usage
Temperature range	±0.5°C from contact thermometer

6.5 Usability Testing and User Feedback

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Screenshots of the Excel Sheet should be here

6.6 Technical Exposure and Educational Value

The project gave the team a general chance to combine theory from the academic environment with real engineering problems.

- **Technical Skills Used:**
  - Embedded programming (ESP32, C++).
  - Power management and hardware development.
  - Real-time database-driven application development.
  - Collaboration and Project Management:
  - Utilized GitHub for version control.
  - Bug fixing and sprint review meetings bi-weekly.

6.7 Ethical and Safety Considerations

As this device was being used on live animals, an additional level of care was followed so that it would be responsible, safe, and humane design.

• Safety in Materials: Material that came into contact was soft, hypoallergenic, and non-toxic.

• Data Privacy: The users' access to data and verification was secured with token-based access.

• Emergency Failsafes: The emergency alert had priority over regular data upload so that primary information were communicated even in the case of poor signal.

• Removal Detection: Contact plate sensors in the collar detected unit removal, notifying the owner through the app.

6.8 Final Words in terms of Methodology

This method hit the ideal blend of human factors engineering and technical expertise. Through combining field testing with hardware, software, and cloud infrastructure, the team managed to create a functional and stable intelligent pet device. The process is best practice for modern IoT product development and presents a future development and commercial scalability roadmap.

7. Conclusion

The development and implementation of the **Smart Pet Collar** mark a significant step toward the future of pet care, where **technology, compassion, and data-driven decision-making** converge. Through this project, we sought to address real-world challenges faced by millions of pet owners globally—namely, the fear of losing their pets, being unaware of their pets' health conditions, and the inability to monitor pets' behavior and wellness in real-time. With the rise of the Internet of Things (IoT) and advancements in embedded systems, we saw an opportunity to **design a solution that empowers pet owners** with reliable, continuous, and actionable insights into their pets' lives.

At its heart, the Smart Pet Collar is a **synthesis of engineering innovation and humane responsibility**. We integrated multiple technologies—PPG sensors, GPS tracking modules, accelerometers, GSM-based communication, cloud computing, and mobile applications—to create a wearable system that truly understands and protects animals. The collar doesn't just track location; it **monitors health parameters, detects behavior changes, prevents theft, stores long-term medical data**, and alerts users in emergencies. This is a major leap forward from the traditional pet collars which serve only as identification tools or decorative accessories.

Our project delivers not just **functionality but foresight**. By processing data locally through edge computing on the ESP32 microcontroller, we've reduced latency and ensured real-time alerts without reliance on cloud availability. This architecture allows our system to respond immediately to health emergencies—like abnormal heart rate or sudden changes in temperature—potentially saving the pet's life in critical moments. The inclusion of **geofencing and anti-theft features** ensures not just the pet's health, but their physical safety. In an era where pet theft and accidental escapes are common, such capabilities offer real peace of mind.

Academically, this project aligned well with our curriculum in **IoT, software engineering, data communication, and cloud computing**. Beyond textbooks and simulations, we encountered and solved practical problems: battery efficiency, GSM signal loss, sensor noise, and firmware conflicts. These challenges taught us the value of debugging, documentation, hardware optimization, and most importantly, patience and persistence.

What sets this project apart is its **social and emotional relevance**. For many, pets are more than animals they are companions, family members, and emotional support systems. Yet, they cannot communicate verbally when they are unwell, anxious, or lost. Our Smart Pet Collar becomes a voice for the voiceless, translating health signs into alerts, behavior patterns into graphs, and movements into interactive maps. This is **technology with empathy** a concept often missed in traditional tech development.

We also ensured that **ethical considerations** were respected at every stage. The hardware is pet-safe and non-invasive. Data privacy is protected through secure authentication and encrypted transmission. We collected no unnecessary data, and users retain full control of what is stored, shared, or deleted. Field testing was done with full consent from pet owners, ensuring no stress or harm to the animals involved. As future technologists, we recognize the **importance of responsibility in innovation**.

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Gimhan Pramodya Algama	10953025	Arduino Code & Testing
Uwage Don Nethum	10952752	
Balasinghege Sarali Thiloka	10952772	
Mathara Arachchige Malith Ashen Chularathana	10952987	Sensor Assembly (Hardware)
Mahara Mudiyanselage Dulni Thimethya Sandasini	10952728	GPS + SIM Setup
Ravith Sandil Samarasekara	10952855	Casing Design
Sunilge Siripadma Ruchira Ilangasinha	10952979	Blynk App & Cloud
Manchanayaka Arachchige Don Thisun	10952725	
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