OMNI (Optimized Machine for Navigation & Interaction)

an automated solution for efficient OMNI (Optimized Machine for Navigation & Interaction)

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Abstract — This paper presents OMNI (Optimized Machine for Navigation and Interaction), a fully offline, affordable, and intelligent home assistant robot designed to assist elderly individuals and children through natural voice interaction, autonomous navigation, face recognition, and smart home automation. Traditional home environments lack intelligent robotic systems capable of providing genuine companionship, physical assistance, and home device control in a unified offline platform. OMNI addresses this gap using a dual-processor architecture combining a Raspberry Pi 3B as the primary AI brain and an ESP32 microcontroller as the real-time body controller. The four-wheeled differential drive chassis is powered by 100RPM geared DC motors controlled through an L298N

Keywords: OMNI, Home Assistant Robot, Raspberry Pi, ESP32, Autonomous Navigation, Offline AI, Speech Recognition, Face Recognition, Natural Language Processing, Large Language Model, Human-Robot Interaction, Home Automation, Obstacle Avoidance, Edge AI, OpenCV, Whisper STT, Piper TTS, MQTT, Socially Assistive Robotics, Differential Drive.

1. INTRODUCTION

Agriculture plays a vital role in the global economy; similarly, intelligent robotic assistance plays a vital role in improving the quality of life for elderly individuals and children in the modern era. In India, the rapidly growing elderly population, projected to exceed 300 million by 2050, faces increasing challenges including limited mobility, social isolation, and difficulty managing smart home devices without assistance. Children benefit enormously from interactive educational robot companions that engage them in learning, storytelling, and play. Traditional home environments lack intelligent systems capable of addressing these needs affordably.

The advancement of embedded computing, open-source artificial intelligence, and IoT communication has made it possible to build genuinely intelligent home assistant robots at low cost. By integrating a Raspberry Pi 3B as an AI cognitive processor with an ESP32 as a real-time hardware controller, it is now possible to implement offline speech recognition, natural language conversation, face recognition, autonomous navigation, and home automation in a single unified robot platform costing approximately Rs. 4,200.

This paper presents OMNI — Optimized Machine for Navigation and Interaction — a four-wheeled autonomous home assistant robot that wakes up when called by name, listens to natural language voice commands, generates intelligent responses using a locally hosted large language model, recognizes family members by face, navigates home environments while avoiding obstacles, carries small objects, and controls smart home devices through voice commands. All intelligence operates entirely offline on local hardware — no voice data, face data, or conversation is ever transmitted to any external server, ensuring complete user privacy.

2. ABBREVIATIONS AND ACRONYMS

The following abbreviations and acronyms are used throughout this research paper:

Abbreviation	Full Form
OMNI	Optimized Machine for Navigation and Interaction
AI	Artificial Intelligence
IoT	Internet of Things
ESP32	Espressif Systems 32-bit Microcontroller
Pi	Raspberry Pi Single-Board Computer
GPIO	General Purpose Input Output
PWM	Pulse Width Modulation
LEDC	LED Control — ESP32 PWM peripheral
I2S	Inter-IC Sound — audio communication protocol
USB	Universal Serial Bus
UART	Universal Asynchronous Receiver Transmitter

3. HEADINGS

The headings in this paper are organized in a structured manner to ensure clarity, readability, and proper presentation of the content. Different levels of headings represent the hierarchy of information.

- Main Headings are numbered and written in bold capital letters to indicate major sections of the paper such as Introduction, Methodology, Results, and Conclusion.
- Subheadings are used to divide sections into smaller topic-specific parts and are written in bold with title case for better understanding of subsystem details.
- Sub-subheadings are used for further division where required and are written in bold italic format.
- All headings are aligned to the left margin and follow a consistent numbered hierarchy throughout the document.
- Adequate spacing is maintained before and after each heading to visually separate sections and improve document navigation.

4. FIGURES AND TABLES

Figures and tables are used throughout this paper to present system architecture, hardware specifications, software components, wiring configurations, and experimental results in a clear and structured manner.

- Figures include the OMNI system block diagram, voice pipeline flowchart, face recognition flowchart, Data Flow Diagram, and photographs of the assembled prototype.
- Each figure is properly labeled and numbered (e.g., Fig. 1, Fig. 2) with a descriptive caption placed below the figure.
- Figures are placed adjacent to the relevant content for easy cross-reference.

Table 1: OMNI Hardware Components and Specifications

Component	Function	Specification	Cost (Rs.)
Raspberry Pi 3B	Primary AI brain — voice, face, LLM	1GB RAM, 1.2GHz Quad-core, Wi-Fi	~5,000
ESP32	Real-time body controller	520KB RAM, 240MHz Dual-core, Wi-Fi+BT	~350
L298N Motor Driver	Motor direction & speed control	12V, 2A per channel, dual H-bridge	~150
DC Geared Motor x2	Drive the robot chassis	100RPM, 12V	~300

5. LITERATURE REVIEW

The development of OMNI is informed by published research across multiple technical domains including socially assistive robotics, offline speech recognition, edge AI deployment, computer vision, autonomous navigation, and IoT home automation.

A. Socially Assistive Robotics

Mataric et al. (2007) formally defined socially assistive robotics as a discipline focused on robots that assist through social interaction rather than physical manipulation, demonstrating significant potential for elderly care and child development. Studies conducted in care facilities showed that interactive robots reduce loneliness and improve psychological wellbeing in elderly participants. Despite these promising results, existing socially assistive robots such as Softbank Pepper and Embodied Moxie are priced beyond Rs. 7,00,000, making them inaccessible to ordinary households. OMNI directly addresses this affordability gap.

C. Edge AI and Local LLM Deployment

Kumar and Patel (2024) validated the feasibility of running quantized large language models on Raspberry Pi single-board computers using the Ollama framework. Their study demonstrated that the Phi-3 mini model in 4-bit quantized form produces contextually appropriate conversational responses within 6 to 10 seconds on Pi 3B hardware. This confirmed the viability of offline AI conversation on edge devices without cloud dependency, forming the foundation for OMNI's conversational intelligence module.

D. Face Recognition on Embedded Platforms

Mehta and Jain (2023) evaluated face recognition accuracy using OpenCV and the face_recognition library on Raspberry Pi hardware and demonstrated 94% recognition accuracy under adequate indoor lighting at processing rates of 5 to 10 frames per second. Their work confirmed the practical viability of real-time face recognition on single-board computers, validating the approach adopted in OMNI for personalized family member identification.

6. METHODOLOGY

The development of OMNI follows a modular methodology where each functional component is designed, implemented, and individually tested before integration into the complete system. This approach ensures reliability at the component level before system-level validation is performed.

A. System Architecture Design

OMNI employs a master-slave dual-processor architecture. The Raspberry Pi 3B serves as the master cognitive processor responsible for all artificial intelligence tasks. The ESP32 serves as the slave body controller managing all real-time hardware operations. Communication between the two processors occurs via USB serial at 115200 baud. The Raspberry Pi sends single-character movement commands (F, B, L, R, S, A) to the ESP32, which responds with sensor data and status messages.

B. Hardware Assembly

The hardware assembly process proceeded in the following sequence: chassis construction and motor mounting; L298N wiring to ESP32 GPIO pins; HC-SR04 sensor mounting and connection with voltage divider protection; INMP441 and MAX98357 I2S audio hardware connection to Raspberry Pi GPIO pins; USB webcam attachment;

C. ESP32 Firmware Development

The ESP32 firmware was developed using Arduino IDE with ESP32 Core v3.x. The firmware initializes the L298N direction pins as digital outputs and configures PWM using the updated LEDC API: ledcAttach(pin, 1000, 8) for initialization and ledcWrite(pin, value) for speed control. The firmware receives movement commands from the

D. Raspberry Pi Software Pipeline

The Raspberry Pi hosts a multi-threaded Python application coordinating all AI modules. The installation sequence on Raspberry Pi OS Bookworm includes: Python dependencies via apt and pip; Ollama framework installation and Phi-3 mini model download; Whisper tiny model installation; Piper TTS model download; Porcupine wake word engine setup; OpenCV and face_recognition library installation; PySerial for ESP32 communication; and Paho-MQTT for home automation.

captures webcam frames, detects face regions using OpenCV, extracts encodings, and compares them against registered encodings using Euclidean distance with a threshold of 0.6.

7. RESULTS AND DISCUSSION

The OMNI robot prototype was successfully assembled and comprehensively tested across all planned functional modules. Table 4 summarizes the performance results achieved against defined targets.

Table 4: OMNI Comprehensive Performance Test Results

Sr. No.	Test Parameter	Result Achieved	Target	Status
1	Motor Control — Forward / Backward / Turn / Stop	All commands executed correctly	Reliable execution	✓ Achieved
2	Obstacle Avoidance (HC-SR04)	100% success at 25cm threshold	>95% success	✓ Achieved
3	Pi ↔ ESP32 Serial Communication Latency	<50ms round-trip over 2 hours	<100ms	✓ Achieved
4	Wake Word Detection (Hey OMNI)	<2 false positives per hour	Reliable detection	✓ Achieved

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14. AUTHORS' BIOGRAPHY

Chaitanya Nagapure is a diploma engineering student in the field of Information Technology at TGPCET, Nagpur. He is the lead developer of the OMNI project and has hands-on experience with embedded systems, Raspberry Pi, ESP32, Arduino, and AI pipeline development. His primary contributions to OMNI include the ESP32 motor control firmware, the Raspberry Pi-ESP32 communication system, and the overall system architecture design.

Karan Ambule is a diploma engineering student in Information Technology at TGPCET, Nagpur. He has a strong interest in artificial intelligence and machine learning applications. His contributions to the OMNI project include the integration of the OpenAI Whisper speech recognition pipeline and the Ollama large language model deployment on the Raspberry Pi.

Lucky Nikule is a diploma engineering student in Information Technology at TGPCET, Nagpur, with keen interest in computer vision and image processing. His contributions to the OMNI project include the face detection and recognition system implementation using OpenCV and the face_recognition library, and the face registration workflow development.

Chaitanya Ukey is a diploma engineering student in Information Technology at TGPCET, Nagpur, with interest in IoT and home automation systems. His contributions to the OMNI project include the MQTT-based home automation integration, Mosquitto broker configuration, and the voice command to device control mapping implementation.

Pavankumar Jinka is a diploma engineering student in Information Technology at TGPCET, Nagpur. He has interest in embedded systems and hardware design. His contributions to the OMNI project include hardware assembly.

15. REFERENCES

- **[1]** Mataric, M. J., Eriksson, J., Feil-Seifer, D. J., and Winstein, C. J., "Socially Assistive Robotics for Post-Stroke Rehabilitation," Journal of NeuroEngineering and Rehabilitation, Vol. 4, No. 1, pp. 1–12, 2007.
- **[2]** Radford, A., Kim, J. W., Xu, T., et al., "Robust Speech Recognition via Large-Scale Weak Supervision," arXiv:2212.04356, OpenAI, September 2022.
- **[3]** Kumar, A., and Patel, S., "Offline Voice Assistants Using Whisper and Local LLMs on Resource-Constrained Edge Devices," International Journal of Computer Science and Engineering, Vol. 12, No. 3, pp. 145–152, 2024.
- **[4]** Mehta, S., and Jain, R., "Real-Time Face Recognition Using OpenCV on Raspberry Pi for Home Applications," International Journal of Computer Vision and Applications, Vol. 14, No. 4, pp. 78–86, 2023.
- **[5]** Singh, K., Gupta, R., and Sharma, P., "ESP32-Based Embedded Motor Control Systems for Mobile Robotics Applications," Elsevier Internet of Things Journal, Vol. 18, pp. 100–112, 2022.
- **[6]** Brown, M., Clark, J., and Wilson, P., "Human-Robot Interaction Enhancement with Animated Facial Expression Displays," IEEE Conference on Social Robotics, pp. 145–152, 2021.
- **[7]** Verma, P., Gupta, N., and Singh, K., "MQTT-Based IoT Home Automation Framework for Smart Environments," International Journal of Engineering Research and Technology (IJERT), Vol. 12, Issue 6, pp. 67–73, 2023.
- **[8]** Chen, L., Wang, Y., and Liu, H., "Socially Assistive Robots for Elderly Care Using Edge Artificial Intelligence," Springer Journal of Smart Systems, Vol. 9, No. 2, pp. 200–215, 2024.
- **[9]** Sharma, R., Verma, P., and Singh, A., "Edge AI Deployment on Resource-Constrained Single-Board Computers for Embedded Applications," IEEE Access, Vol. 13, pp. 45230–45242, 2025.
- **[10]** Roy, A., and Sen, D., "Autonomous Indoor Navigation for Differential Drive Home Robots Using Ultrasonic Sensing," International Journal of Robotics Research, Vol. 13, No. 2, pp. 55–64, 2022.
- **[11]** Meng, T., Zhang, L., and Zhao, W., "Voice-Controlled Companion Robot for Elderly Assistance Using Raspberry Pi," IEEE Transactions on Human-Machine Systems, Vol. 53, No. 4, pp. 312–321, 2023.
- **[12]** Bradski, G., and Kaehler, A., Learning OpenCV: Computer Vision with the OpenCV Library, O'Reilly Media, Sebastopol, CA, USA, 2008.
- **[13]** Patel, R., Desai, A., and Mehta, K., "I2S Audio Pipeline Implementation for Raspberry Pi in Embedded Voice Interaction Systems," International Journal of Embedded Systems, Vol. 14, No. 3, pp. 178–186, 2022.
- **[14]** Espressif Systems, ESP32 Series Datasheet, Version 3.9, Espressif Systems Co., Ltd., Shanghai, China, 2023.
- **[15]** Raspberry Pi Foundation, Raspberry Pi 3 Model B Product Brief, Cambridge, United Kingdom, 2022.