Design and Implementation of a Semi-Autonomous Quadruped Assistive Robot for Remote Elderly Monitoring and COVID-19 Response

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ABSTRACT This paper presents the design and development of an assistive quadruped robot capable of autonomous or semi-autonomous interaction in healthcare settings, with a focus on elderly care and infectious disease environments. The robot leverages low-cost, off-the-shelf components—including an ESP32-CAM module [1] for real-time vision, an MLX90614 infrared sensor for thermal sensing [2], and MG90S micro servos [3] for locomotion—demonstrating that affordable hardware can support autonomous healthcare robotics applications. The system supports multiple functional modes, including autonomous follow mode, manual control, and measurement of body temperature at a safe distance. The server-side interface allows the user to view real-time video, control the robot, and monitor live health-related data. Three key implementation aspects were demonstrated to validate the system's usability: UART-based inter-device communication [4], modular hardware design using 3D printing [5], and a custom-designed printed circuit board (PCB) developed using KiCad [6] to integrate the ESP32 chipset [1], camera, distance sensor, and MLX90614 temperature scanner [2] into a small form factor—while enabling the user full control of the robot; and automatic object tracking of our reconnaissance model in a compact form factor using TensorFlow Lite [7]. The prototype demonstrated strong capability both as an indoor robot, with a modular design that allows it to be reconfigured and used for broader and alternative use cases, including pandemic monitoring and remote elder care. This research project advances low-cost utilization of assistive robots intended to improve healthcare safety and quality of living. By directly addressing urgent need for accessible and affordable healthcare technology, this work contributes to the public good by expanding the reach of advanced care solutions to broader communities.

INDEX TERMS Assistive Robotics, Elderly Care, COVID-19, ESP32-CAM, MLX90614, Arduino, 3D Printing, UART Communication.

I. INTRODUCTION

The emergence of intelligent robotic systems, driven by an aging population and epidemic or pandemic medical challenges, is increasingly influenced by the growing applications in healthcare and domestic assistance technologies. Assistive robots, defined as autonomous or semi-autonomous machines designed to support human well-being, have become an important and emerging technology for enabling elderly and vulnerable individuals to live more safely and independently [8].

A primary objective of assistive robotics is to facilitate real time monitoring, support and interaction in environments that have limited or hazardous human presence. The COVID-19 pandemic demonstrated the urgency for deployable systems that reduce interactions between individuals while simultaneously maintaining critical services, such as temperature monitoring and health surveillance. The proposed quadruped robot directly addresses this need by enabling contactless body-temperature screening and remote visual monitoring, thereby reducing caregiver exposure while ensuring continuity of essential health services. Moreover, the need for monitoring and remote caregiving systems for older adults living independently at home has increased.

This research presents the design and implementation of a quadruped assistive robot incorporating vision processing, wireless communication, and temperature sensing. The robot's hardware and software include mechanical, electronic, and software components to perform intelligent functions, including visual detection of human subjects, automated following behavior, body temperature measurement via a non-contact infrared sensor [2], and user-controlled manual navigation. The system is intended to operate in domestic or semi-clinical contexts for preventive and responsive applications.

Unlike surveillance or telepresence robots, this prototype is modular, relatively low-cost, and capable of operating with minimal human guidance, incorporating a degree of onboard intelligence. The system is powered by an ESP32-CAM microcontroller [1] featuring Wi-Fi and camera capabilities, enabling video streaming and AI-based object detection [7]. The ESP32-CAM communicates with an Arduino Pro Mini microcontroller [9] that drives the servo motors and interprets movement commands issued to the ESP32-CAM [1]. All components are biomechanically connected to a custom-designed PCB [6] and housed in a 3D-printed quadruped chassis [5] to provide greater utility and mobility.

The robot operates in three modes: (1) Auto-Detect – autonomously follows a person detected via computer vision; (2) Manual Control – allows the user to remotely control the robot through a web interface; and (3) Temperature Check – detects a person within a defined range and estimates their body temperature, which is transmitted to the server. These modes collectively enable (a) support for elder care and (b) contactless COVID-19 screening.

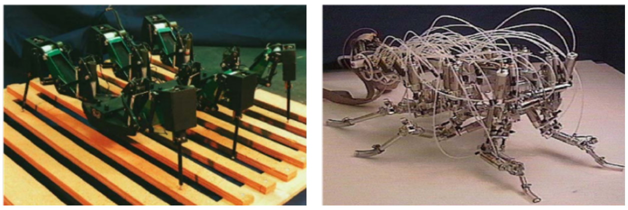
This paper is organized as follows: Section II presents the relevant literature and introduces essential technologies in assistive robotics; Section III outlines the hardware and software structure of the proposed system; Section IV describes the implementation process, including the mechanical design, PCB development, and software modules; Section V discusses the experimental results and performance characteristics; Section VI highlights the system's limitations and suggests directions for future work; and Section VII concludes with broader implications of the study.

II. RELATED WORK

Over the past two decades, the assistive robotics sector has made substantial advancements, particularly in areas driven by technological advancement. Embedded systems, comprising the core hardware platforms of robotic applications, have substantially progressed. Additionally, artificial intelligence and sensor fusion technologies have matured and are now widely adopted in autonomous and assistive robotic systems. Significant strides in mechatronics have likewise facilitated fine-grained, compliant control, which is essential for ensuring the safety and precision of human–robot interaction, particularly in humanoid and adaptive technology. Together, embedded systems, AI-driven sensor fusion, and advanced mechatronic control form the technological foundation of modern assistive robots. These systems support individuals with serious disabilities, assisting them in live more independently and safely, whether due to limited mobility, cognitive impairments, or chronic medical conditions. In this section, we review prior research and progress related to the proposed system, specifically in the areas of quadruped robots, visual tracking systems, and temperature sensing.

A. BIOLOGICALLY INSPIRED LEGGED ROBOTS

Historically, preliminary research regarding legged locomotion focused on replicating biological systems to enhance agility and adaptability. For instance, the CWRU III hexapod robot, developed by the engineering team at Case Western Reserve University, was influenced by insect locomotion and driven by double-effect pneumatic cylinders to preserve firm stable posture [10]. Two versions of CWRU hexapod robots illustrated in FIGURE 1(a) and FIGURE 1(b). Such developments have spurred interest in creating quadruped robots that combine mechanical stability and adaptability to interact with uneven terrain.



(a) CWRU II (b) CWRU III

FIGURE 1. Two versions of CWRU hexapod robots.

More recently, HyQReal, a hydraulic quadruped robot developed by the Dynamic Legged Systems Lab at Istituto Italiano di Tecnologia (IIT), exhibited remarkable strength by pulling a small passenger aircraft while maintaining dynamic balance and mobility over varied terrain [11], FIGURE 2. In addition, a new generation of quadruped robots is exemplified by Boston Dynamics' Spot robot and Ghost Robotics' Q-UGV have also demonstrated autonomous navigation, environmental mapping, and remote surveillance—capabilities that represent an initial step toward performing assistive functions in unpredictable environments [12, 13].

(a) HyQReal *(b) Q-UGV*

FIGURE 2. Quadruped robots.

B. Vision-Based Human Detection and Tracking

Vision-based systems act as a primary sensory data source for robots to develop spatial awareness and act upon it. The fusion of real-time video processing, object detection, and human-tracking algorithms has enabled service robots to follow, understand gestural cues, and provide spatial awareness.

The ESP32-CAM is a low-cost yet capable microcontroller for edge facial recognition applications [1]. It can run lightweight, computationally efficient convolutional neural networks (CNNs) using TensorFlow Lite to detect and track human users in real time [14, 7]. UART communication with a motion controller enables distributed control on low-power embedded platforms—an essential feature for mobile assistive robots [4].

Boston Dynamics' Spot robot is among the largest robots used in underground and hazardous environments, where it autonomously navigates and maps its 3D surroundings using onboard lidar, visual, and thermal sensors [15]. While robots like Spot are prohibitively expensive for home applications, they have inspired downscaled systems like the concept presented in this paper.

C. Temperature Sensing for Healthcare Applications

Temperature sensing has emerged as an essential capability within healthcare monitoring systems, gaining particular significance for non-contact screening protocols enacted during pandemic responses. The MLX90614 is a contactless infrared (IR) digital temperature sensor [2] that can be utilized to measure the temperature of a particular object with sufficient accuracy and safety, ranging from -70°C to 382.2°C. With its I²C interface [16], the device facilitates straightforward incorporation into mobile robotic systems, providing continuous monitoring without the need for physical contact [2]. Responding to the exigencies of the COVID-19 outbreak, mobile platforms outfitted with thermal cameras were distributed across transit hubs and healthcare facilities to screen for elevated body temperatures, thereby protecting medical personnel. The robotic platform described herein combines contact-free thermal sensing and visual tracking capabilities, responding to these urgent operational demands and striving for wider adoption by leveraging open-source software and off-the-shelf electronic components.

D. Low-Cost Robotic Platforms and PCB Integration

Open-source hardware initiatives have dramatically reduced the financial and technical obstacles previously associated with robotics experimentation. By leveraging Arduino-compatible microcontrollers alongside commercially available sensors and actuators, teams can create fully operational prototypes within constrained budgets. When these electronics are paired with 3D-printed structural parts and custom printed circuit boards designed in KiCad [6], the resulting platforms are modular and readily replicable, permitting straightforward adaptation to varied research objectives. Reference [6] presents a quadrupedal prototype that employs Arduino Pro Mini [9] and custom printed circuit boards to investigate diverse gait-generation algorithms. The current research follows a similar paradigm, embedding a self-fabricated PCB that centralizes power regulation and signal routing among servomotors, environmental sensors, and the principal processing unit, thereby enhancing the robustness and responsiveness of the locomotion system.

E. Comparison with Existing Quadruped Platforms

Table 1 provides a comparative overview of the advanced quadruped robotic systems described in the text alongside the proposed design. While systems like HyQReal [11] and Q-UGV [12] have advanced perception modules and greater gait versatility, their high acquisition and maintenance costs, complicated operational protocols, and limited adaptability strongly constrain their use in the healthcare and in-home assistive contexts. On the other hand, the open-source robotic prototypes greatly lower costs, but their subpar advanced embedded sensing, environmental interfacing, and overall system reliability hamper their applicability. The articulated result here proposes a design which incorporates additional advanced assistive application specific sensing and control components, thus bridging the gaps presented by proprietary systems.

Unlike commercial platforms such as Spot [15] and HyQReal [11], which cater to high-end robotics applications due to their complexity and cost, the proposed quadrupedal robot design is an affordable prototype intended for healthcare-related functions such as elder care and pandemic screening. Its construction from off-the-shelf parts, custom PCB designs, and the modular 3D-printed body provides a refined balance of cost, multifunctionality, and specialization as compared to institutional-grade robotics or ad-hoc designs from the hobbyist community. In particular, the inclusion of advanced features, for example, thermal sensing, distinguishes this system from other low-cost frameworks, expanding the scope of functions usually found lacking in high-cost commercial robots and basic hobbyist versions.

TABLE I. Comparison of Quadruped Robotic Platforms

Robot	Quantity	Key Features	Primary Use Case
HyQReal [11]	Very High	Hydraulic actuation, dynamic balance, high payload	Research, industrial tasks
Spot (Boston Dynamics) [15]	Very High	Autonomous navigation, lidar, vision, remote surveillance	Security, inspection
Ghost Robotics Q-UGV [12]	High	Rugged design, modular sensors, autonomy	Defense, field operations
Open-Source Quadruped [5]	Low	Arduino, Bluetooth, basic gait	Hobbyist, education
Proposed Quadruped (this work)	Low	ESP32-CAM vision, MLX90614 thermal sensing, dual-microcontroller PCB, modular 3D-printed chassis	Elder care, contactless screening, domestic robotics

III. System Architecture

The suggested helpful robot has a modular quadruped foundation, designed to find and trail human subjects. The body temperature of the human subject is measured and sent, along with real-time video data, to a server for easy access. The system has three major parts: hardware, software, and communication protocol. Each subsystem is designed to operate under tight power and processing budgets, maximizing real-time responsiveness and reliability for assistive tasks.

As shown in FIGURE 3, the system architecture is divided into two main processing units: the ESP32-CAM for vision processing and head control, and the Arduino Pro Mini for leg movement and temperature sensing. These microcontrollers communicate via a UART protocol, coordinating sensors and actuators for seamless robotic behavior.

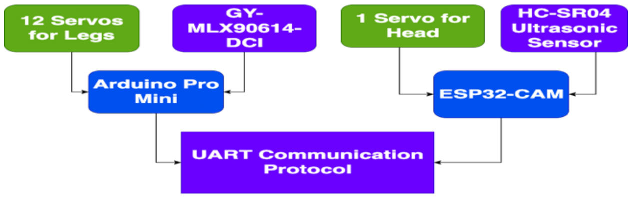


FIGURE 3. Block diagram of the proposed assistive robot system.

A. Hardware Architecture

Component selection prioritized commercial availability, minimal energy draw, and seamless integration with open-source ecosystems. The principal hardware elements comprise:

1. Microcontrollers:
   - ESP32-CAM: Acts as the system's cranium for vision processing and Wi-Fi communication. It contains the web interface, executes object detection models, and sends live video streaming to remote clients [1].
   - Arduino Pro Mini: Responsible for the low-level motor control logic for the quadruped locomotion [9]. It takes movement commands from the ESP32-CAM via UART and translates them into specific locations for the servos [1, 4, 3]. The system attains real-time performance with this dual microcontroller approach since the more demanding vision processing and high-level decisions are executed on the ESP32-CAM while the time-critical motor control is handled by the Arduino Pro Mini. This configuration makes the quadruped platform responsive, cost-efficient, and energy-efficient.

2. Sensors and Actuators:
   - MLX90614: Provides instantaneous body temperature readings of the detected subject at a range of up to 1 meter [2].
   - HC-SR04: An ultrasonic distance sensor that detects nearby obstacles and implements a safety buffer around detected subjects [17].
   - MG90S Servo Motors (x13): Twelve servos coordinate the quadruped's gait by positioning each leg (three motors per leg), while one additional servo adjusts the head to maintain focus on the moving object of interest [3].
3. Power Supply:
   - Two DC-DC Buck Converters (LM2596) are used to power the various components [18]. One provides 5V to the ESP32-CAM, MLX90614, and twelve servos [1, 2, 3], while the other supplies 3.3V to the Arduino Pro Mini and the ultrasonic sensor [9, 17].
4. Mechanical Design:
   - The robot's chassis—specifically the legs and body—was adapted from an open-source quadruped design [5]. A custom head module was designed in FreeCAD [19] to integrate the ESP32-CAM and ultrasonic sensor [1, 17] as illustrated in FIGURE 4. All mechanical parts were fabricated using desktop FDM 3D printing. The resulting modular structure allows convenient access to internal electronics and supports future hardware expansions.

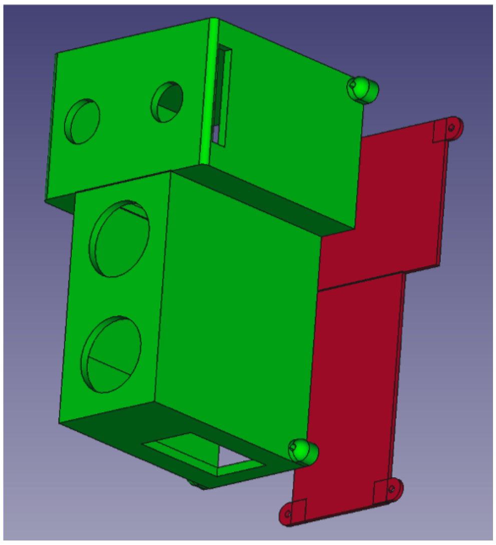


FIGURE 4. 3D visualization of the head design.

5. Custom PCB:
   - KiCad was used to design a two-layer printed circuit board (PCB) that connects and routes not only power but also signals between the components [6]. In addition, the board includes pin headers for the servos, microcontrollers, and sensors, improving the robot's overall wiring resilience. The PCB design and layout are illustrated in FIGURE 5 and FIGURE 6, respectively.

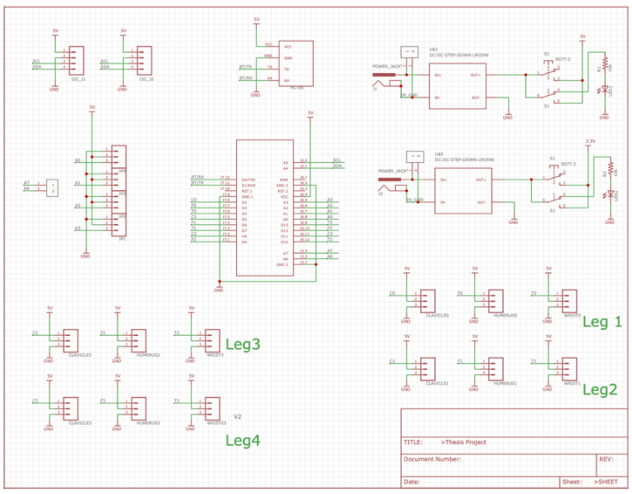


FIGURE 5. Electrical schematic of the control system showing power routing, microcontroller connections, and servo output mapping.

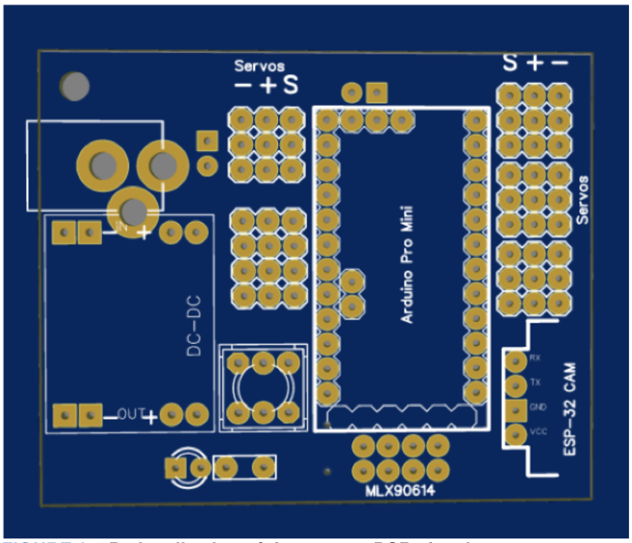


FIGURE 6. **3D visualization of the custom PCB showing component arrangement and board footprint.**

B. Software Architecture

The software architecture of the robot spans embedded C++, HTML/CSS/JavaScript for the web interface, and Python-based AI models executed on the ESP32-CAM using TensorFlow Lite [7].

1. ESP32-CAM Module:
   - Real-time video is captured and streamed via a web interface hosted directly on the microcontroller (see FIGURE 11).
   - Executes a pre-trained TensorFlow Lite object detection model to recognize and monitor human figures [7].
   - Receives object tracking commands through UART communication [4], processes the commands through Arduino Pro Mini [9], and executes the calculated movements for object tracking.
   - Manages the head servo and the ultrasonic sensor for dynamically changing the camera angle and detecting obstacles [17, 1].
2. Arduino Pro Mini:
   - A lightweight system for controlling the gait of a servo is implemented, and movement commands (e.g., Front, Back, Left, Right, Stop, Head up, Head Down, Sit, and Shake Hand) are mapped to coordinated servo actions.
   - Acquires temperature readings from the MLX90614 sensor [2] and forwards the information to the ESP32-CAM for display on the server [1].
3. Web Interface:
   - Offers control options in real time, such as Start Detection, Auto Control, Auto Search, Manual Control, and Temperature Monitoring as shown in FIGURE 11.
   - Designed with HTML and JavaScript, which permits use from mobile or desktop browsers.
   - Allows users to change the gait delay, frame resolution, and enable or disable the flashlight [20].

C. Communication Protocol

A UART-based protocol is used to streamline communication for various devices with limited processing power and to ensure reliable communication [4].

- UART Serial Link:
  - The RX pin of the Arduino Pro Mini is connected to the TX pin of the ESP32-CAM, and the Arduino Pro Mini's TX pin is connected to the RX pin of the ESP32-CAM [4, 9, 1].
  - The encoded command packets sent by the ESP32 are based either on results from object detection or on user input [1].
  - The commands are decoded by the Arduino Pro Mini [9], which then activates the appropriate sequences of servos.

This ensures that both microcontrollers can operate independently without requiring synchronized clocks, thereby reducing system complexity.

The architecture employs a dual-microcontroller assemblage—namely, the ESP32-CAM [1] and the Arduino Pro Mini [9]—an explicit, deliberate stratagem. Mounted upon the ESP32-CAM are native Wi-Fi, on-demand video streaming, and neural inference capacities [1, 14], yet the device is hamstrung by precision error and computational overhead in any sub-cycle requiring stringent real-time control. In opposition, the Arduino Pro Mini [9] embodies a deterministic execution model, thus affording low-jitter servo modulation and steadfast sensor integration, yet is bereft of the communicative and vision-analytic assets necessary for advanced task execution. The compartmentalization of tasks thereby delivers the benefits of agile locomotion alongside cognitive perception, while retaining modular extendibility and easing the regimen of fault localization. Such a distribution of functional obligation would, if imposed upon a monolithic architecture, surmount the affordability of the constituent hardware or, alternately, magnify the intricacy of the software layer to an unmanageable degree.

IV. Implementation

This section details the hands-on procedures employed to transform the proposed quadrupedal assistant robot from a conceptual idea into a proof-of-concept working prototype. We discuss mechanical construction, electronic circuit development, software deployment, and system integration, with a focus on the key design principles that make the robot not only functional but also maintainable, low-cost, and accessible to others who might want to build a similar assistant robot.

A. Mechanical Design and Assembly

The mechanical design of the robot is based on an open-source platform for quadruped robots [5]. Although the original chassis was kept for the legs and the body, a new head was designed in FreeCAD [19] for the specific purpose of integrating the ESP32-CAM module [1] and the ultrasonic sensor [17]. This design is unlike the original, which relied on an Arduino and Bluetooth to control the robot [9]. The proposed system here is a dual-microcontroller architecture with remote, web-based operation. All of the physical components of the robot were fabricated using FDM (Fused Deposition Modeling) 3D printing technology. Standard 1.75 mm PLA filament with ~20% infill was used due to its affordability, ease of printing, and adequate rigidity for prototyping. After printing, only minimal post-processing was performed (support removal and light cleaning), which allowed the parts to be assembled directly with standard screws.

An intermediate stage of the mechanical assembly, including the leg units and interlocking body frame, is shown in FIGURE 7.

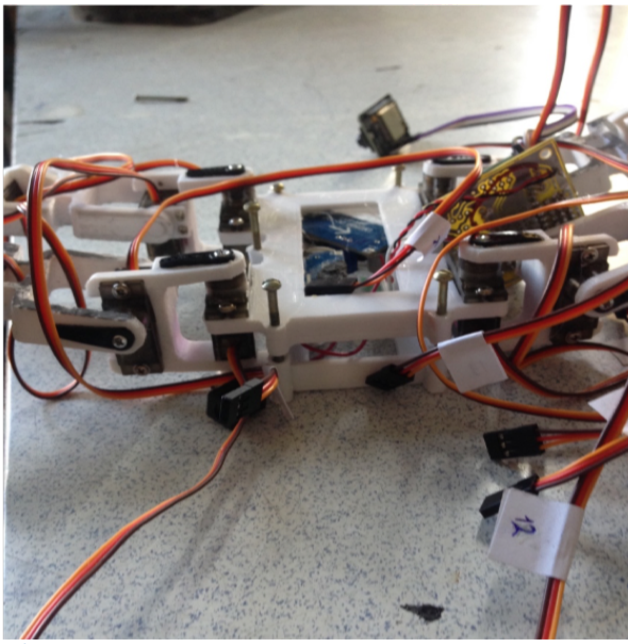


FIGURE 7. Partially assembled mechanical structure of the robot, showing the interlocking body and four legs prior to final integration of sensors and head unit.

The design is morphologically divided into three main assemblies:

- Leg Mechanism: Each of the four legs is driven by three MG90S micro servo motors [3], allowing motion in three degrees of freedom. The servo horns were secured with M2 screws. In this case, we reinforced the parts more than usual to ensure and test that the legs could move properly, as this is the primary function of a leg [5].
- Body Frame: A two-part interlocking body (top and bottom) provides the structural integrity needed to house all the electronics and hold the battery packs that power the robot. Between the two halves of the body frame, the leg assemblies are suspended using threaded fasteners [5].
- Head Unit: The head, mounted on a separate servo, accommodates the ESP32-CAM, MLX90614 temperature sensor, and ultrasonic distance sensor [1, 2, 17]. The ESP32-CAM is mounted horizontally due to its limited image rotation capabilities, a modification made after initial testing revealed that vertical alignment could not be corrected in software [1].

After the parts were printed (removal of support material and stringing), and post-processing was completed, the parts were assembled using standardized screws, which can be found in many common household items.

B. Printed Circuit Board (PCB) Design and Fabrication

A custom PCB was designed using KiCad [6], a cloud-based electronic design automation tool, to facilitate reliable connections and compact integration of components as shown in FIGURE 6.

- Schematic Design: The schematic included footprints for the Arduino Pro Mini, power converters, header pins for servos and sensors, and decoupling capacitors for noise reduction (see FIGURE 5).
- Layout and Fabrication: A two-layer board was laid out and sent for fabrication. The finished board was soldered by hand, with each joint checked for continuity before final assembly. A photo of the soldered board is shown in FIGURE 8.
- Power Distribution: For clean and regulated power distribution, two LM2596 buck converters were used as shown in FIGURE 9. One converter buck outputs 3.3V for the microcontroller as well as the ultrasonic sensor [1, 9, 17]. The other buck converter outputs 5V for the servos and the ESP32-CAM [1]. Powering separately the servos and ESP32-CAM reduces the chances of voltage drop or resets during activation [3, 1]. Besides reducing the amount of wires needed, using a custom PCB strengthens the reliability of the system by providing stable mounting points for all components, reducing potential failure points and increasing the ease of future maintenance or upgrades.

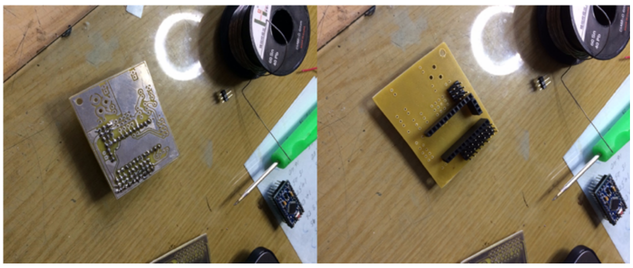


FIGURE 8. Soldered custom PCB showing completed component integration and hand-soldered joints.

C. Embedded Software Development

Two distinct firmware programs were developed—one for the ESP32-CAM and one for the Arduino Pro Mini [1, 9].

1. Arduino Firmware:
   - Written in C++ and compiled using the Arduino IDE [21].
   - Handles real-time servo control through predefined gait sequences.

- Communicates with the MLX90614 through the I²C bus to fetch temperature data [2, 4, 16].
- Receives commands serially through UART [4] and maps them to movement states (such as walking, turning, standing, and sitting).

2. ESP32-CAM Firmware:
   - Developed using the Arduino core for ESP32 and tailored libraries for video streaming and TensorFlow Lite [9, 1, 7].
   - Initializes the camera and sets up an HTTP server with user controls.
   - A lightweight object detection model is loaded that identifies persons in a given frame and computes the coordinates of the bounding box around them [7].
   - Calculates tracking commands (Front, Back, Left, Right, Stop, Head up, Head Down, and Sit) based on the subject position in relation to frame center and sends those commands to the Arduino over UART [22].
   - Controls head servo positioning and ultrasonic distance checks in real time.
3. Web Interface:
   - A responsive HTML/CSS/JavaScript frontend offers real-time interaction and feedback through the web server of the ESP32-CAM [1], FIGURE 11.
   - Features include:
     - Start Detection: Allows for the identification and tracking of an individual.
     - Auto Control: Initiates autonomous following behavior.
     - Taking Control: Permits the user to direct the robot manually using buttons that command direction.
     - Temperature Monitor: Shows the present corporeal temperature from the MLX90614 sensor [2].
     - Flash Toggle & Resolution Setting: Optimize the lighting and video quality, as required [14, 20].

D. Integration and Testing

Once the hardware was established and the corresponding firmware uploaded, the full system underwent step-by-step testing.

- Initial Testing: Each component of the system (servos, sensors, UART communication, web interface) was verified for electrical and software integrity as shown in FIGURE 9.
- Integration: When subsystems completed basic testing, comprehensive integration was done. A Li-Po battery pack powered the robot [23]; performance during prolonged use was observed.
- Tracking Calibration: Detection thresholds and servo delay timings were refined on TensorFlow to guarantee that real-time tracking works smoothly and that responsive locomotion happens as intended [7].
- Head Redesign: A key hardware change was reorienting the ESP32-CAM [1], and its associated sensors, due to their lack of 90° image rotation as illustrated in FIGURE 10. This made a second head design in FreeCAD necessary [19].

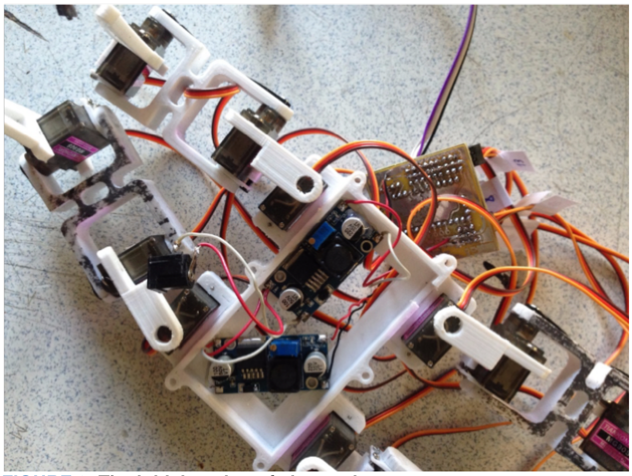


FIGURE 9. **The initial testing of electronics.**

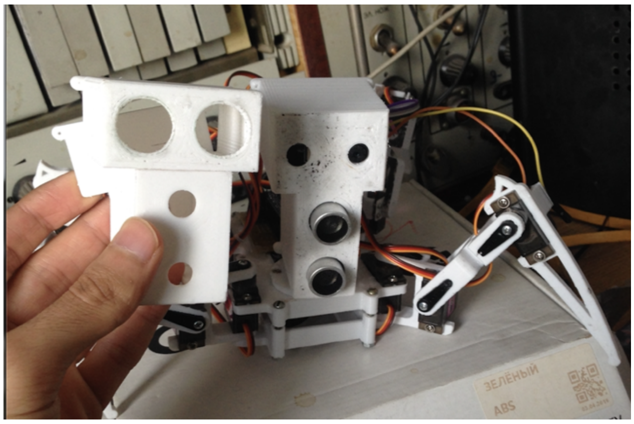


FIGURE 10. **The robot head redesign (before/after).**

The integrated system achieved real-time stable operation in a domestic indoor environment. It was able to follow a subject, detect temperature, and respond to remote commands with an observed latency of approximately 150–200 ms.

V. Experimental Results and Performance Evaluation

The indoor environment was arranged to simulate a typical household scenario, including tiled flooring, moderate lighting variation from windows, and furniture positioned along the walls. The test area measured approximately 5 m × 4 m. A human subject walked at normal speed while the quadruped attempted autonomous following, temperature sensing, and response to web-based commands. FIGURE 12 shows the experimental setup, with the quadruped deployed in the test area. The evaluation focused on four aspects: (1) robustness of person-tracking under different lighting and occlusion conditions, (2) accuracy of non-contact temperature measurement, (3) latency and reliability of remote commands via the web interface, and

(4) stability and maneuverability of the mechanical gait on indoor flooring.

A. Object Detection and Visual Tracking

The ESP32-CAM has an object detection system that uses a TensorFlow Lite model optimized for person detection [14, 20, 7]. Experiments were carried out at various distances, from 0.5 to 3.5 meters, and under a variety of lighting conditions. Likewise, the system was evaluated on three criteria: tracking accuracy—how well it can follow a person; latency—how much time it takes to recognize a person and initiate tracking; and fidelity—how reliably it maintains tracking when the subject moves in and out of the camera's field of view within a feedback loop.

- Detection Accuracy: The system effectively detected human figures in 93\% of the frames when they were as close as 3 meters. Slightly poorer detection occurred under inferior lighting and when the figure was not entirely unobstructed.
- Responsiveness Tracking: After the subject moved, the robot altered its course in fewer than 0.5 seconds. Head servo motion, controlled directly by the ESP32-CAM, ensured that the subject remained in frame during movement [1, 14].
- Bounding Box Analysis: The size of the bounding box was used to gauge distance, which was used to issue movement commands (forward, stop) to the Arduino controller [9]. With this technique, the robot could maintain a dynamically close proximity to a subject without making contact. An example of live person tracking is illustrated in FIGURE 11.

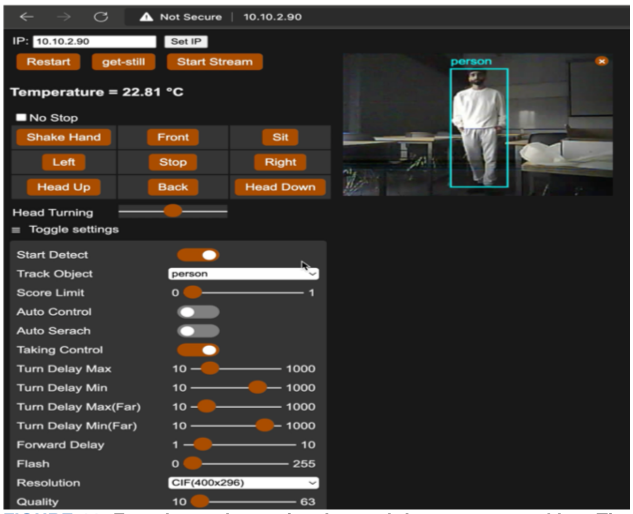


FIGURE 11. **Experimental test showing real-time person tracking. The bounding box is generated by the TensorFlow Lite model running on the ESP32-CAM, guiding the robot's movement via UART commands.**

B. Locomotion and Stability

Tests of locomotion were done to assess the stability of the gait, the precision of the servos, and the maneuverability of the system on flat surfaces. A snapshot of the testing phase is shown in FIGURE 12.

- Quadruped gait precision: The Arduino Pro Mini executed the quadruped gait sequence with stable and repeatable motion [9]. However, it was not very fast—averaging 0.15 m/s—with is an appropriate speed for indoor assistive scenarios. The gait had a duration and an overall pace remarkably similar to that of a person walking in slow motion.
- Current draw: Surfing the power curve caused naturally occurring current spikes to give the ESP32-CAM some hiccups in stability [1]. Dedicated buck converters and careful power routing on the PCBs smoothed those spikes out.
- Obstacle Handling: Basic proximity detection was provided by the HC-SR04 ultrasonic sensor [17]. The robot was able to avoid obstacles within a 20–50 cm range. This shorter detection range proved more suitable than the default 0–2 m range, as it allowed for more convenient operation in confined indoor environments and gave the robot time to make slight adjustments before actually hitting something.

FIGURE 12. **Locomotion and stability test of the quadruped robot on indoor flooring.**

C. Temperature Measurement Accuracy

The MLX90614 infrared temperature sensor was tested against a calibrated contact-based thermometer at various distances between 0.5 and 1.0 meters [2].

- Precision: Temperature readings were within ±0.5°C of the reference thermometer, which is acceptable for non-clinical monitoring applications.
- Latency: The total measurement and transmission cycle took roughly 1.2 seconds, which

encompassed the I²C communication and the latency associated with updating the web server [16, 4].
- Web Exhibit: Values received from the temperature sensors were displayed on the ESP32-CAM's live web server and updated continuously during tracking or on-demand during manual control [1, 14] as illustrated in FIGURE 11.

D. Web Interface Usability
A real-time, lightweight web interface hosted on the ESP32-CAM allowed users to interact with the robot [1, 20].
- Reactivity: The latency of a website, viewed over local Wi-Fi, ranged from 80 ms to 120 ms. This was tolerable for human hands to operate and for us to keep an eye on things.
- Functionality: Performed reliably all features (streaming video, control buttons, mode switching, flash toggling, resolution selecting). However, the feature of streaming video at a high resolution brought on a slight lag and increased CPU load on the ESP32-CAM [1, 20].
- User Feedback: User feedback from informal testing showed that the interface was intuitive and responsive in both desktop and mobile browsers.

E. Limitations and Observations
Despite successful prototype operation, there were a number of observed limitations:
- Mechanical Wear: Prolonged operation caused noticeable wear on 3D-printed servo mounts. Reinforced parts or upgraded materials, such as carbon-fiber filament, are recommended for extended use.
- Camera Constraints: Image rotation capabilities are absent in the ESP32-CAM [14]. Thus, the head module housing images must be physically re-oriented to produce usable, right-side-up images.
- Processing Overhead: The ESP32-CAM has reduced performance when trying to run high-resolution video and a simultaneous AI model [1, 7]. The future plan is to run models on a more capable processor, like a Raspberry Pi, while using the ESP32-CAM only for vision [1].
- 3D-Printed Components: All structural parts were fabricated using 1.75 mm PLA filament with 20% infill. While PLA provided ease of fabrication and low cost, prolonged testing revealed noticeable wear on the servo mounts. Stronger alternatives such as PETG or carbon-fiber–reinforced filament are recommended for durability in long-term use.

VI. Discussion and Future Work
The assistive quadruped robot demonstrates that it is possible to create a low-cost, multifunctional robotic platform capable of supporting real-time interaction, autonomous decision-making, and health monitoring. This platform could be used in an array of real-world settings, from rehabilitation to research. The implications of the current system, some key design trade-offs, and possible future enhancements are what we discuss here.

A. System Impact and Use Case Relevance
The proposed system has primary value and dual-use capability for elder care and the screening of infectious diseases. Screening for infectious diseases is vital both now and in the near future for national security and public health. In tests, the robot successfully executed two main functions vital for reducing the exposure of human caregivers to potentially infected individuals: remote temperature sensing and vision-guided following.

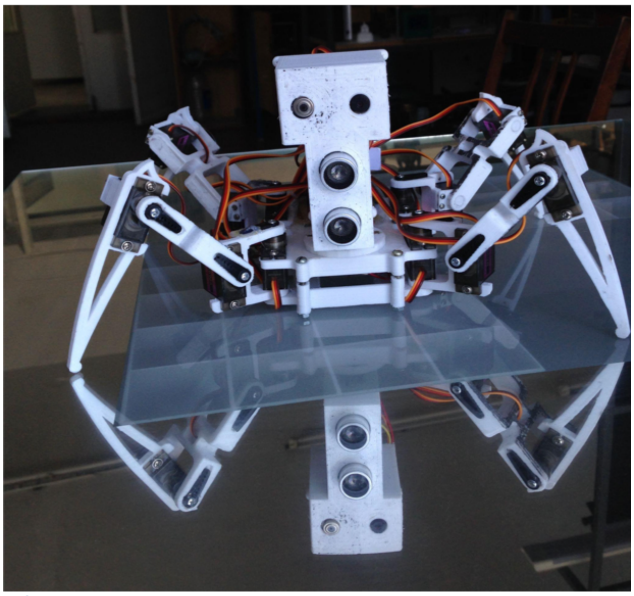


FIGURE 13. Fully assembled assistive robot including head-mounted sensors and dual microcontroller integration.

As shown in FIGURE 13, the robot's physical configuration supports autonomous operation in indoor environments. It combines real-time computer vision, wireless data transmission, and a mobile quadruped platform, enabling safe interaction with human subjects without direct contact.
- In elder care, the robot can independently follow people, transmit video, and provide real-time responses to off-site caretakers. This capability is especially important when the elderly live alone or in assisted living, as those in such circumstances can be at heightened risk for emergencies.
- In scenarios of mass contagion, such as COVID-19, the system acts as a contactless screening assistant, measuring body temperature and sending the results over the network. This is a critical function for reducing human exposure while maintaining effective triage protocols.

These services are directly related to public health, healthcare automation, and robotics—national interest areas that make our system a strong fit for research and development efforts that could qualify for a National Interest Waiver.

B. Design Trade-offs

A number of determinations were made to balance cost, complexity, and efficiency:

- Microcontroller vs. Single-Board Computer: The use of ESP32-CAM enabled low-cost AI inference and server hosting [1], but also introduced processing limitations. More advanced implementations would require the use of higher AI performance peripherals such as Raspberry Pi 4 or Jetson Nano, which offer more advanced AI functionalities [24, 25].
- Servo-Based Locomotion: While micro servos provided simplicity and affordability, they limit the robot's payload capacity and motion smoothness [3]. First, they provide a very low payload. Second, they do not generate smooth motion in the robot. Digital servos and smart actuators (Dynamixel, for example) might be good alternatives for future versions of the robot [26].
- Web Server on MCU: Hosting the interface directly on the ESP32-CAM minimized infrastructure dependencies but came at the cost of reduced frame rate and limited concurrent user support [1, 14].

For a functional prototype, these trade-offs were suitable, but next-generation versions may use distributed processing architectures. That would enable them to separate artificial intelligence, motion control, and networking operations.

C. Planned Enhancements

Further development has been identified in several areas:

1. Enhanced Locomotion: Subsequent research will concentrate on taking the robot's mobility to the next level by changing from a four-legged to a six-legged robot architecture. This shift is anticipated to enhance not just stability but also adaptability over a broader variety of surface conditions. At the same time, advanced control algorithms will be implemented, including inverse kinematics and gait optimization. These are expected to give the six-legged robot not only smooth gait transitions but also greater efficiency compared to the current control system.
2. Advanced Perception: Planned improvements include the integration of a 3D camera, such as Intel RealSense or stereo vision [27], to enable depth-aware obstacle avoidance and environmental mapping. Furthermore, facial recognition or skeletal tracking will be incorporated to allow the robot to identify specific individuals and detect unusual postures, such as falls, thereby extending its usefulness in healthcare scenarios.
3. Autonomous Navigation: Autonomous navigation constitutes a key area for subsequent research initiatives. The complementary fusion of odometry measurements and a SLAM-based architecture is anticipated to empower the platform to derive and refine indoor topological maps while executing autonomous patrol trajectories [28]. Usability enhancements are being pursued through the integration of multimodal human-system interaction channels; specifically, natural language processing and robust gesture interpretation modalities will be embedded to enable users to command, query, and modulate mission parameters via voice or kinetic input, thus increasing the system's intuitiveness and broadening its accessibility to diverse user populations [29].
4. BCI and VR Integration: One of the continual goals of the Biorobotics Lab has been the creation of humanoid assistive robots which are controllable via Brain–Computer Interfaces (BCI) [30] and are virtually realized using Virtual Reality (VR) [31]. The objective of this Brain-BCI-Robot setup is to enable users with deep physical disabilities to control and interact with assistive robots using their brain signals which would significantly improve their autonomy and the ability to perform tasks of daily living. Apart from personal assistance, such a system can aid in decreasing the burden on caregivers and improve rehabilitation services in healthcare facilities. Moreover, the envisioned control precision is expected to enable system controllers (trained tele-operators) in laboratories, industrial sites, and medical facilities to remotely operate the assistive robots [32] which would allow safe operation in dangerous or high-stress situations. These dual contributions: accessible technological aid for vulnerable populations improve last mile healthcare delivery and enhanced safety in critical sectors broaden the significance and importance of the research in the context of the society and the nation. By giving people with severe physical disabilities the ability to control assistive robots autonomously, and improving operational safety in high-risk environments, this research directly addresses the national interest by supporting gaps in healthcare, rehabilitation, and industrial safety.
5. Cloud Integration: A further enhancement under consideration is the extension of the local interface out into a dash-board based in the cloud. This would allow for the secure storage of health metrics, video logs, and system diagnostics on remote servers—and of course facilitate integration with not just our own telehealth platform, but with the wide variety of platforms out there, each serving the individual health needs of its customers. That's the sort of networked living we envision for our household robot.

D. Research and Publication Potential

The current system provides a robust foundation for future publications in areas such as:

- Human-Robot Interaction (HRI)
- Edge AI for Robotics
- Assistive and Social Robotics
- Low-Cost Mechatronics Platforms for Healthcare

The project's inherent interdisciplinarity—melding embedded systems, computer vision, artificial intelligence, and mechatronics—positions it as an exemplary subject for IEEE-sponsored symposia and for National Interest Waiver (NIW)-aligned robotics activities focused on the common good. Of particular relevance is the proposed coupling of Brain–Computer Interface (BCI) and Virtual Reality (VR) systems, which enlarges the project's societal reach by affording persons with profound motor limitations the capability to manage assistive robots via extracted neural commands. Such a capability steers decision-making toward sustained autonomy and broadens the availability of health care, while the operational disparities that it addresses satisfy NIW stipulations by clearly targeting unmet demands in rehabilitation and assistive technology for marginalized demographic groups.

VII. CONCLUSION

This paper described the design, development, and evaluation of a low-cost, quadruped assistive robot for elder care and remote medical screening. The system integrates multiple disciplines—embedded systems, computer vision, and mechanical design—to make a functioning prototype capable of autonomous human tracking, temperature sensing, and interacting remotely with a lightweight web interface.

The robot, built using inexpensive parts like the ESP32-CAM [1, 14, 20], MLX90614 sensor [2], and Arduino Pro Mini [9], presents a real-world assistive solution that is both scalable and accessible, particularly to settings with limited resources. The use of custom PCBs and 3D-printed parts further underscores the system's modularity and reproducibility [6, 19].

The system was experimentally validated for real-time tracking of individuals, responsive-motion following, and safe-distance body-temperature measurement. Limitations in raw processing power and smooth locomotion were noted, but these can be fixed in the future via beefed-up sensors, actuators, and processing units.

This paper describes a development that could be viewed as a foundational milestone towards the more sophisticated assistive robotic systems that have full-body control capabilities, environmental mapping, and even brain-computer interfacing. The neuro-controlled assistive robots outlined in this future work would serve the national interest by directly enabling targeted impact for the most severely limited individuals, while improving safety within the healthcare sector and critical industries.

With further refinements and comprehensive research, this platform can transform to a socially impactful novel tool for improving healthcare access, augmenting life quality, and advancing the domain of low-cost assistive robots.

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