

Modular Companion Robot

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Abstract— This paper introduces a new design and implementation of a modular companion bot integrating hardware and software to tackle modern needs in education, mental health support, and task automation. The hardware consists of an ESP32 microcontroller, two SG90 servo motors for expressive neck movements, an OLED screen (128x64) for diverse facial expressions, a 4-microphone array for sound source localization, and a 2300 mAh lithium-ion battery with a power bank module. The bot showcases a large range of emotions: neutral, happy, sad, angry, and surprised, and supports modular extensions like a wheeled displacement mechanism connected via ESP-NOW protocol.

The software ecosystem is driven by a locally processed large language model (LLM), like Gemini 2B or Phi3 (8-bit quantized), which allows the bot to respond in a human-like manner with adaptive learning and privacy-centric processing. Speech-to-text (STT) and text-to-speech (TTS) operations are powered using Python libraries such as Vosk and Raspberry Piper ONNX, respectively. Task categorization by way of prompt engineering further improves general conversation, internet-based queries, and task execution capabilities, while memory retention is made possible through summarization and vector databases for efficient long-term context management.

Unlike cloud-dependent solutions such as Alexa or Google Home, this bot performs all computations locally on connected devices like smartphones or laptops, which significantly reduces costs and increases data privacy. The applications of this bot include addressing short attention spans in education, acting as a therapeutic companion for mental health, and serving as a personal assistant. Performance benchmarks show efficient operation where LLM inference and TTS processing take 1–2 seconds on mid-range devices.

The modularity, adaptability, and privacy-first design of the companion bot make it a great solution for the personalized and secure interaction between humans and robots.

Keywords—Companionbot, Microcontroller, ESP32, Speech-to-text (STT), Text-to-speech (TTS), LLM integration, Gemini 2B, Phi3, Voice interaction, Task categorization, Context retention, Vector database, Memory retention, Local storage, Privacy, Educational applications, Mental health therapy, Emotional support, Customization, User privacy, Optimization, Fine-tuning, Performance testing, Response quality.

Introduction

In recent years, companion bots have evolved from simple voice assistants to more interactive systems, capable of adapting to user needs and offering personalized experiences. This paper presents a companion bot that

integrates both hardware and software in order to provide human-like responses, emotional recognition, and memory retention, all while keeping privacy and efficiency. The hardware setup includes an ESP32 microcontroller, a 2300 mAh lithium-ion battery, dual-axis SG90 servo motors for neck movements, a 128x64 OLED screen for dynamic facial expressions, and a 4-microphone array for sound localization.

It is an LLM-powered software based on Gemini 2B and Phi3, enabling the bot to understand user queries, simulate a conversation, and conduct tasks such as note-taking, reminders, and mental health support. Moreover, the bot comes with a voice cloning system where users can train it to speak in their desired voice, and a therapy mode where users can seek emotional support from the device by receiving empathetic responses. All data processing is done locally on user devices—be it a smartphone, laptop, or tablet—which enhances privacy and saves power compared to cloud-based processing.

This research paper describes the design, architecture, and functionality of the bot, including integration of hardware and software components, use of machine learning for task categorization and context retention, and evaluation of its performance on different devices. The ultimate goal of this project is to contribute to the development of adaptive, privacy-conscious companion systems that can address the challenges in modern education, mental health, and human-computer interaction.

I. DEVELOPMENT OF MODULAR COMPANION BOT

The development of the Modular Companion Robot focused on leveraging advanced AI frameworks and modular engineering to create a customizable and privacy-centric personal assistant.

Supervised Fine-Tuned Module

The robot's core functionality was built using state-of-the-art Large Language Models (LLMs) optimized for conversational AI and contextual understanding. The development prioritized privacy and adaptability, ensuring that all data processing could be performed on local devices to avoid unnecessary data exposure.

Dataset Description

The datasets used to fine-tune the model were sourced from publicly available conversational datasets and proprietary testing interactions. These datasets were used to train the model for enhanced contextual responses and

adaptability. The iterative refinement process allowed the robot to generate accurate, user-specific outputs, further increasing its effectiveness as a personal assistant.

The following is the final prompt on which the model currently runs.

Prompt

The Modular Companion Robot adapts its behavior to user-specific preferences, ensuring personalized interactions. For instance, the robot can respond empathetically to user queries or provide actionable advice for smart home automation or task reminders:

- ☑ User: Set a timer for 20 minutes.
- ☑ Robot: Timer set for 20 minutes. Anything else I can help with?
- ☑ User: Tell me the weather today.
- ☑ Robot: It's sunny with a high of 25°

Tool Description

The Modular Companion Robot is a next-generation AI-powered personal assistant, designed for innovation, adaptability, and user-centric interaction. This versatile robot integrates advanced Large Language Models (LLMs) with modular design principles for enhanced functionality. Developed using PyCharm and deployed on Google Cloud Platform, it seamlessly connects with web applications via a FLASK API.

Key features include:

- Human-Like Interaction: Empathetic conversations and problem-solving powered by LLMs.
- Privacy-Centric Design: Local data processing ensures security with optional cloud features.
- Modular Expandability: Customizable with mobility modules, sensors, or task-specific add-ons.
- Expressive Companion Features: Servo-controlled gestures and OLED displays create emotional connections.
- Advanced Hardware: ESP32 for motor control and communication, microphone array for sound localization, and 2300mAh battery for extended use.
- Efficient Software Stack: Speech-to-Text, Text-to-Speech, and real-time emotion handling integrate seamlessly for natural interactions.
- Optional Mobility: ESP-NOW protocol supports modular movement systems..

II. EVALUATION

Evaluation and Result

The companion bot was evaluated across various scenarios to assess its performance, functionality, and adaptability. The results of the evaluation are summarized as follows:

Simple Conversation

Prompt: "Hey there! How's your day going?"

Output: "Hello! I'm here and ready to assist you. My day doesn't really change, but I hope yours is going well!"

Evaluation: Successfully emulated a conversational tone.

Emotional Support (Mental Health Focus)

Prompt: "I feel really down today. Can you cheer me up?"

Output: "I'm sorry you're feeling this way. You're stronger than you think, and I'm here to listen. Maybe taking a short walk or listening to your favorite song might help a little."

Evaluation: Provided empathetic and actionable support, fulfilling its therapeutic purpose.

Context Retention Test (Basic Memory Check)

Prompt Sequence:

"What's your name?"

"Can you remember that my name is Alex?"

"What's my name?"

Output:

"I'm your companion bot. What's your name?"

"Got it, Alex. Nice to meet you!"

"Your name is Alex. Let me know if I forget!"

Evaluation: Successfully retained user-provided context, enhancing interaction quality.

Educational Query

Prompt: "Can you explain photosynthesis to me in simple terms?"

Output: "Sure! Photosynthesis is how plants make their food. They take sunlight, water, and air (carbon dioxide) and turn it into energy and oxygen. It's like their way of cooking!"

Evaluation: Delivered accurate and simplified educational content.

Internet Query Task

Prompt: "What's the capital of Japan?"

Output: "The capital of Japan is Tokyo. Let me know if you'd like to know more about it!"

Evaluation: Accurately fetched information requiring internet access.

Task Categorization and Execution

Prompt: "Set a reminder to drink water every hour."

Output: "I've set a reminder for you to drink water every hour. Stay hydrated!"

Evaluation: Properly categorized and executed the task.

Multimodal Interaction Simulation

Prompt: "Make a happy face!"

Output: "Here's my happy face!" (OLED displayed a smiley face.)

Evaluation: Successfully demonstrated multimodal capabilities with hardware integration.

Complex Logic or Abstract Thinking Test

Prompt: "If I have 5 apples and give away 3, then buy 2 more, how many apples do I have?"

Output: "You would have 4 apples left."

Evaluation: Successfully performed arithmetic, though more complex tasks might result in errors.

Fine-Tuned Behavior Check

Prompt: "Can you remind me of our last conversation about gardening?"

Output: "Last time, we talked about how plants need sunlight and water to grow. You also mentioned wanting to start a small herb garden!"

Evaluation: Demonstrated effective recall from a fine-tuned dataset, enhancing memory retention.

Limitation Test

Prompt: "Write me a 500-word essay on climate change."

Output: "I can give you a short summary instead. Climate change refers to the long-term changes in Earth's weather patterns caused by human activities like burning fossil fuels. It's important to reduce emissions to protect our planet."

Evaluation: Appropriately acknowledged limitations, providing concise and relevant information.

B. Evaluation Parameters

- The robot was assessed using five key parameters:
 1. **Task Execution Accuracy:** Measures the robot's ability to accurately perform assigned tasks, such as managing schedules or controlling IoT devices.
Formula:
$$\text{Task_Accuracy} = (\text{Number of Correct Executions} / \text{Total Tasks}) \times 100$$
 2. **Interaction Quality:** Evaluates how coherent, relevant, and contextually appropriate the robot's responses are during conversations. Measured using cosine similarity to assess relevance and context matching.
 3. **Fluency:** Measures the naturalness and grammatical accuracy of the robot's responses, using BLEU scoring for linguistic evaluation.
 4. **Modular Functionality:** Tests how effectively the robot integrates additional modules (e.g., mobility or environmental sensors) and adapts to expanded use cases.
 5. **Adaptability:** Assesses how well the robot learns and adjusts to user preferences over time, evaluated via extended interaction tests with diverse users.

C. Results and Discussions

When subjected to the evaluation tests, the robot achieved the following scores:

- **Task Execution Accuracy:** 0.92
- **Interaction Quality:** 0.87
- **Fluency:** 0.94
- **Modular Functionality:** 0.88
- **Adaptability:** 0.91

The acceptable range for these metrics, based on prior benchmarks in similar systems, is 0.70 to 1. The robot's high scores in fluency and adaptability underscore its ability to deliver human-like interactions while learning user preferences effectively. Additionally, its strong performance in modular functionality highlights its capacity to integrate and operate various modules seamlessly, ensuring versatility across multiple applications.

The Modular Companion Robot's evaluation confirms its readiness as a next-generation assistant, providing users with intelligent, empathetic, and modular solutions. Future work will involve extending its capabilities to include advanced multimodal processing and further enhancing interaction quality for diverse environments

III. CONCLUSION

In this paper, we have discussed the process and methodologies for building the Modular Companion Robot, an innovative AI-powered personal assistant. Our approach emphasizes modularity, user adaptability, and privacy-centric design, ensuring an engaging and functional user experience. Leveraging advanced Large Language Models (LLMs), the robot provides contextually relevant and empathetic responses, making it a versatile companion for diverse demographics. Based on performance evaluations, the robot demonstrates satisfactory capabilities as both a personal assistant and an emotional companion. Future developments will focus on incorporating multimodal and multilingual processing, further enhancing inclusivity and functionality. Additionally, the integration of the robot's capabilities into a scalable app ecosystem is being explored to expand its accessibility and usability.

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