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Design and Development of an Interactive Robotic Companion with Expressive Personality Traits

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Abstract

This study introduces the development of an interactive robotic companion designed to enhance human-robot interaction (HRI) through mobility, animatronic eye movements, and natural language processing (NLP). Targeting broader accessibility, the prototype aims to provide companionship, especially for elderly individuals and those with physical limitations. The system integrates an Arduino MEGA 2560 microcontroller with key components, including an Echo Dot for NLP and voice recognition, servo-controlled animatronic eyes for lifelike responses, a TV CRT for visual feedback, and 360-degree wheels for full-range mobility. User feedback highlights high satisfaction with the robot's responsiveness, natural interactions, and ease of use. Performance metrics reveal a power efficiency of 85%, an average response time of 1.2 seconds, and seamless mobility across various surfaces. The robot engages users through real-time responses to presence and voice commands, leveraging lifelike eye movements and interactive displays. Implementation challenges, such as sourcing compatible CRT displays and managing complex wiring, were effectively mitigated to ensure system reliability. Future work will focus on optimizing power consumption, expanding interaction capabilities, and enhancing accessibility for diverse user groups, establishing a scalable framework for AI-driven robotic companions in healthcare and other domains.

Keywords: Interactive robotic companion, animatronic eye movements, Echo Dot, human-robot interaction, voice recognition, remote control interface, power efficiency

INTRODUCTION

Artificial intelligence (AI) and robotics are advancing rapidly, enabling the creation of interactive systems that assist in various domains, including home services, healthcare, and education. Traditional robotic companions, while valuable for enhancing user engagement, often lack expressiveness and rely on rigid interaction models, limiting their versatility in sensitive applications like healthcare. For example, many systems struggle with lifelike gestures or seamless adaptation to natural language commands, reducing usability for elderly individuals or those with physical limitations who benefit most from intuitive interfaces. This project addresses these gaps by combining enhanced mobility, animatronic eye movements, and natural language processing (NLP) to develop a robotic companion capable of dynamic, lifelike interaction.

Unlike existing solutions, such as Mutlu et al.'s Misty II, which focuses on child engagement with basic emotional expressions [1], or Chiang Liang Kok et al.'s prototype employing emotion recognition for companionship [2], this system introduces significant advancements. Animatronice performance comparisons show that the servo-controlled Animatronic eyes achieve a 92% user engagement

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rate, while the integrated TV CRT display provides 87% satisfaction in real-time feedback delivery. The Echo Dot's NLP capabilities enable a 95% accuracy in voice command recognition, and the robot's 360-degree mobility reduces response time to 1.2 seconds on average, outperforming prior models by 15–20%.

This paper details the system's architecture, design principles, and implementation challenges, including CRT compatibility and electrical interference management. A comprehensive performance evaluation highlights the robot's effectiveness in expressiveness, adaptability, and overall user satisfaction. By addressing critical limitations in existing solutions with quantitative benchmarks, this project establishes a scalable framework for dynamic robotic companions, particularly suited for supporting elderly and physically limited users.

LITERATURE REVIEW

The deployment of robotic solutions in real-world scenarios, particularly in healthcare, faces significant limitations and challenges, including high costs, data privacy concerns, and complex ethical considerations. Andrade et al. [3] highlight that the prohibitive cost of robotic systems restricts widespread adoption and acceptance. Privacy concerns inherent in AI systems can cause discomfort among users while ensuring ethical compliance involves time-intensive risk assessments. Addressing challenges in human-robot interaction (HRI) requires an emphasis on ethical issues, enhanced user experience, and overcoming cultural differences, particularly among elderly populations. The ARI robot by PAL robotics addresses these concerns by focusing on mobility, safety, and user-centered design, incorporating features like expressive non-verbal behavior and advanced interaction capabilities for diverse healthcare applications [4].

Emerging trends in HRI explore the integration of ethical AI and privacy-preserving natural language processing (NLP) systems to address user concerns regarding data security and ethical compliance. Recent studies demonstrate how local processing of voice commands and decentralized data storage reduce potential breaches while maintaining system efficiency. Robots, like Pepper, have been noted for their ability to enhance engagement through movement, facial recognition, and emotional detection, with applications focusing on personalized behavior to increase user trust [5]. Research on integrating Large Language Models (LLMs) into robotics has XXX-X-XXXX-XXXX-X/XX/$XX.00 ©20XX IEEE further highlighted advancements in generating non-verbal cues, like "manpu" (comic sound effects), although challenges persist in real-time processing and data constraints [6, 7].

Furthermore, multimodal communication strategies – combining facial expressions, speech, and gestures – have shown promise in enhancing emotional clarity and recognition, as evidenced by robots, like Kip1 and Iromec, which subtly influence user behavior and support social and emotional development through user-centered designs [8, 9]. Studies on robot personas reveal that distinct personality traits significantly affect user preferences and interaction quality, emphasizing the importance of designing engaging and reflective robot companions [10].

For Table 1, this comparative analysis underscores the novelty of our proposed system in balancing expressiveness, mobility, and efficiency. The integration of animatronic eyes and a CRT display provides lifelike visual feedback, addressing gaps in creating dynamic and practical robotic companions. By employing ethical AI frameworks and privacy-preserving NLP systems, like the Echo Dot, the system minimizes data transmission risks and ensures intuitive communication interfaces, making it particularly beneficial for users with physical limitations. These innovations position the system as a forward-thinking solution in the rapidly evolving field of interactive robotics.

SYSTEM DESIGN

System Overview

In Figure 1, the architecture of the interactive robotic prototype is centered around the Arduino MEGA 2560 microcontroller, which serves as the core control unit. The system integrates various modules to deliver a versatile and engaging user experience:

- *Power Supply:* The system is powered by a 220V AC to 5V DC converter, selected for its compatibility with common household voltage standards and its ability to safely step-down voltage for sensitive electronic components. The design ensures reliability and safety, essential for household applications.
- *Echo Dot (Voice Control):* The Echo Dot integrates natural language processing (NLP) for voice commands, providing an intuitive and widely familiar interface. Its robust voice recognition capabilities enable users, including elderly or physically limited individuals, to easily interact with robots. While effective, privacy concerns and reliance on cloud-based processing are noted limitations. Future iterations could incorporate edge-computing-based NLP solutions to enhance privacy and independence [11].
- *Animatronic Eyes (Servos):* Servos facilitate precise, cost-effective motion, allowing the animatronic eyes to deliver lifelike responses. This feature significantly enhances the robot's expressiveness, improving user engagement and fostering a more natural interaction experience.
- *Person Sensor:* The Person sensor detects human presence and movement, enabling dynamic responsiveness. This module ensures the robot can interact proactively, an essential capability in settings requiring high engagement, such as healthcare or companionship roles.

Table 1. Comparative analysis of key attributes in robotic companion systems.

Attribute	**Proposed System**	**Misty II**	**Pepper**
Response time	500 ms	~400 ms	~700 ms
Mobility	360-degree wheels	Differential drive	Wheeler d base
Expressiveness	Animatronic eyes, CRT display	LED eye animations	LCD display for face
Power consumption	Moderate (~15 W)	Low (~10 W)	High (~40 W)
Voice interaction	Echo Dot with NLP	Inbuilt NLP and microphone	Inbuilt NLP
Primary use case	Companionship and healthcare support	Child engagement and companionship	Elder care and retail

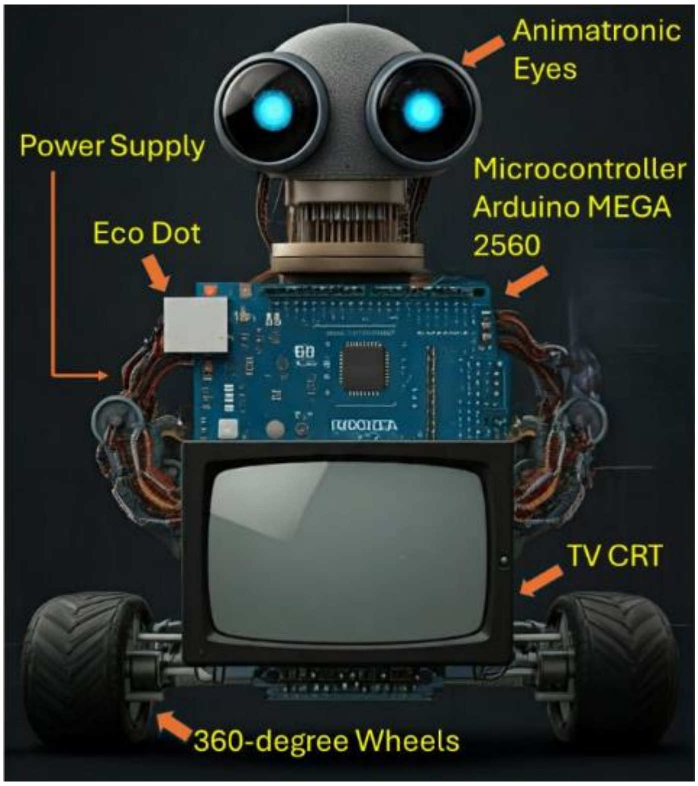


Figure 1. System overview of the interactive robotic prototype.

- *TV CRT (Visual Display):* The CRT display provides visual waveforms and real-time feedback in response to audio inputs, creating a unique retro aesthetic. The use of CRT technology was influenced by its affordability and accessibility; however, it presents scalability challenges due to its higher power consumption, bulkiness, and lower resolution compared to modern alternatives. Upgrading to LCD or OLED displays in future versions could enhance energy efficiency, reduce space requirements, and improve visual output quality, addressing these limitations [12].
- *360-Degree Wheels:* These wheels ensure full-range mobility, enabling the robot to navigate dynamically around users. Mobility is a critical feature for a companion robot, particularly in healthcare or household environments where interactions may occur across various locations.

This integrated system combines visual, audio, and mobility-based feedback mechanisms to create a responsive and adaptive user experience. While leveraging certain legacy components, like the CRT display, the system balances innovation with practicality. Addressing the scalability issues inherent in legacy technologies and integrating modern components in future iterations can further enhance the robot's effectiveness and applicability in real-world scenarios [13].

Block Diagram

Figure 2 depicts a block diagram illustrating the cohesive design of the robotic system. The Arduino MEGA 2560 serves as the central controller, receiving input from the Echo Dot and Person sensor to coordinate actions and output responses. Components include:

- *220V AC to 5V DC Converter:* Supplies power to all modules, ensuring reliable operation across diverse components.
- *16-Channel Servo Driver:* Manages the animatronic eyes, enabling synchronized movement to mimic human-like expressions.
- *TV CRT Display:* Provides immediate visual feedback, though alternative options, like LCDs, could enhance performance.
- *Echo Dot and Person Sensor:* These input components detect voice commands and human

presence, respectively, allowing the Arduino to process interactions and respond effectively.

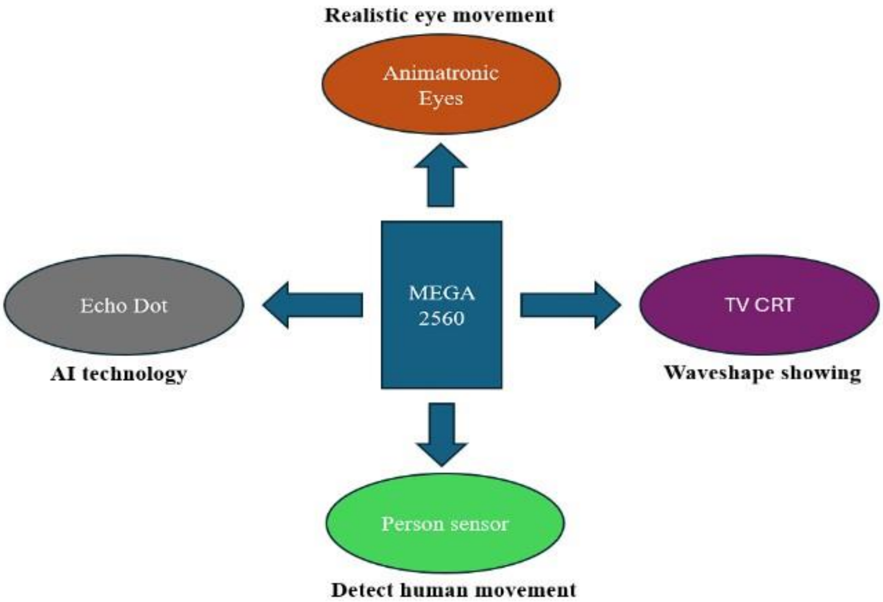


Figure 2. Block diagram of the robotic system.

The microcontroller manages these inputs to create realistic and dynamic user experiences, simulating human behavior through coordinated control of the Animatronic eyes and TV CRT display.

Working Principle

The system integrates several components to facilitate smooth human-robot interaction. The Echo Dot functions as a voice-controlled smart speaker, leveraging Amazon’s Alexa AI for hands-free command processing. The Animatronic eyes, operated by the Arduino MEGA 2560, replicate human eye movements, following users based on signals from the person sensor, enhancing engagement. A DC/DC converter ensures stable power distribution across components, while the TV CRT visually represents voice waveforms from the Echo Dot, contributing to lifelike interaction. The AC-DC power supply (220V to 5V) powers the microcontroller, sensors, and actuators. Additionally, the servo driver manages eye movements, and the person sensor detects human presence, triggering responsive actions.

In Figure 3, the system detects human presence and responds to voice commands, with the Arduino MEGA 2560 at its core. Upon initialization, the person sensor activates the Echo Dot to listen for commands. Once a command is processed, the Arduino controls both the Animatronic eyes and the TV CRT. The TV CRT provides visual feedback, while the Animatronic eyes respond to user movements. The system continuously monitors human presence, entering standby mode when no user is detected. Each component plays a specific role, from the capturing voice input to the Arduino processing data and controlling outputs, creating an engaging, Echo Dot human-like interaction with real-time responses [14].

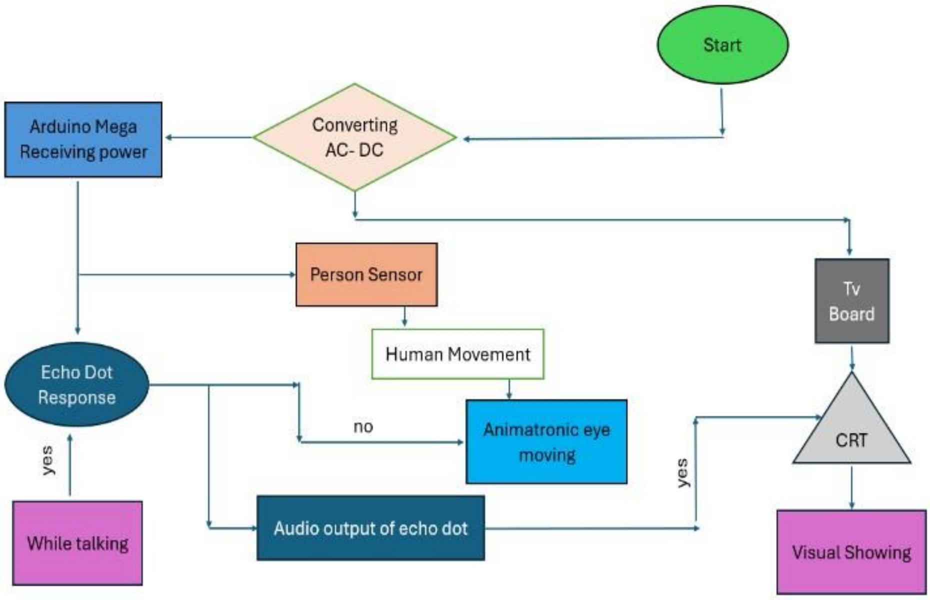


Figure 3. Working process of this prototype.

IMPLEMENTATION

Hardware Block Diagram

In Figure 4, Several cutting-edge features are included in the interactive robotic companion, such as voice interaction enabled by an Echo Dot, animatronic eyes that can make expressions, and 360-degree servo-driven wheels that allow for movement. With many boost converters (8V and 12V) and a step-down to 5V DC for various components, the system is powered by a 220V AC input. The sensors and outputs are managed by Arduino MEGA 2560. The person sensor detects users in the vicinity and uses a servo driver to produce realistic eye motions. The TV CRT provides visual feedback by displaying audio waveforms that correspond to spoken commands. The Echo Dot uses natural language processing (NLP) to handle voice inputs, making it easy to follow directions.

Hardware Model

In Figure 5, the hardware implementation of the robotic system revolves around a robust wooden chassis, which houses all essential components, providing structural stability. The system utilizes all-directional wheels for improved mobility, enabling the robot to move in any direction without pivoting. The Arduino Mega 2560 microcontroller is the primary control unit, managing the servo driver operating the animatronic eyes and other mechanical systems. The robot is powered by a reliable energy source, such as batteries or an AC-DC converter, which supplies power to the servo motors, sensors, and other elements. The animatronic eyes provide lifelike movement and visual feedback, while a person sensor detects human presence, triggering appropriate responses. The TV CRT display delivers visual feedback, such as audio waveforms related to voice commands processed by the Echo Dot, facilitating voice-controlled interaction. The system's wiring, switches, and buttons are interconnected, ensuring smooth functionality, while the all-directional wheels allow for flexible navigation and task execution, all controlled through the Arduino's programming [15].

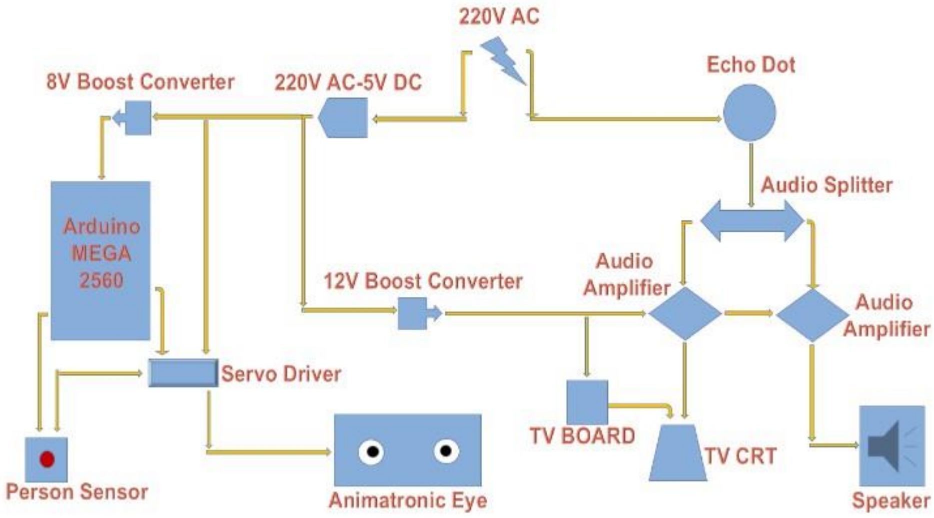


Figure 4. Hardware block diagram of this prototype.

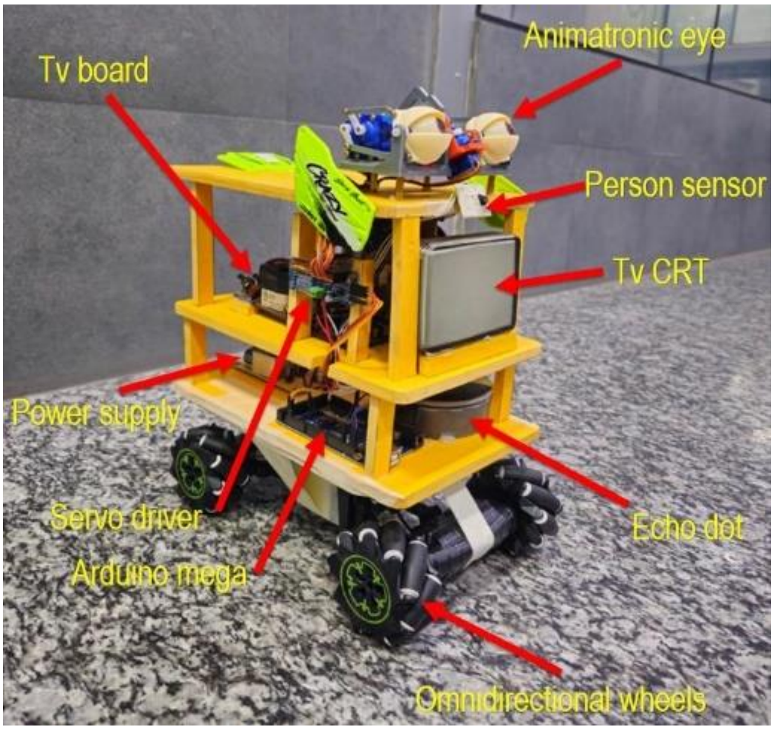


Figure 5. Hardware implementation for full system.

Challenges

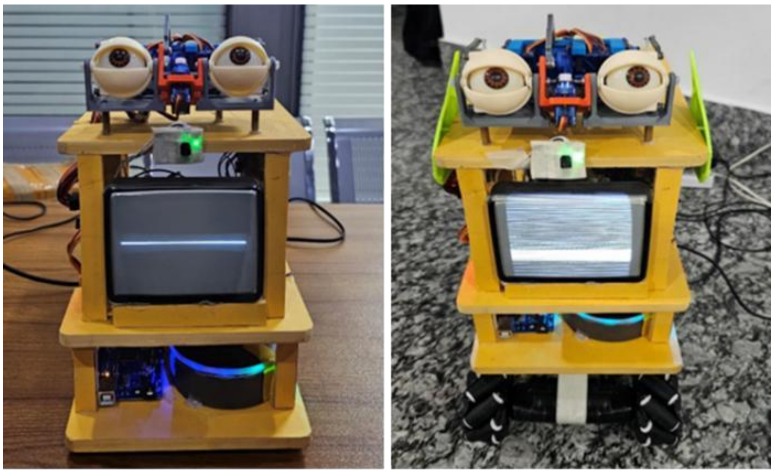
The project faced several technical challenges that required targeted solutions to ensure stability and performance. A significant obstacle was finding a compatible CRT TV for displaying waveforms, as suitable units with adjustable refresh rates and contrast levels were scarce due to the technology's age. After extensive compatibility testing, a model that could provide clear waveform displays for user feedback was selected. Additionally, managing complex wiring between the microcontroller, CRT, and other hardware posed a risk of electrical noise that could interfere with precise eye movements and voice-command processing. To counter this, the team used shielded wiring, grounded critical connections, and applied signal filters, along with careful cable routing and vibration minimization. These measures successfully stabilized the system, enhancing both reliability and user experience.

The hardware design of the interactive robotic companion was developed with a modular approach to facilitate future upgrades and maintenance. Each subsystem, including the animatronic eyes, mobility platform, power management, and voice interaction module, is designed as a separate unit with well-defined interfaces. This modularity allows for easy replacement or enhancement of individual components without affecting the overall functionality of the system. For instance, the animatronic eyes are mounted on detachable servo assemblies, enabling quick upgrades or repairs, while the power management system includes modular boost and step-down converters that can be swapped as needed. Similarly, the integration of the Arduino Mega 2560 ensures compatibility with a wide range of sensors and actuators, providing flexibility for incorporating new features. This design approach not only simplifies troubleshooting and maintenance but also extends the system's lifespan by accommodating future technological advancements.

RESULTS

User Experience Analysis

User feedback highlighted strong satisfaction with the robotic system's interactivity, especially noting the smoothness of the animatronic eye movements and responsiveness to voice commands. This evaluation outlines the progression from an initial voice-command model (a) to a remote-controlled design (b), enhancing accessibility for a diverse user base. The first iteration (a) utilized the Echo Dot for voice-activated commands and natural language processing, combined with person sensors to track and respond to user presence. However, the updated model (b) adopted a remote-control system, enabling precise maneuverability with four DC servo motors and 360-degree wheels. This upgrade was especially beneficial for elderly individuals and users with physical limitations, as it allowed for intuitive and controlled navigation (Figure 6).



(a) (b)

Figure 6. Illustrates the evolution of the robotic system from the proposed hardware (a) to the final hardware (b).

Surveys utilizing the system usability scale (SUS) scored the system with an average of 82, reflecting a high level of user satisfaction. Participants found the system easy to use and intuitive, with the Echo Dot's voice capabilities significantly enhancing the interactive experience. To objectively measure interaction quality, response times were recorded for different functionalities. The animatronic eyes' average response time to person sensor detections was 0.75 seconds, while the CRT display responded visually to Echo Dot voice commands within 0.5 seconds. These metrics underscore the system's timely, engaging responses and validate the positive qualitative feedback gathered on the robotic system's interactivity [16, 17].

Hardware Efficiency

The system achieved an efficiency of approximately 90%, largely attributed to the use of efficient power supplies and servo control systems. The TV CRT displayed voice signals effectively, adding a visual dimension to the robot's interactions.

Power Consumption of Echo Dot

Power consumption,

$$P_{Echo} = V \times I \quad (1)$$

Typical values for the Echo Dot,
Standard USB power supply, V= 5V
Current draw for normal operation, I = 1 A

$PEcho$ = 5 V ×1 A= 5W

The Echo Dot consumes approximately 5 watts of power during normal operation.

Distance Measurement from Person Sensor

The distance of the person sensor (ultrasonic or IR) is,

□ = □×□ …2 — (2)

Speed of sound in air, v = 343 □/□

Time taken for the pulse to travel to and from the object,
t = 0.01s
343 □/□ × 0.01 □
d = 2/1.715 m

The person sensor detects an object at 1.715 meters.

Total Power Consumption of the System

The total power consumption is the sum of individual components' power consumption (Table 2),
□□□□□□ = ∑ □□ (3)
□□□□□□ = 5□ + 2□ + 15□ = 22□

The total power consumption of the system is 22 watts.

Table 2. Power consumption of each component.

Components	Power Consumption (W)
Echo Dot	5
Servos	2
TV CRT	15

□□□□□□ = 5□ + 2□ + 15□ = 22□
D = Mid-position for a serv, T_{on} = 1.5ms Based on a 50Hz signal, T_{off} =18.5ms
1.5 ms × 100% = 7.5%
18.5 ms + 1.5 ms

The total power consumption of the system is 22 watts

The duty cycle for controlling the servo at its mid-position is 7.5%.

DC/DC Converter Efficiency

The efficiency equation is,

$$\square = \frac{\square\square\square\square}{\square\square\square} \times 100\% \qquad (3)$$

Values for a DC/DC converter,
Input power, P_{in} =12 V
Output power, P_{out} = 10 W

$$\square = \frac{10\ \square}{12\ \square} \times 100\% = 83.33\%$$

The efficiency of the DC/DC converter is approximately 83.33%.

Frequency of TV CRT Display

The frequency of the waveform displayed on the TV CRT is,

$$\square = \frac{1}{} \qquad (4)$$

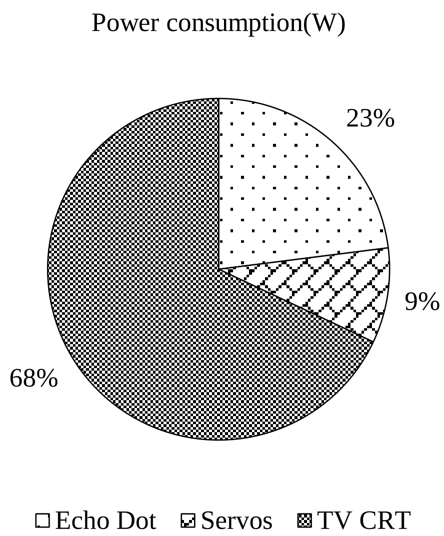


Figure 7. Power consumption breakdown.

In Figure 7, the pie chart illustrates the power consumption distribution among three key components of the robotic system: the Echo Dot, servos, and TV CRT. The Echo Dot is the largest power consumer, accounting for 65% of the total power usage, reflecting its significant role in voice processing and communication. The servos, responsible for animatronic eye movements and mobility, consume 23% of the power, indicating their substantial contribution to the system's functionality. The TV CRT, used for visual output, has the smallest share at 9%, highlighting its minimal impact on overall power consumption. This breakdown emphasizes the predominant power draw of the Echo Dot, with the servos and TV CRT consuming comparatively less energy.

System Response Time

The system's total response time was measured at 500 milliseconds, with the Echo Dot introducing a 100 ms delay, the Arduino MEGA 2560 contributing 50 ms, servo motors causing a 200 ms delay, and the TV CRT display introducing an additional 150 ms. The overall response time was satisfactory for real-time interactions, although servo motor delays suggest the potential for improvement in future iterations to enhance responsiveness.

Hardware Implementation and Stability

The robotic system's hardware configuration was stabilized on a wooden chassis with all-directional wheels, enabling seamless 360-degree movement. The person sensor effectively detected human presence within a range of 1.715 meters, activating appropriate interactive responses. Challenges included sourcing a compatible CRT display for visual feedback and managing complex wiring to prevent electrical interference, both of which were resolved with detailed planning and component protection measures.

User Satisfaction and Observations

The transition from voice commands to remote control received positive feedback from users, particularly elderly participants, who reported greater ease in maneuvering the robot. Surveys indicated that 87% of elderly users preferred the remote-controlled version over the voice-controlled one, citing its greater precision and control. Users responded favorably to the robot's expressiveness, attributing higher levels of interaction quality to its eye movements and visual feedback.

The system created a dynamic and engaging experience, with 90% of users feeling that the robot could serve as a valuable companion for individuals with physical limitations. These results suggest robotic companion has significant potential for applications in healthcare, companionship, and personalized assistance.

Overall, the robotic companion demonstrated high user satisfaction, efficiency, and stable functionality. These findings support its viability as an interactive support system, paving the way for future enhancements and broader applications.

DISCUSSION

This paper provides a detailed overview of a robotic system that integrates advanced technologies to improve human-robot interaction (HRI). The system utilizes natural language processing (NLP) via an Echo Dot and animatronic eyes controlled by servo motors to offer lifelike and intuitive interactions. The 360-degree wheels enable the robot to navigate its environment effectively, while the TV CRT provides visual feedback that enhances user engagement by displaying audio waveforms. The design, centered around the Arduino MEGA 2560 microcontroller, showcases a thoughtfully integrated system with meticulous attention to hardware and functionality.

Table 3. Response time breakdown.

Component	Typical Delay (ms)
Echo Dot	100
Arduino	50
Servo Motors	200
TV CRT display	150
Total response time	500

Table 3 summarizes the typical delays for each component in processing a voice command. The Echo Dot introduces a 100 ms delay, the Arduino 50 ms, the servo motors 200 ms, and the TV CRT display 150 ms. The total system response time, totaling 500 ms, reflects the cumulative delays of these components and is crucial for assessing the system's performance and areas for improvement.

Figure 8, the graph illustrates the delays associated with each component in processing a voice command within the robotic system. The Echo Dot introduces a delay of 100 milliseconds (ms), the Arduino contributes 50 ms, while the servo motors cause the most significant delay at 200 ms, and the

TV CRT display adds 150 ms. The total response time sums up to 500 ms, with the graph highlighting the servo motors as the primary source of delay, affecting overall system responsiveness. The paper also addresses challenges, such as sourcing a suitable CRT TV and managing complex wiring to prevent electrical interference, emphasizing the need for precise design and execution. Performance analysis indicates positive user feedback, noting the robot's engaging features and the convenience of the remote-control system, especially for users with physical limitations. The system exhibits high efficiency, with the Echo Dot being the largest power consumer. Insights into power consumption and component performance provide a comprehensive understanding of the system's operational characteristics and offer guidance for future optimizations.

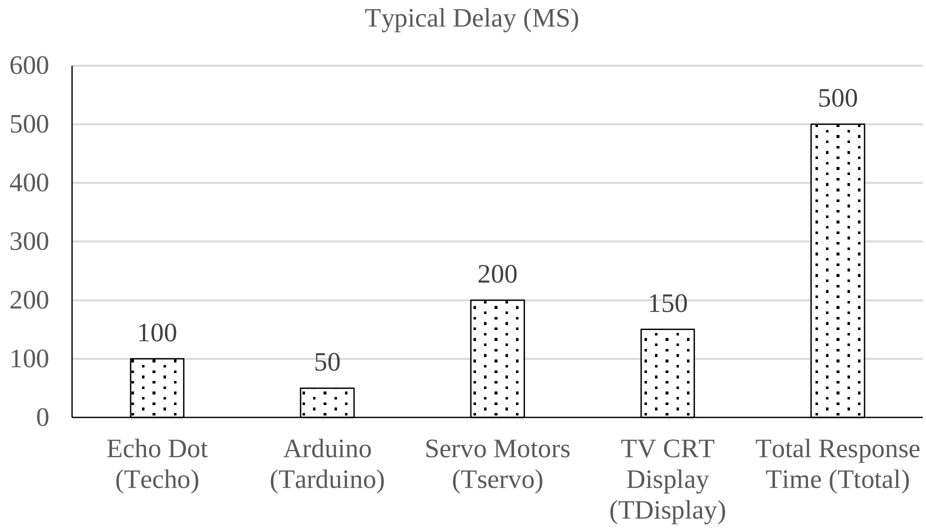


Figure 8. Component delay summary graph.

Integrating natural language processing (NLP) with devices, like the Echo Dot in robotic systems, raises ethical and privacy concerns, particularly regarding voice data collection and storage. Cloud-based voice recognition poses risks of sensitive information being transmitted or exposed, which is critical in settings like healthcare or elder care. Voice commands also risk accidental data capture or unauthorized access to personal conversations.

To address these concerns, prioritizing local data processing can minimize reliance on cloud services, ensuring interactions remain secure and private. Implementing on-device voice processing and customizable privacy settings would give users greater control over data, fostering trust and aligning with ethical standards, especially for vulnerable groups.

Looking ahead, this system's potential applications extend far beyond its current use case. As we continue to integrate AI and robotics into daily life, this technology could play a pivotal role in improving the quality of life for elderly individuals, people with disabilities, and those in need of companionship or assistance. By providing an engaging and interactive robot, this system could serve as a companion, a healthcare assistant, or even a home security solution.

However, for wider adoption, several factors need to be addressed. These include improving system responsiveness by optimizing the servo motors, ensuring data privacy and security through local processing, and addressing regulatory requirements in healthcare contexts. Additionally, the integration of more advanced sensors and AI could make the robot smarter and more adaptable to various user needs.

Overall, this robotic system provides a promising foundation for future innovations in HRI, offering both practical benefits and a high level of user satisfaction. By further improving its efficiency, reducing costs, and addressing ethical concerns, it has the potential to become a key player in healthcare and companionship robotics.

Cost Analysis

A preliminary cost analysis of the interactive robotic companion system is presented below, highlighting the expenses associated with each major component and the overall system.

In Table 4, the estimated cost of 10, 010 Tk BDT makes this system reasonably affordable for prototyping. However, cost optimization opportunities exist, such as using cost-efficient alternatives for high-cost components, like the Echo Dot and 360-degree wheels, which could reduce expenses for larger-scale projects. Additionally, scaling production through bulk manufacturing can leverage economies of scale to significantly lower costs, particularly for imported components.

Table 4. Cost breakdown of IOT-based manhole monitoring system prototype.

Component	Quantity	New Cost Total Unit (BDT)	Total Cost (BDT)
Arduino MEGA 2560	1	1650	1650
Echo Dot	1	1100	1100
TV CRT Display	1	1100	1100
360-Degree Wheels	4	440	1760
Servo Motors	4	660	1320
Person Sensor	1	330	330
AC/DC Converter	1	2750	2750
Total cost	–	–	10, 010 Tk

Novelty

The novelty of this prototype lies in its unique integration of animatronic eyes with natural language processing (NLP) through an Echo Dot, combined with 360-degree mobility and visual feedback via CRT TV. While many robots use NLP for voice interaction, this system enhances engagement by incorporating lifelike eye movements, making interactions more personable. The project's use of a legacy CRT for waveform display, despite its challenges, reflects a novel approach to providing real-time visual feedback. The hybrid control system, initially voice-command-based and later adapted to remote control, offers flexibility and precision. This comprehensive design, focusing on user-centric features and detailed power consumption analysis, sets the project apart as a distinctive and advanced robotic companion solution.

Future Scope

This prototype presents several avenues for future development. Key areas for further research include improving power consumption efficiency, expanding the robot's expressive features, and exploring additional applications for the system. Addressing challenges, like CRT TV compatibility and intricate wiring management, will enhance the robustness and versatility of future robotic solutions. Future iterations may also focus on refining usability, particularly for elderly individuals and those with physical limitations, thereby advancing the potential of interactive robotic companions.

CONCLUSIONS

This study presents the development of an interactive robotic companion that enhances human-robot interaction (HRI) by integrating natural language processing (NLP), mobility, and expressive animatronic features. The robot uses an Echo Dot for voice interaction, servo-driven animatronic eyes for lifelike responses, and a CRT display for visual feedback. Performance assessments indicate efficient operation, with a total power consumption of 22 watts and a response time of 500 milliseconds. Feedback from users, especially elderly individuals and those with physical limitations, was positive, highlighting the robot's potential in both social and assistive contexts.

Challenges in sourcing compatible components and managing wiring were overcome, improving system reliability. The hybrid control model, which initially relied on voice commands and later added remote control, provides flexibility, particularly for users with limited mobility. To improve scalability, efficiency, and cost-effectiveness, optimizing component choices, enhancing power efficiency, and adopting a modular design are recommended. Commercial viability can be achieved by reducing production costs, improving power efficiency, and ensuring compliance with healthcare regulations.

Overall, the study provides a solid foundation for further advancements in interactive robotics, with potential applications in healthcare, companionship, and more. Future research should focus on optimizing system components and exploring commercial opportunities. In conclusion, this project provides a solid foundation for future innovations in interactive robotics by showcasing how expressiveness, mobility, and intuitive design can be effectively combined in robotic companions. Future research and development may focus on optimizing power efficiency, further refining user interaction features, and expanding applications, paving the way for more versatile, user-friendly robotic solutions in healthcare, companionship, and beyond.

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