Smart Home IoT System For Blind Dogs

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March 12, 2021

1. Declaration

”The design elements of this project and report are entirely the original work of the authors and have not been submitted for credit in any other course”

- Rushabh Patel - Luisa Palechor

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2. Abstract

Recent advancements in interconnected devices have simplified many aspects of our lifestyles including the automation of our homes. In the upcoming years, we will see more interconnected devices in our homes and our lives; these devices will not only improve our lives but also the lives of our pets. The purpose of this paper is to integrate our recently developed wearable device (smart vest for blind dogs) as a part of a home IoT system in order to improve a dog's overall health. We will be explaining the functional, software, and hardware requirements as well as the design and operation of our IoT system. The technologies we will be exploring in this paper are the smart vest, smart dog house, smart food dispenser, and smart chewing toys.

Keywords: IoT, Wearable Technology, Dog, Pet, Health, Smart Home

3. Background

3.1 Motivation

Vision loss is very common in dogs and they can suffer anywhere from hazy vision to complete blindness [12]. There are many causes for vision loss such as normal ageing process, heredity, disease, or an injury [12]. Common diseases include cataracts and glaucoma; however, vision loss can also occur alongside other canine diseases such as diabetes [12], [21]. Although the loss of vision is difficult for dogs, it is not their primary sense as it is for humans; therefore, they can manage vision loss more easily by relying more on their other senses [12], [21]. In our earlier paper, we designed a smart vest for blind dogs with the primary function aimed at a dog's sense of touch to provide directional cues in place of the owner's voice using haptic feedback. The secondary function of the smart vest focused on monitoring the dog's health using heartbeat sensor, pressure sensor, and temperature sensor. In this paper, we will expand our wearable device to be a part of a home IoT system to improve the dog's overall lifestyle and to further monitor its health.

Home automation has seen a surge of growing interest alongside the development of new and improved IoT sensors and devices. There are an estimated 41.3 million smart homes in the United States and this is expected to grow up to 63 million by 2022 [2]. As the number of smart homes increases, there will also be a rise in smart pet solutions such as a smart dog house, smart food dispenser, smart chewing toys, smart pet doors, etc. The purpose of this IoT system and our motivation for developing it are to improve a dog's health via smart pet home solutions.

3.2 Dog's health

Having a dog as a pet is popular around the world. According to recent studies, the 40% of households in Australia own at least one dog [15], the rate for the United States, Canada, and the United Kingdom are 38.4% [20], 35% [4] and 31% [29] respectively. Therefore,

pets are getting more attention in different research areas. For example, dogs' health research is improving the prevention and treatment of some known deadly dog diseases such as canine distemper, canine parvovirus, heartworm, rabies, lyme disease, Kennel cough, leptospirosis and Kidney disease. Martella et al. [28] worked on canine distemper virus symptoms, treatments and preventions. In their research, the authors mentioned symptoms such a fever, respiratory and enteric signs, and neurologic disorders. They mentioned virus can be prevented with vaccines and with supportive care, and antibiotics. Goddard et al. [26] investigated the canine parvovirus which symptoms include fever, lethargy, vomiting, and diarrhea. Ames's research [24] expelled that heartworm infection complications could result in heart failure, which may prove fatal. The author suggested that early diagnosis and treatment are essential for dogs with heartworm, as the risk of these complications increases with disease progression.

The research on the dog pet and the current technologies have brought new smart devices that help improve the quality of life of the pet and the owner. Commercial smart devices that exist include remote playtime devices, potty training devices, and pet-specific cameras. However, the industry is more focused on executing scheduled tasks rather than collecting information and building IoT systems.

The IoT research area is broad for pets. Sangvanloy [31] created an IoT system to train the pets for scheduled meals. Chen et al. [25] included a smart food feeder, water dispenser, and a defecation box in his IoT system. By using a smartphone, the authors monitored and controlled the system in real-time and collected and processed data to display statistical records. Own [30] created an IoT system that includes not only eating control but also a pet location-awareness. The modules Own combined a smart pet door, smart pet feeder and smart pet collar. Luayon [27] developed an IoT application introducing a defection pad to monitor the number of times the pet has defecated. Other modules that Luayon built are the automated feeding system, camera service monitoring, room temperature monitoring and smart door scheme. However, to the best of our knowledge an IoT system that includes a smart dog vest, smart doghouse, smart dog toy and smart dog food has not previous developed.

4. Functional requirements

Our IoT system will collect and process data from the interconnected devices and sensors for the purposes of improving dogs' quality of life and prevent diseases. This system will focus on dog health and entertainment to showcase the improvements in a dog's health by introducing IoT in their ecosystem.

- The IoT system will have a unified mobile application hosted on the Android and Apple app store to monitor the devices.
- Statistics will be displayed in the mobile application by means of statistics and graphs.

- Backup power supply unit will be utilized so the IoT system will operate even if the primary power source fails.
- Bluetooth and Wi-Fi will be supported as wireless communication protocols.
- The IoT system will include communications with local veterinary clinics to share the dog's health data.
- The IoT system will include communications with local dog training centers to share the dog's health data.
- The IoT system will be able to request dog food delivery from local or online pet stores.

4.1 Smart dog vest

- The smart vest will include a tight strap to ensure the vest fits well. Moreover, it will be lightweight, and rechargeable.
- There will be smart vest sizes for small, medium and large blind dogs.
- The system will detect objects that are 30 cm away from the dog and notify blind and deaf dogs.
- The system will detect when dog positions, e.g. laying down, are accidentally blocking any of the proximity sensors.
- Positions like standing, lying down, walking, stair climbing, or going down a ramp will be detected by the system.
- The system will provide the dog's location, heartbeat pulse and temperature to the dog's owner cellphone via Bluetooth.
- Mobile application for Android and iOS will display the health monitoring and the dog's location data to its owner.

4.2 Smart food dispenser

- The smart pet food dispenser will support up to 10 scheduled feedings.
- Each meal can be portioned anywhere from 20g to 400g.
- The dispenser will keep up to 6lbs of dry food.
- Weight sensor within the food dispenser will measure the remaining amount and notify the user when it is lower than 30%.

4.3 Smart doghouse

- The smart doghouse will fit in indoor rooms. It will be light and small. The dimensions and weight will not exceed 48 x 48 x 49.5 cm and 13.5 lb.
- The temperature can be adjusted inside the smart doghouse according to the dog's needs.
- The smart doghouse will detect when the dog is inside via infrared sensor and it will record dog's resting time.
- The smart doghouse will absorb the moisture and condensation inside so it is always dry.

4.4 Smart dog toy

- The IoT system will communicate with smart dog toys that will be remotely controlled by a smartphone.
- The entertainment/activity time will be measured by the system.

5. Hardware design

In this section we are going to explain the required hardware to build the modules of out IoT system.

5.1 Edge devices

- **Smart dog vest**: As outlined in our previous report, the required hardware for this wearable device includes a microprocessor, power source, GPS, ultrasonic sensors, vibration motor, temperature sensor, accelerometer and gyroscope, heart rate analog front-end, pressure sensor and LEDs. For the IoT system design we decided to change the wireless protocol communication to Wi-Fi.
  - Rated power: 2500mAh @ 3.7V lithium-ion rechargeable battery
  - Wireless Protocol: Wi-Fi 2.4 - 5 GHz.
  - Cost: $115.322

  The description of this module is presented in our previous report. Please refer to the parts list for the breakdown of the parts and the device references.

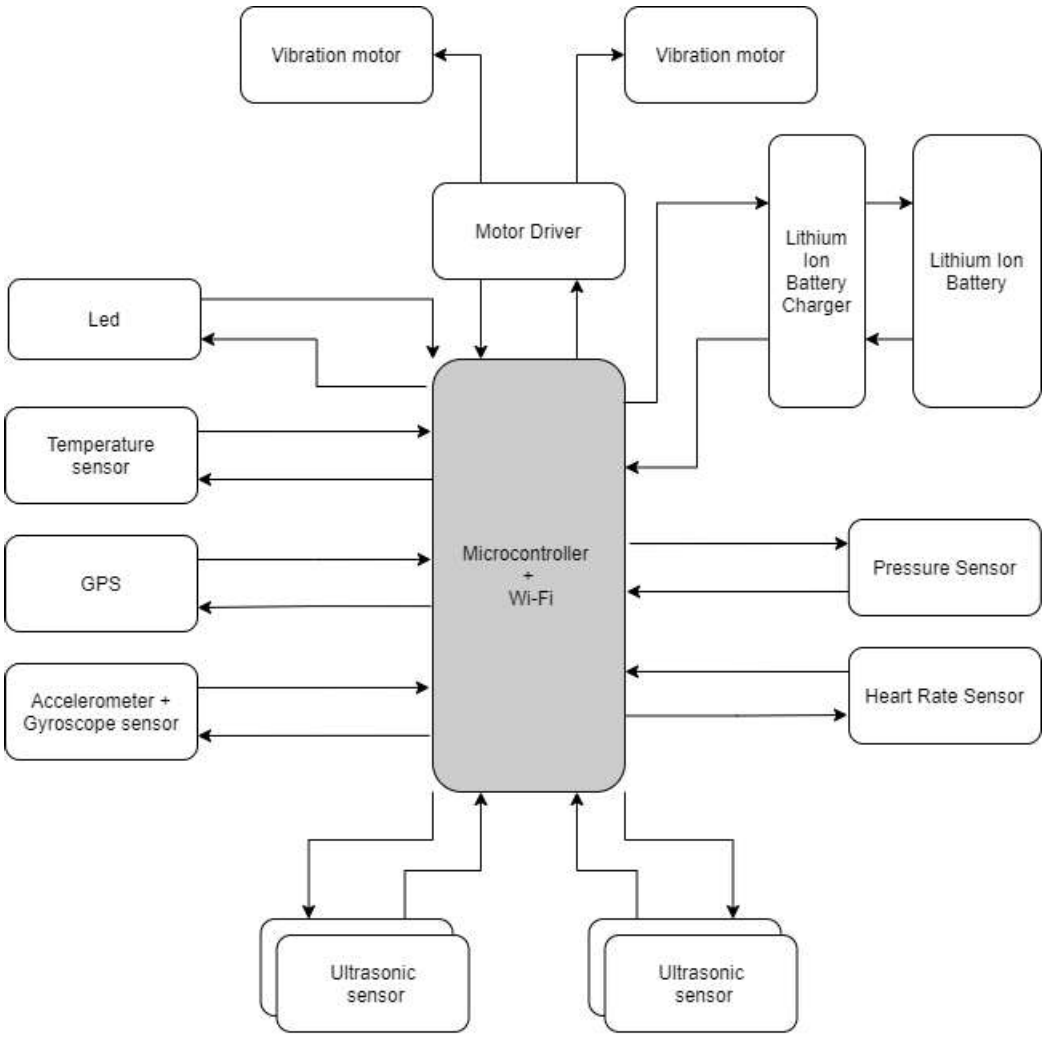

Fig. 1. Smart Dog Vest Hardware Block Diagram

- **Smart doghouse**: The Petkit cozy product [7] satisfied the functional requirements for the smart doghouse module.
  - Sensors: the Petkit cozy device includes temperature and humidity sensors to modify the doghouse temperature. To detect if the dog is inside the doghouse, this product has infrared sensors at the doghouse entry to measure when the pet enters.
  - Rated power: 18W/3000mA.
  - Wireless Protocol: Wi-Fi
  - Cost: $209.99

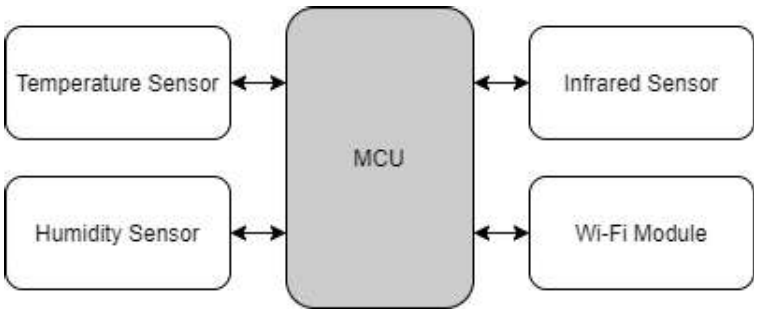

Fig. 2. Smart Doghouse Hardware Block Diagram

- **Smart food dispenser**: The Petkit fresh element [9]
  - Sensors: Weight sensor is used to check the weight of the remaining food in the dispenser. Infrared sensor is used to ensure the motor and wheel system operate efficiency.
  - Wireless Protocol: Wi-Fi
  - Power: AC adapter
  - Battery backup: 4D Alkaline.
  - Cost: $129.99

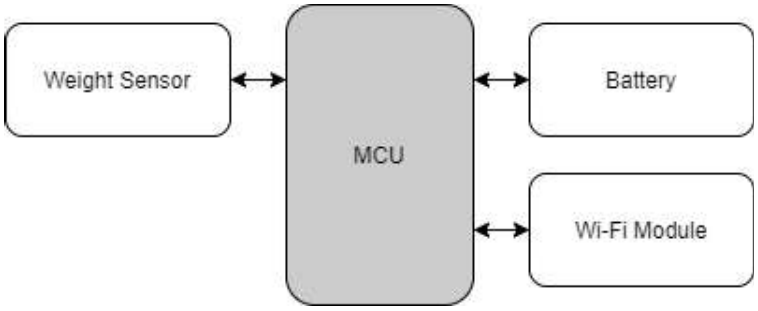

Fig. 3. Smart Food Dispenser Hardware Block Diagram

- **Smart dog toys**: Petcube Play 2 [17]
  - Sensors: 1080p camera with night vision to get live feed on the user's dog and a 3R class laser pointer to interact with the pet via moblie interface or have it in automated mode to keep the dog entertained. Also has microphone and speaker to have two-way communication with the dog.
  - Wireless Protocol: Wi-Fi 2.4 - 5 GHz.
  - Cost: $179.00

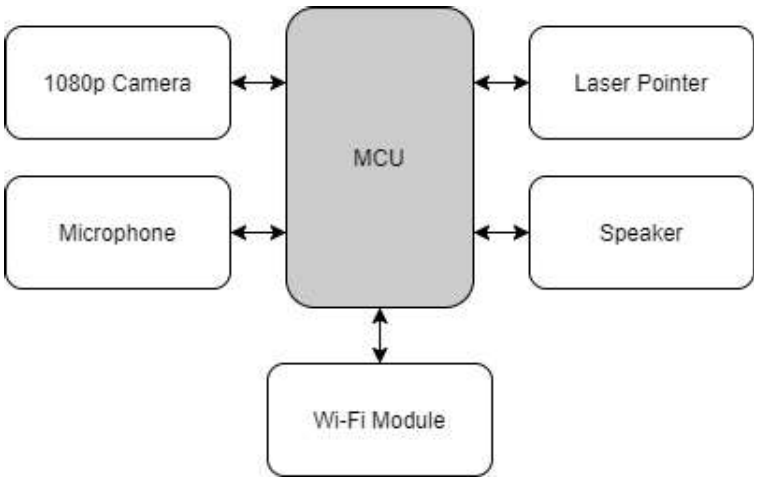

Fig. 4. Petcube Play 2 Hardware Block Diagram

5.2 Gateway

- Xiaomi router [22]: this device is a dedicated router that allows to forward data in and out from the network.
  - Dual-band 880Mhz with 128 MB ROM and Memory
  - 1 Gbps data rate
  - 2.4 Ghz - 5.0 Ghz
  - Network protocols supported: IEEE 802.11a/ac/b/g/n and IEEE 802.3/3u/3ab
  - Wireless security: WPA, WPA-PSK, WPA2, WPA2-PSK
  - Cost: $79.69

5.3 Power backup

We will support the main system with a UPS device UPSEC850LCD [1], then the system will have power even in a power outage up for 2 hours.

- Watts: 390
- Battery power 650 volt-ampere

6. Software design

6.1 Network communication pattern

- Smart doghouse: This device will periodically send the doghouse temperature to the cloud and check if the temperature inside the doghouse needs to by adjusted by following the polling pattern. In addition, the resting time information will be sent only when the system requires (pull network pattern).

- Smart dog toy: The video stream will be push-based since the video content will be sent only when it is required. Moreover, polling-based network communication will be required to verify if the laser, microphone or speaker need to take action.
- Smart food dispenser: Scheduled feeding data will use the pull communication method so the server can request the amount of scheduled feedings data before allowing another serving. The weight data will use the push method to send data at regular intervals (in cases of dispenser not being filled more than 30% or food being emptied out) and upon meeting conditions (dispensing food).
- Smart dog vest: This module will push out the temperature, heart rate and pressure measurements to the cloud only when there is a significant change compared with the previous information. The module will be able to send the information to the cloud when requested (pull network pattern). The MCU of this module will first storage and analyze the data before sending it out to the internet.

6.2 Application protocol

Our architecture will use MQ Telemetry Transport (MQTT) protocol to send messages. The reason we chose MQTT is because of its publish-subscribe model and because most of our devices use push based network communication protocol. In addition, MQTT is also much more lightweight and efficient compared to HTTP. MQTT is also very scalable in case we decide to add more devices in the future and also supports bi-directional communication between all the connected devices.

6.3 Security

We will be using MQTT over OAuth authentication protocol to encrypt messages between the devices and the servers. OAuth allows us to authorize tokens to the IoT devices to verify their identity rather than sharing passwords.
For users to access our services, our identity and authentication service will utilize the AES encryption algorithm to encrypt and decrypt the user's identity. The AES encryption can generate a cipher text of 128 bit, 192 bit, and 256 bit from plain text and a secret key. We will be using AES 128 as it is quite a bit faster than AES 256 and provides nearly the same level of security.

6.4 Data analysis

Initially all the sensor data will be sent to a stream processing engine such as Kafka or Stream analytics. Stream processing engines allow our architecture to provide real-time analytics to the user and store the processed data in our sensor database for it to be used by our data analytics service.
The sensor data will then be used for machine learning to train our models (informing user of pet's health, recommendations, guidelines, etc.). These models will be stored in our

model database and will be accessed when data analytics service is called by the mobile application.

6.5 Architecture

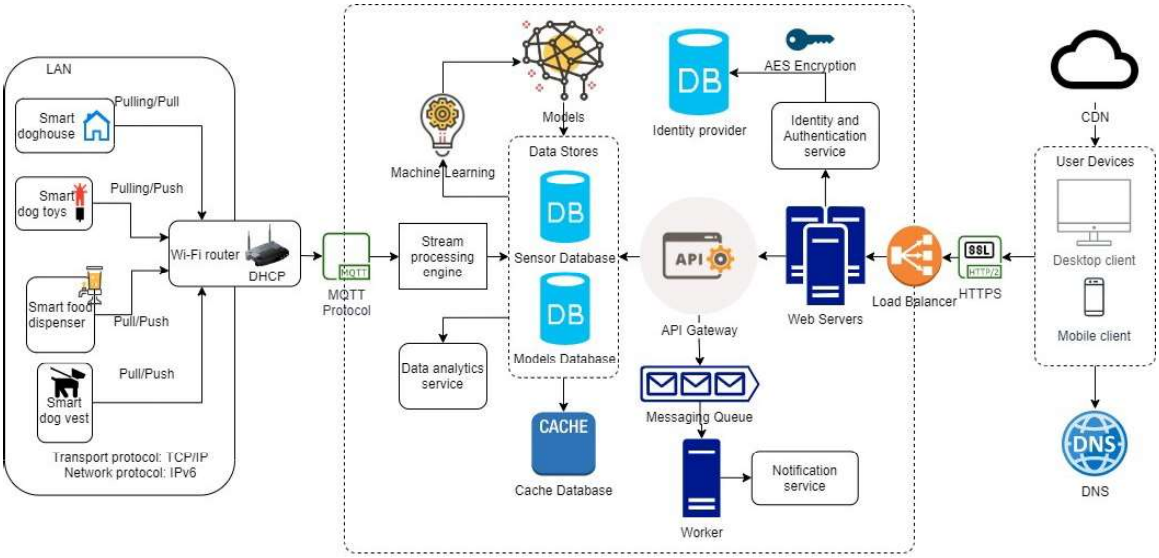

Fig. 5. IoT Architecture

7. Operation

7.1 Data generation

Each module will generate its data according to the sensors the module has. Following the details for the data.

- The smart dog vest module is responsible for sending the dog's temperature, pressure and heart rate data. The sensors will measure every 20 minutes, and the MCU will analyze and store this information hourly before sending it to the cloud. If MCU detects changes in the measurements, then the MCU will send the information to the cloud.
- The Smart doghouse will locally store the temperature data every 10 minutes, and the time the dog enters or leaves the doghouse is asynchronous. Otherwise, if the dog is not using this module, the temperature sensor will be in sleep mode and will wake up if the dog enters.
- The food dispenser will provide information about how much dog food is in the container by using the weight sensors. This data will be hourly stored in the module. Since knowing how much food is left in the food container is important but not

critical, the weight measurement information will be sent every 4 hours to the cloud or when requested.

- The MCU of the smart dog toy will provide the time the dog spends playing with the laser. The module first will calculate the time the infrared component was on. Second, it will calculate the time the video camera detects the dog playing around. This module will internally store the minutes for dog entertainment and send the data to the cloud only when required.

7.2 Data acquisition

Each module will send the data through Wi-Fi to the Wifi-router. Inside the LAN the data will be sent by TCP protocol, and it will be secured by

- Smart dog vest frequency: Polling intervals. If the measures change with respect to the previous data then the data will be sent to the cloud.
- Smart doghouse frequency: Event based. Data will be sent only when requested.
- Smart food dispenser frequency: Continuous monitoring. Data will be sent every 4 hours or when required.
- Smart dog toy frequency: Event based. Data will be sent only when requested.

7.3 Data validation

- We will monitoring the system logs to check if the system is receiving the data.
- The system will ping every minute each edge node to verify if it is connected to the network.

7.4 Data storage

Except for the food weight measurement in the food dispenser and the doghose temperature, the system will store the dog's data for ten years. The data from the food dispenser and doghouse temperature will be store only for 6 months.

7.5 Data processing

Before processing the data, the system will be verify the correct format of the information and review if there is data missed. We also will carefully review any duplicate value. Following the format for each type if data.

- Date: date format.
- Temperature: Celsius scale. Float format with two decimal places.

- Heart rate: BPM (beats per minute). Int format.
- Pressure: Float format with two decimal places.
- Play time: Minutes. Int format
- Food weight: Pounds scale. Float format with two decimal places.

7.6 Data analysis

- Smart Vest:
  Using the data from ultrasonic sensors, accelerometer, and gyroscope, we will report the number of times a dog collided with its environment per day, per week and then compare with the numbers to the previous week. We can also report the daily steps via the built-in pedometer in our IMU. Using the GPS module we will allow the user to set a safe zone, which when crossed by the dog will raise a notification. It will also allow the app to report the dog's previous location, and routes. With the temperature and the heartbeat sensor, the app will report max, mean, min and current temperature as well as heartbeats, this data will be used by our app to give insights on the dog's health. The pressure sensor is used for sleep monitoring, which combined with the heartbeat sensor can report accurate sleep times per day and average sleep hours per week. For an overview of the data flow process.

- Smart doghouse:
  Using the data from the all the doghouse sensors we can provide analysis on the amount of times the dog entered the doghouse and the amount of time spent resting. We can also provide analysis on the temperature changes throughout the day. The app will also report basic statistical data like min, max, average for both the infrared and the temperature sensor.

- Smart food dispenser:
  Using the data from the weight sensor and the set amount of scheduled feedings we can report the time until the user would have to refill (shipping time might be included if we can interact with the shipping company's API). We can also report the price of pet food within a timeline (weekly, bi-weekly, monthly, etc.) according to the user set dog food price.

- Smart dog toy:
  Using the data from the this device we can provide analysis on the amount of time the dog spent playing with the toy and for how long the dog was in front of the camera. We will also report the basic statistical data to the user.

8. Part list and cost

The following table consists of a list of items with their corresponding reference ID and cost:

Module	Device Reference	Price (USD)
Smart Vest		
GPS	Beitian BN-220 [3]	$21.11
Accelerometer + Gyroscope	LSM6DS3 [10]	$11.50
2x Vibration Motor	ROB-08449 [6]	$4.30
LED	COM-09590 [23]	$0.35
Battery	LIPO785060 [11]	$14.95
USB LiIon/LiPoly charger	MCP73833 [18]	$12.50
SparkFun Haptic Motor Driver	DRV2605L [8]	$8.50
4x Ultrasonic sensor (2 each leg)	HC-SR04 [19]	$12.28
Oximeter and Heart Rate Sensor	MAX30112EWG+ [13]	$8.94
Temperature Sensor	MLX90614 [14]	$8.56
Pressure sensor	SF15-130 [16]	$7.80
MCU + Wi-Fi	CC3235SF [5]	$4.53
		$115.32
Smart Dog House		
Petkit COZY + Eversweet Solo	[7]	$209.99
Smart Food Dispenser		
Petkit Fresh Element	[9]	$129.99
Smart Toys		
Petcube Play 2	PP20USMS [17]	$179.00
Gateway		
Xiaomi Router	AC2100 [22]	$79.69
Any cellular device	-	-
UPS		
CyberPower UPS	EC850LCD [1]	$72.95
Total		$778.25

Table 1. Parts list and Cost

9. Conclusions

The IoT system could be good opportunity to continue taking care of our pets. This integration of the smart dog vest, smart food dispenser, smart doghouse, and smart dog toy is a novel system that may improve a dog's overall health and quality of life.

There are many great opportunities in the IoT market for pet devices; however, the great solutions require a lot of work in addition to high research and development costs. It is more difficult to find a sustainable IoT solution for pets as their behaviour is overall different from humans and also different among breeds.

There is a lack of standardization between IoT devices. This is an issue that mainly handles interoperability between the systems and impedes the complete system's development.

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