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Development of internet of things based security robotic dog

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Abstract
This paper discusses the design and implementation of a smart IoT-based security robotic dog for intelligently monitoring surveillance. Traditional surveillance systems suffer from issues such as fixed observation points, blind spots, response delays and poor performance in harsh surroundings. In order to mitigate these drawbacks, a quadrupedal robot was designed, which integrates Arduino Uno microcontroller, ESP32-CAM module, ultrasonic sensors, servo motors and various wireless communication schemes. This robotic dog is designed for automatic movement, obstacle detection, environmental detection, video streaming to a web-browser and control of robot movement. An Arduino board serves as the main controller to maneuver the legs and operate sensors and the ESP32-CAM module is used to perform live video surveillance and provide wireless connectivity. Obstacle detection and the awareness of environment are controlled by ultrasonic sensors which allows the robot to navigate in its surrounding environment. The system was designed, assembled, programmed and tested to verify its capabilities. The experiment was successful and demonstrated that the robotic dog is capable of autonomously navigation, obstacle detection, live video stream and movement in response to sensor inputs. The system developed here proves that the merging of IoT technologies and quadrupedal robotics can enhance security monitoring. This proposed robotic dog offers an inexpensive and adaptable option to intelligently monitor and secure areas. Future work can be extended to incorporate artificial intelligence, cloud service and decision making functions in this robotic dog.

Keywords: Internet of Things (IoT), security robotics, robotic dog, ESP32-CAM, Arduino Uno, surveillance system, obstacle detection, autonomous navigation

Introduction

Background of the Study

In recent years, the field of robotics has dramatically improved by encompassing key computer science, sensoring and vision technologies (Culha *et al*. 2020) [1] and continues to grow as it is described as one of the most exciting fields in modern science (Berriozabalgoitia *et al*. 2020) [6] especially with advances in Artificial intelligence and robots finding their place in more areas than manufacturing, such as the health, educational and emergency services sectors (Dziubek *et al*. 2020) [12]. It is now more common to see robots as companions for their human owners and rescue robots working to support in emergency situations (Hagner-Derengowska *et al*. 2020) [17], and robots smaller than previously considered becoming key workers in logistics thereby increasing the convenience and comfort of every-day tasks (Timotius *et al*. 2021) [37].

Amongst the many types of robots, it is mobile robots which hold the most interest with numerous fields in the domain focusing their attention in this area as well as dedicating much of their research in a sector with a lot of potential (Kowalsky *et al*. 2021) [41]. One particular area that has drawn much attention is footed robots that are being developed to move across uneven terrain where wheeled robots are restricted. Such areas include forests, grasslands, disaster zones (Bailey *et al*. 2021) [5] and were robots would be able to navigate around terrain quickly to search and deliver supplies efficiently during crisis (Lee *et al*. 2021) [25]. The key defining feature of a footed robot is the distinct point like shape of its foot which enables it to maneuver efficiently across non-continuous and irregular surfaces and help to increase the safety and welfare of mankind (Agm *et al*. 2020) [2].

Footed robots can be categorized based on the number of legs available ranging from bipedal, quadrupedal and hexapodal robots (Lee *et al*. 2021) [25]. In comparison to bipedal robots, quadrupedal robots demonstrate more advantageous capabilities and attributes, including higher stability, adaptability of movement and improved payload capabilities (Kunha *et al*. 2020) [24], it is the quadrupeds that dominate most research and application based environments due to their comparatively less complex nature when compared to the hexa-legged and many other complex robots which makes them more straight forward to implement a reliable model for the robot's movement (Pea *et al*. 2022) [31]. Quadrupedal robots are also equipped to vary their speed and gait in accordance to their environment which results in various types of gaits to be implemented, including wave, diagonal and running gaits on smooth terrain, however the speed and gait selection will always be dependent on the nature of the surface and slope that it encounters.

Current robot literature predominantly involves the study of the individual gait mechanisms for quadruped robots focusing on the coordinated control of the limbs, foot path planning and also system stability with a number of predictive models such as the linear inverted-pendulum model and the virtual-limb model established (Ji *et al*. 2020). Various foot path plans such as elliptical and parabolic trajectories have been presented (Gieysztor *et al*. 2021).

This thesis addresses a gap within current literature whereby limited investigation into the biological fidelity of the systems and the transition from one gait to another has been performed with considerable more focus given to the individual gait control mechanisms. The concept of gait transition has proven to be particularly challenging to implement as it requires precise calculations for the movements between different gait types while still ensuring robustness and system stability.

Analysis of existing bionic quadruped robots demonstrates their movement limitations in relation to biological organisms, primarily due to their joint articulation. It is therefore proposed to implement a quadruped robot that is inspired by the anatomical and functional features of biological dogs to achieve stable locomotion considering appropriate limb coordination, and the development of reliable high, low and transitioning gaits.

The continued expansion of robotics has broadened its range of applications from industrial tasks to user companion technology. Engineering robots in the form of animals and particularly dogs poses unique engineering challenges, as well as providing a new mode of human robot interaction. The work presented here aims to develop a semi-autonomous robotic dog that has basic movements, can perform real-time video streaming and react to its environment using ultrasonic sensors.

Problem Statement

Limitations of traditional static surveillance systems arise from spatial coverage and access issues. Standard security cameras provide static fields of view that leave numerous blind spots where intruders can evade detection. They also have a limited range, and rudimentary remote-controlled robots are only as intelligent as the operator controlling them, thus making constant surveillance of large or complex spaces difficult (Culha *et al*., 2020) [1]. This difficulty is intensified when security is required for a large facility consisting of many buildings, outside grounds, or complicated terrain arrangements.

In cases of emergency such as security breaches, timely response is paramount to both avoid harm and contain damage. When security incidents arise, traditional security solutions will depend on human guards patrolling the grounds or dispatching guards after an alarm goes off. These systems inherently involve delays between initial detection of threats and response, which could be devastating in situations involving active intruders, fires, etc. Robots are increasingly integrating into the daily life as evidenced by the rescue robots employed in disaster situations (Berriozabalgoitia *et al*., 2020) [6]. Security situations are at their worst at night, and other low-light, low-visibility situations that make it impossible for humans to clearly see their surroundings. Traditional security measures rely on vigilant humans which are ineffective under these conditions, making these the prime time for criminals or trespassers to violate facilities as they have the highest likelihood of avoiding detection.

Despite training and motivation, humans are prone to natural limits on their cognitive abilities and physical endurance. Guard vigilance deteriorates when bored by the monotonous repetition of observation, the attention of a security guard can be distracted by any number of stimuli during long shifts, and fatigue coupled with potential for human psychological stress affect guard vigilance and ultimately security. Studies show that attention can fall significantly during repetitive monitoring tasks, with detection rates decreasing dramatically with increasing exposure (Bailey *et al*., 2021) [5].

The pressure to improve security while at the same time containing expenses is a common challenge. As described above, the cost associated with traditional security staff-salaries, benefits, training, the need for coverage-can be unsustainable, especially in a large facility needing a 24/7 guard staff. These costs often result in subpar security coverage or guard staffing, which could be reduced by robotic solutions (Dziubek *et al*., 2020) [12].

Aim and Objectives

This project intends to build an IoT based security robotic dog and then analyze the results.

Objectives

1. Design the chassis and mechanical structure of the robotic dog.
2. Assemble the chassis and mechanical structure of the robotic dog.
3. Make the connection between ESP32-CAM and the web interface for live video streaming and recording.
4. Implement the controlling of the robot from Arduino.
5. Test and analysis of results.

Justification of the Study

This study provide a broad and thorough investigation on robotic technology that integrates computer, sensing and vision technology, which represents one of the frontiers of the development of the sciences and technology (Culha *et al*., 2020) [1]. The scope of robot researches in this work also has the tendency to enlarge from the conventional application in the industry field to those new application fields like biomedical science, educational service, exploration, and search-and-rescue. The particular interest of the quadruped robots is due to the importance of their ability to locomotion on complex terrain that wheels and track robots could barely move, such as forest, grass, disaster and so on. Compare to biped robot, quadruped robot possesses steady locomotion, variety in movement and stronger bearing capability (Kunha *et al*., 2020) [24]. This work proposes a combination of Arduino controlled system and ESP32-CAM for real time live streaming of the video and Ultrasonic Sensors for automatic movement and human detection, a valuable improvement in security technology.

Literature Review

1. Evolution of Robotics Technology

As part of computing, vision and sensing technologies, robotics are considered one of the most influential scientific fields currently (Culha *et al*., 2020) [1]. Advances in computing and the development of AI speed up advances in robotics leading to applications in different fields, such as education, disaster response or health care (Berriozabalgoitia *et al*., 2020) [6].

Today robotics are all around us. A robotic dog can go for a walk with his owner or even a robot designed to locate victims during disaster circumstances and transport supplies can enter the site of the disaster (Dziubek *et al*., 2020) [12]. Other types of robots are specifically created for packages and cargo transportations (Hagner-Derengowska *et al*., 2020) [17].

2. Related Studies

The implementation of the Internet of Things (IoT) has impacted a number of industries including security by enabling intelligent devices to be connected with their surroundings (Atzori *et al*., 2010) [4]. One specific implementation in the security industry of IoT, is to develop intelligent security robotic dogs which leverage the characteristics of mobile robotics coupled with real-time connectivity.

Research has previously studied and used IoT to implement in security robots; Kim *et al*. (2018) [22] developed a surveillance system on the robotic platform using IoT technologies and highlighted the capability of the robotic platform to monitor and respond to surrounding dangers. Chen *et al*. (2020) [9] developed a security robot that could navigate autonomously within the environment while detecting unusual activities.

Specifically in robotic dogs, IoT technology has been used to enhance the robots sensing capability and real time communication. Li *et al*. (2019) presented a robotic dog able to detect and sense potential dangers such as hazardous gases and intruders. Zhang *et al*. (2022) [44] developed a quadruped robotic dog and provided it with IoT capability for enhanced interaction and autonomy within its environment in real-time.

Incorporate IoT within the security robot framework is expected to enhance awareness and responsiveness to the surrounding environment (Gungor & Hancke, 2009) [16] for varied security purposes such as surveillance, and quick emergency responses.

Wang (2021) [41] analyzed motion planning approaches for quadruped robots to navigate over obstacles so the robot would be able to navigate itself within the environments regardless of obstacles, establishing a set of guidelines that quadruped robots must be able to satisfy. Gao *et al*. (2022) [14] implemented visual and LiDAR-based precise localization in environments without GPS. Miki *et al*. (2022) [29] explored how the movement behavior of quadruped robot could be adapted by a deep learning approach and applied to achieve high-performance navigation of uncertain environment. Sheng (2022) [35] discussed rhythmic motion control strategy for quadruped robots and Liu (2022) [28] discussed optimal gait planning of quadruped robots to maintain stable locomotion. Xu *et al*. (2019) [42] proposed analysis on the leg movement of quadruped robots based on the walking pattern of human beings and animals.

Su *et al*. (2024) demonstrated how an AI-enabled robotic dog could accurately and quickly detect invasive species much better than human inspector does. Yang et al. (2021) [43] develop an unified system of vision-guided quadrupedal movement, which could effectively integrate perception and control. Owoeye *et al*. (2023) [30] explored the use of deep learning for robotic surveillance, enabling robust object detection and tracking. Bledt *et al*. (2018) [7] proposed MIT Cheetah 3, which can achieve advanced rough terrain navigation capabilities. Different research projects on home surveillance robots were also introduced in (Efe & Ogunlere, 2020[13]; Dhakolia *et al*., 2023), which provide context for various quadruped applications. Tang *et al*. (2023) [30] developed a language-based interaction system for quadruped robots that is user friendly through natural language translation (SayTap). Hoeller *et al*. (2021) [18] developed an end to end system to guide robot in clutter environment, which can be important in robot application like security robot.

3. Mobile Robots and Footed Robot Systems

Mobile robot is an important technology of robotic field and receives great attention from many research institutes all over the world due to their wide applications (Timotius *et al*., 2021) [37]. Within the domain of mobile robots, footed robots have gained increasing interest.

Footed robots are indispensable for navigating in about half of the natural terrain regions such as forest regions and disaster regions, since wheeled robots can't navigate in such terrains (Kowalsky *et al*., 2021). Those terrains will require assistance, and footed robots are better for terrain adaptation and are getting more and more indispensable in promoting human services and lives (Lee *et al*., 2021) [25].

4. Quadruped Robot Advantages and Applications

Robots are defined by the number of legs and quadruped robots are a common one (Agm et al., 2020) [2]. Robot types of this configuration provide a number of advantages over their alternatives. In comparison with bipedal robots, quadruped robots offer improved stability, flexibility and payload capacity. Compared to hexapedal robots, quadruped robots have simpler designs, hence have become popular in the field of robotics for research and applications. This type of robots are capable of changing its gaits to suit a particular environment or speed requirement. Ground slope and terrain type are factors that will impact on what walking method is chosen for particular circumstances.

5. Bionic Design Principles

Walk gait is the basic way to walk and the most often seen gait for quadruped motion. The walk gait involves a regular and systematic locomotion pattern, and remains stable by keeping three legs on ground when one leg is swinging, enabling its center of mass be in equilibrium state during slowly moving forward and the fluctuation of its center of mass being minimal vertically (Hagner-Derengowska *et al*., 2020) [17].

The body shapes, structure and motion patterns of creatures are perfectly developed through evolutionary mechanism, and achieve optimum state of being utilized in the nature environment (Timotius *et al*., 2021) [37]. As an animal that has perfect body shape and locomotion pattern, Bionic Quadruped robots can present similar walking behavior like creature. A common domestic dog is ideal for this topic in that it is easy to find it and observe its behavior. (Kowalsky *et al*., 2021).

6. ESP32-CAM Technology for Robotic Vision

Robotic dogs have gone from very simple designs where they would simply walk on an incline, to modern, AI powered, robots (Wadekar *et al*., 2016) [40]. A lot of modern designs use the ESP32 micro-controller, to handle tasks such as inverse kinematics, and create web based control systems, making use of the integrated Wi-Fi connectivity (Vijaykumar & Ramya, 2015) [38].

The ESP32-CAM is one of the inexpensive, and effective ways, of being able to achieve live streaming for a project that is based in the IoT domain. The module is capable of being a web server where it is able to stream live video over a Wi-Fi network, to be accessed from a web browser on any device (Shah, 2017). The ESP32-CAM includes the ESP32-

S system on chip (SoC), which is essentially a micro processor along with memory and storage in one component, which then uses the expansion board to build upon the capabilities by including a 2 megapixel camera (OV2640), built-in Wi-Fi and Bluetooth, general purpose inputs/outputs, and a micro SD card reader to store data (Amatulla *et al*., 2017) [3].

7. Sensor Integration and Control Systems

One of the classic applications of incorporating ultrasonic sensors to servo motors to detect obstacles is a cornerstone of robotics (Reza *et al*. 2014) [33]. This application involves timing the reflected sounds that reach an ultrasonic sensor upon impact with an object and converting the time to an object distance, to be translated to either robot orientation control (servo motor orientation or overall direction). (Javanmard *et al*. 2013) [20]. In this specific project the robotic interface will be implemented with a common Arduino Uno with an ATmega328P microcontroller. Arduinos are common with robotics beginners because the Arduino Integrated Development Environment (IDE) is simplistic enough to understand (it is similar to C++ in terms of coding) but capable enough of more difficult tasks. The Arduino's openness and standardized hardware has allowed it to become the model for robotics education and DIY projects. (Bailey *et al*. 2021) [5].

8. Power Management in Mobile Robotics

Due to its advantages over other rechargeable battery technologies, such as higher specific energy, better energy density, better efficiency, longer life cycle and a much better long term use compared to the rest, lithium-ion battery technology has become the most popular standard for the usage on the mobile robotics systems. These batteries work by reversibly intercalating lithium ions into conductor materials for energy storage (Lee *et al*., 2021) [25]. The regulation circuits, for example the DC-DC boost converter, such as the one built around the MC34063A IC enable higher voltages from lower battery voltages in order to be capable to power those components of a multi-components robot that require such a power. For the charging part, separate regulation circuits, such as the one built around the TP4056 module provide constant current and voltage charging to lithium batteries with integrated protection against overcharging and short-circuit (Agm *et al*., 2020) [2].

Materials and Method

1. ESP32-CAM for Video Streaming

The ESP32-CAM is an affordable way to add live streaming video capabilities to many types of IoT projects. It is very small and it is able to quickly host a web server which streams live video over Wi-Fi, to be watched on any web device with a web browser. This makes it practical for a very wide range of surveillance and robotics projects and the module itself has a great deal of utility for this purpose. The chip which underlies the ESP32-CAM is the ESP32-S System-on-Chip (SoC) designed and manufactured by Ai-Thinker. The ESP32-S is actually a very sophisticated device as it contain an entire computing system, the processor and ram, storage and other parts, on a single integrated chip and the dev board added to this gives an even more fully equipped system.

Fig 1: The ESP32-CAM

As depicted in Figure 3.1 the ESP32-CAM is a small and portable camera module which is running on the ESP32 microcontroller along with an OV2640 image sensor, enabling the module to produce high-quality images and stream videos smoothly along with variety of image processing tasks that can be accomplished. With its integrated Wi-Fi and Bluetooth technology it has great advantage over other modules in an IoT application such as for the security surveillance.

The basic components of the ESP32-CAM are listed below:

1. ESP32 microcontroller for computation.
2. OV2640 2Megapixel camera sensor.
3. Wi-Fi and Bluetooth support for connectivity.
4. GPIO pins to interact and connect with other hardware.
5. Micro SD card support to store data locally and for further image processing.
6. 5V DC power for its working.

To work with ESP32-CAM module the basic know-how of programming, especially programming the microcontroller using Arduino IDE is important as we have used Arduino IDE for this purpose, and basic knowledge about electronics like for connecting wires to GPIO pins. The ESP32-CAM module can be used in various creative projects, ranging from the smart security camera to a car controlled remotely with an added camera on it, and a face recognition system. Its small size and powerful processing capabilities makes it a widely used component among makers.

2. FTDI Programmer

The FTDI programmers are a collection of devices to program and communicate with other electronic devices using an FTDI chip for the USB communication, aFTDI programmer is illustrated in Figure 3.2 and usually includes an FTDI USB-to-serial converter chip and a pin header to connect with the device under test.

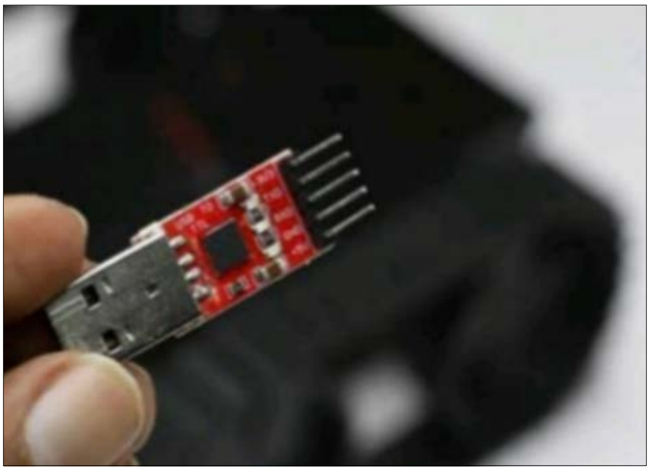

Fig 2: FTDI Programmer

FTDI programmers are common in programming and debugging microcontrollers using such architectures as Atmel AVR and Microchip PIC. In addition they can also be used in GPS receivers, data loggers and a number of other electronics systems where a USB-to-serial interface is desired. Asides from providing a simple USB-to-serial interface, FTDI programmers often include optional features such as voltage regulation and programmable clock sources. In essence they are an essential electronic tool used for programming and communication..

The pin configuration of an FTDI programmer:

The pins available on FTDI chips or on the programming board or cables are usually defined by a standard 6-pin connector, which is often called an FTDI cable or FTDI header. The pinout of this cable or header is described below:

1. Data Terminal Ready (DTR)
2. Receive Data (RXD)
3. Transmit Data (TXD)
4. Voltage Supply (VCC)
5. Clear to Send (CTS)
6. Ground (GND)

Each pin's definition can be explained as follow:

1. DTR is the Data Terminal Ready pin, which is used to reset the target or microcontroller before uploading new code into the target or microcontroller.
2. RXD is the Receive Data pin, which is responsible to receive data coming from the target to the programmer.
3. TXD is the Transmit Data pin, which is used to send data to the target from the programmer.
4. VCC is the power supply to the target device; this is usually a 3.3V or 5V power supply, the output voltage on VCC will be either 3.3V or 5V depending on the specifications of the programmer and the target.
5. CTS is Clear to Send pin, used in flow control to tell the target whether the programmer is ready to accept data or not.
6. GND is the common ground for the programmer and the target device.

It should be noted that the order of these pins on an FTDI programmer or cable could be slightly different for some specific models, so it would be necessary to consult the specifications of your FTDI programmer or cable for accurate connections.

3. Ultrasonic Sensor and Servo Control

Fig 3: Ultrasonic sensor and Servo Control

The use of ultrasonic sensors along with servo motors to avoid obstacles is quite common in the robotic applications. The idea is basically to use sound wave reflection for finding the distance from nearest object. Ultrasonic sensor produces sound waves that are reflected by the object and reaches back to the sensor. By measuring the time taken to produce an echo from object, distance to that object can be found out using the velocity of sound. The obtained distance information is then used to decide on a particular course of action. For example if an object is within certain distance range it can be instructed to drive a servo motor for steering, reversing or by any means for an alternative path.

4. Arduino UNO

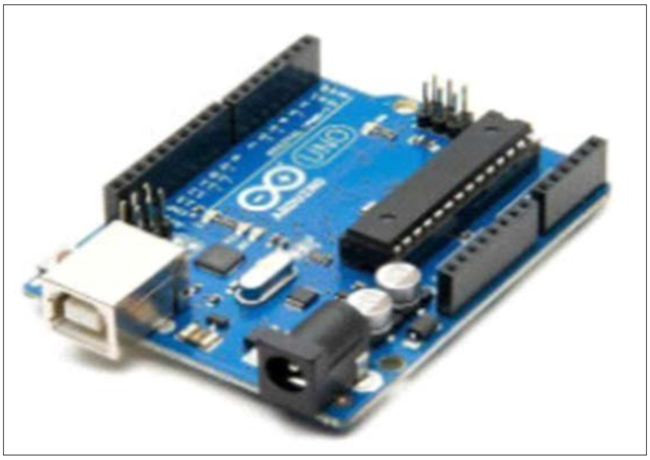

Fig 4: Arduino Uno

The Arduino Uno is an easy to use and low cost microcontroller board that comes with all the necessary components to support the function of the microcontroller. This small board can be powered either using a USB cable connecting to your computer or using a AC-to-DC adapter or battery which means that once you plug it in, it's good to go and there are not many complicated steps needed to get the microcontroller running, allowing users to experiment freely with their projects without fear of breaking anything, because they can just replace the microcontroller chip if they mess anything up.

The Uno is named "Uno" which is Italian for "one" and is a symbol of the fact that this was the first board to be released at the same time that the Arduino Software (IDE) version 1.0 was released. It also serves as a point of reference in the design of new Arduino boards based on USB ports and is the fundamental Arduino board among USB boards, and Arduino itself, is a very popular open source electronics project which consists of both the physical programmable circuit board (often called a microcontroller) and a piece of software, called the Integrated Development Environment (IDE), that runs on your computer. The IDE is used to write and upload code onto the physical board. The language used for programming the board is a simplified version of the C++ programming language, which will be a lot simpler to use for beginners. Arduino also has a standard form factor that separates the many functions of the microcontroller from the microcontroller itself and spreads them out onto the board so that they are easily accessible.

Table 1: Arduino Uno Specifications

Name	Specification
Microcontroller	ATmega328P
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Digital I/O Pins	14 (of which 6 provide PWM output)
PWM Digital I/O Pins	6
Analog Input Pins	6
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328P) of which 0.5 KB used by boot loader
SRAM	2 KB (ATmega328P)
EEPROM	1 KB (ATmega328P)
Clock Speed	16 MHz

In circuit designing, sometimes the input power supply available does not fulfill the voltage necessity of some electronic components. As when there is a shortage of a high input voltage like 9 or 12 V and the input available is 3 V dc then there arises the need of a boost converter. A boost converter is defined as the circuit which is specifically designed to step up a lower input dc voltage to a higher output voltage which can be supplied to the device which demands for that higher voltage. As the conversion from AC to DC is well established; the DC to DC converter which converts from a lower voltage to higher voltage poses another problem. In this project, we are using the "DC-DC Boost Converter using the MC34063A" to perform this function.

5. TP4056 Module

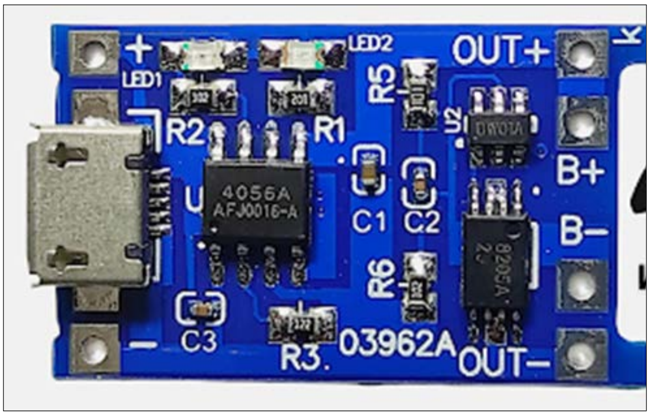

Fig 5: TP4056 Module

TP4056 module: It's a constant-current-voltage linear charging circuit suitable for single 3.7V Lithium cell. This module allows a monitor of the voltage of Li-Ion or Li-Polymer cells in both the charge and discharge processes, while also providing reliable over charge and short-circuit protection. TP4056 module operates at a DC 5V 1A voltage, which normally works via USB A to Micro B cable, the same used in smart phone adapters. It doesn't require much external component, and that makes the TP4056 module suitable for portable electronic devices.

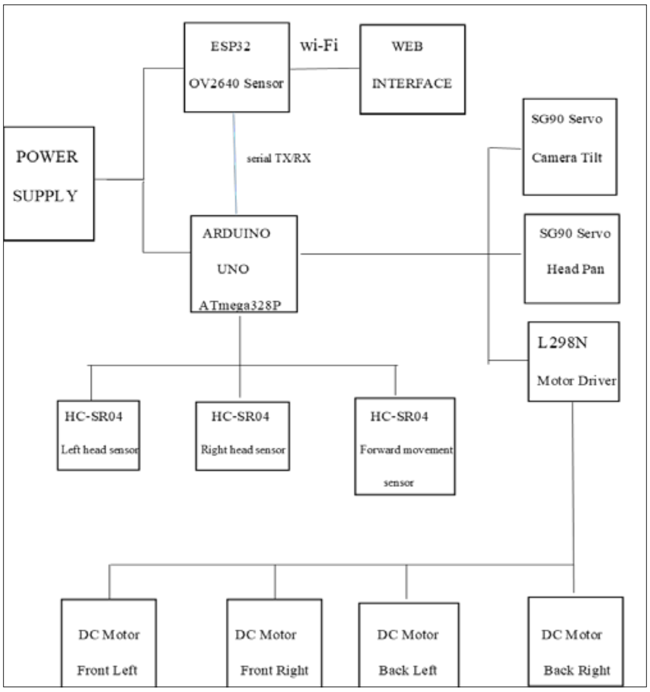

Fig 6: Block Diagram

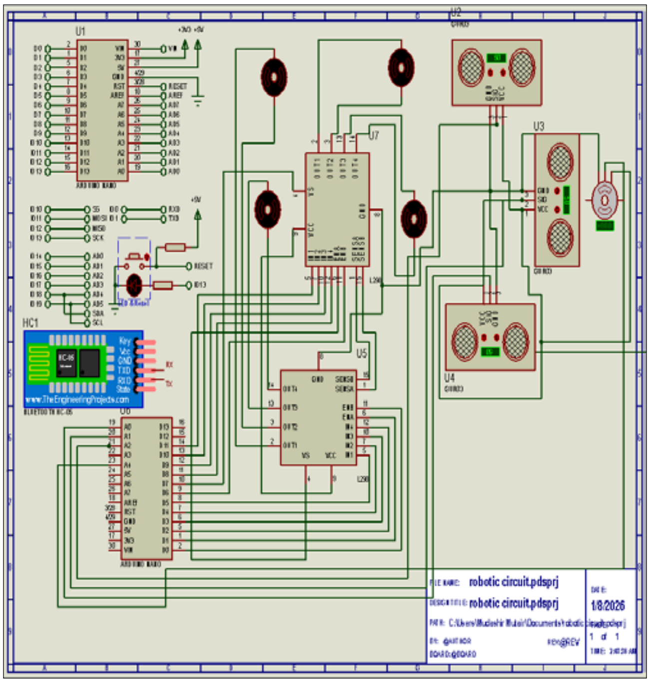

Fig 7: Circuit Diagram and Connection

6. System Architecture

This is a complex system with 3 ultrasonic sensors, 3 servo motors, an ESP32-CAM and an Arduino UNO working together. The ESP32-CAM acts as a web server for video streaming and the Arduino UNO controls all sensors and motors. Communication is between two micro controllers and can be implemented by serial or digital interface.

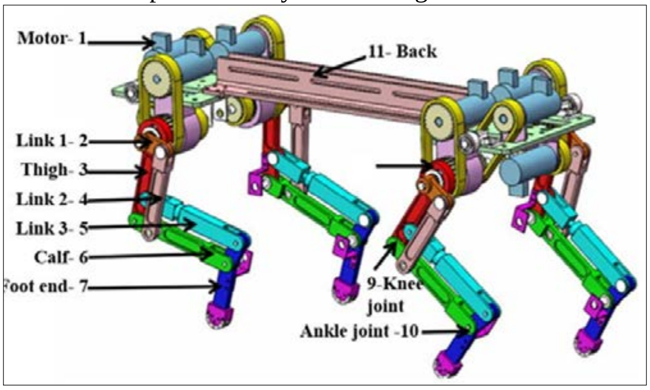

Fig 8: Mechanical Structure of the Robotic Dog

7. Hardware Assembly

The chassis of the project was built using 3D-printed components where it was made sure that the sensors were position to give a high detection rate for the ultrasonic sensors. All servos were secured to place and wires connected in accordance to the original wiring diagram.

7.1 Robot Chases Construction

Here are details of the complete building of an object detecting robotic dog, with a quadruped configuration driven by Arduino and an ESP32-CAM. The robot is built to do the following:

"Chase" behavior via four DC geared motors for the purpose of motion.

- Three ultrasonic sensors (forward mounted, and two mounted on a swiveling head) are implemented for the purposes ofobstacle detection.
- An ESP32-CAM which serves the dual purposes of real-time streaming of video footage and simple object recognition.
- Four DC gear motors, L298N motor driver, two SG90 servo motors (one for head pan, and another for camera pitch), and other actuators were used as part of the system.
- Power components include a lithium battery pack, as well as DC-DC boost converter to achieve a desired voltage level.
- There is a lithium-ion battery (eg 7.4V pack), DC-DC boost converter module (eg XL6009) and MB102 breadboard power supply module or other 5V regulator module.
- Structural components included the chassis/leg mechanism, which was 3D printed/laser cut as well as wiring components and breadboards.
- To communicate with the ESP32-CAM initially when uploading code, one requires an FTDI programmer.

7.2 Leg Mechanism for "Chase" Movement

In order to have smoother, more life-like motion, inverse kinematics is used by the robot. To perform logic with only 4 geared DC motors with regard to the movement "chase," there can be two options:

7.2.1 Trot Gait (Simplified): With the robot's legs moved in diagonally opposite pairs, 2 groups of legs move together at once.

- To move forward, both diagonally opposite leg pairs (say, the left-front with right-rear, and the right-front with left-rear legs) are simultaneously powered forward.
- The robot can turn left or right by slowing down or delaying the rotation of one pair of leg diagonals while powering the other pair forward, causing it to pivot about the left or right sides.

7.2.2 Differential Steering (Wheeled): If the robot is equipped with wheels on the robot chassis, it can use the same four geared DC motors for differential steering.

- **Forward Movement:** All motors are powered forward.
- **Turn Left:** The left two motors are powered backward while the right two motors are powered forward.
- **Turn Right:** The right two motors are powered backward while the left two motors are powered forward.

8. Software Implementation

8.1 Arduino IDE

This IDE is compatible with three of the operating systems in today's world: Windows, OS X, and Linux, and has the purpose of making the programming of any Arduino boards much simpler. These boards and programming language have been built based on a C and C++ based structure. Using the IDE, a programmer may design and load a program onto any available development board. Such a board as the one of the more commonly used, a NodeMCU ESP8266. This microcontroller is capable of performing functions using Wi-Fi, the firmware of this controller utilizes the XTOS based system, utilizes Lua script, and is run by the ESP8266 CPU at a cost of 4 Mbyte memory and 128 Kbyte RAM. This controller is commonly powered by connecting it through a USB cable.

8.2 Arduino (Main Controller)

The Arduino was written for the basic control logic for the robot. The ESP32-CAM was programmed for the example web camera server within the Arduino IDE. Calibration and communication was setup so all components would work together.

1. **Setup phase:** In this phase serial communication is setup and the motor driver pin(s), servo pin(s) and ultrasonic sensor pin(s) are defined.

2. **Loop phase:** Data collected from all three ultrasonic sensors are taken and put through. Data is compared using the forward-most ultrasonic sensor in order to detect obstacles. Once an obstacle directly ahead is encountered the robot will proceed to continue moving forward. The side ultrasonic sensors are then used to discover a pathway by rotating the ESP32-CAM head back and forth and the robot will turn toward the path that is open. If an obstacle is encountered then the command will be set to the motors to continue going forward.

8.3 ESP32-CAM (Visuals and Advanced Control)

1. Setup Phase: Establish Wi-Fi connection, configure camera settings and run a web server to stream video.
2. Loop Phase:
3. The module constantly streams video and is capable of running basic object detection on-board processing

capability. If a command comes through the serial port of ESP32-CAM from the Arduino, it is capable of running such action like capturing an image, stating the status of camera.

Testing and Results Analysis

1. **Individual testing:** Servo motors and Ultrasonic sensors were tested individually for functionality and calibration.
2. **Movement Test:** The heads of robotic dog moved left and right as expected upon reception of signals from side ultrasonic sensors. The frontal sensor activated forward movement correctly upon detection of person.
3. **Video Stream Test:** ESP32-CAM setup resulted in successful creation of web server where video stream can be access by a web server.
4. **Performance Analysis:** The combined system worked as expected; this has proven the concept of combining the system is effective. Problems found during system performance tests were the limited battery life and possibility of video lagging.

Conclusion and Recommendations

Conclusion

An Arduino was well incorporated with an ESP32-CAM in this project to build a robotic canine which can live-streaming video and smart move according to ultrasonic sensor reading. This robotic dog can track and respond to its environment efficiently, setting up a solid framework for subsequent expansions.

Recommendations for Further Study

- **Single Microcontroller:** If it would be feasible to consolidate everything to a single ESP32 this could greatly simplify the architecture by eliminating all of the intra-microcontroller communications issues that would be incurred with more.
- **Advanced Gait:** This project would benefit from a more complex inverse kinematics model for the robotic walk that allows for more natural walking patterns instead of just simply walking forward.
- **Better Person detection:** Integrating advanced image processing techniques with the ESP32-CAM could give an improved system for person detection by not just using the forward facing ultrasonic sensor.
- **Cloud Connectivity:** The ESP32 could connect to the cloud service Firebase so that the user would have control and information about the robotic dog remotely.

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