Abbreviations Used

BLE: Bluetooth Low Energy – Wireless protocol for setup.

ESP32: A microcontroller with Wi-Fi/BLE for processing.

ETB: Ethiopian Birr – Currency used for budgeting.

INMP441: A MEMS microphone model for voice capture.

KPI: Key Performance Indicator – Metric for success.

MEMS: Micro-Electro-Mechanical Systems – Technology for microphones.

MQTT: Message Queuing Telemetry Transport – Protocol for device communication (optional).

PCB: Printed Circuit Board – Board for mounting components.

USD: United States Dollar – Original currency for reference.

Product Plan: Voice-Activated Smart Home Assistant

1. Objectives

Goal: Develop an affordable, offline voice-activated smart home assistant tailored for Ethiopian households, bundled with four basic devices (10W LED bulb, <50W fan, solenoid-based smart lock, <500W heater) to control eight distinct scenarios. The system prioritizes low cost, privacy through offline processing, and ease of use as a complete solution.

Timeline: 4.5 months (18 weeks) from concept to final prototype, executed by a four-person team with embedded systems expertise.

Benefit:

- Provides an all-in-one smart home solution at a fraction of the cost of imported alternatives (e.g., Amazon Alexa, Google Home).
- Ensures privacy by avoiding cloud dependency, critical for users concerned about data security.
- Addresses unreliable internet in Ethiopia, making it accessible for rural and semi-urban areas.
- Bundled devices simplify adoption, offering a plug-and-play experience.

Key Performance Indicators (KPIs):

- Voice Recognition Accuracy: >95% for eight predefined commands in noisy environments (up to 50 dB background noise, typical for homes).
- Response Time: <1 second from wake word detection to relay actuation. Power Consumption: Controller <2W in standby, <5W during active use (excluding bundled devices).
- Cost: Total product cost ≤13,560 ETB (~$110 USD at 1 USD = 123 ETB, April 2025 estimate) per unit, including controller and devices.
- Reliability: System uptime >99% during 24-hour stress tests with all devices connected.

Focus Areas:

- Cost Optimization: Use widely available, low-cost components (e.g., ESP32, INMP441) and pre-made enclosures to minimize manufacturing expenses.
- Offline Functionality: Leverage Picovoice for local speech processing, eliminating internet dependency.
- Bundled Devices: Pre-tested, low-power devices ensure compatibility and reduce user setup complexity.
- User Experience: Simple voice commands in English and Amharic, with LED feedback for intuitive operation.

2. Domain/Market Research

Domain:

- Embedded Systems: Microcontroller-based control (Arduino Uno) for voice processing, relay switching, and BLE configuration.
- Voice Recognition: Offline speech-to-intent processing using lightweight models optimized for resource-constrained devices.
- Bluetooth Control: Command processing via an HC-05 Bluetooth module using an MIT App Inventor app, optimized for resource-constrained devices like the Arduino Uno. Supports eight predefined commands in English and Amharic for controlling four devices (fan, bulb, door, heater). Password-based authentication ensures secure access.
- Low-Power Design: Critical for battery backup during frequent power outages in Ethiopia.

Market Trends:

- Growing Demand: Increasing interest in smart home devices in Ethiopia, particularly among urban and semi-urban homeowners (Addis Ababa, Hawassa, Bahir Dar). ● Affordability Barrier: Imported solutions (e.g., Alexa, Google Home) cost 20,000–40,000 ETB, unaffordable for most Ethiopians (average monthly income ~5,000 ETB in urban areas).
- Offline Preference: Unreliable internet (3G/4G coverage spotty outside cities) drives demand for non-cloud solutions.
- Bundled Solutions: Consumers prefer ready-to-use kits over standalone controllers, as seen in local solar kit sales.
- Local Production: Government incentives for local tech manufacturing (e.g., tax breaks under Ethiopia's Digital Transformation Strategy) support feasibility.

Regulations:

- Electrical Standards: Devices must comply with ES 6141:2017 (Ethiopian standard for 220V, 50Hz appliances).
- Safety: Relays and enclosures must meet fire and electrical safety requirements (e.g., insulation for 10A, 220V loads).
- EMC Compliance: Electromagnetic compatibility to avoid interference with other household devices.
- Import Duties: Using locally sourced or regionally available components reduces costs, as imported electronics face 30–40% tariffs.

Market Analysis:

- Target Audience: Urban/semi-urban homeowners aged 25–45, tech-savvy, with disposable income for home upgrades (~500,000 households in Ethiopia).
- Competitors: Global: Amazon Alexa, Google Home (cloud-dependent, expensive, no Amharic support).
- Local: Basic RF-based controllers (no voice control, limited functionality). Gap: No affordable, offline, voice-activated solution with bundled devices exists locally.
- Positioning: Market as a privacy-focused, all-in-one kit undercutting competitors by 50%+ in price.

Constraints:

- Power Outages: Frequent in rural areas, requiring battery backup.
- Noise: Homes often have background noise (e.g., children, street sounds), necessitating robust voice recognition.
- Skill Gap: Limited local expertise in voice processing; team must rely on open-source tools like Picovoice.

3. Product Definition

Features:

- **Bluetooth Control**: Supports eight scenarios via predefined commands sent through an MIT App Inventor app:
    1. “Fan on” / “Fan off” (or “አየር ማራገቢያ አብራ” / “አየር ማራገቢያ አጥፋ”)
    2. “Light on” / “Light off” (or “መብራት አብራ” / “መብራት አጥፋ”)
    3. “Door lock” / “Door unlock” (or “በር ቆልፍ” / “በር ክፈት”)
    4. “Heater on” / “Heater off” (or “ማሞቂያ አብራ” / “ማሞቂያ አጥፋ”)
- **Authentication**: Password-based security (e.g., “secure123”) required before sending control commands. Optional “logout” command to de-authenticate.
- **Relay Control**: Six-channel relay module (four used: fan, bulb, door, heater; two reserved for future expansion) supports up to 10A, 220V per channel in real hardware, simulated as LEDs in Proteus.
- **Feedback**: In Proteus simulation, feedback is provided via a virtual terminal displaying messages (e.g., “Authenticated successfully”, “Unauthorized”, or received command). In real hardware, optional LEDs (green for success, red for error) can be added.
- **Setup**: Bluetooth Classic (HC-05) pairing via smartphone app (MIT App Inventor, Android-only for now) with a configurable PIN (e.g., “5678” instead of default 1234/0000). Language selection (English/Amharic) via app buttons.
- **Bundled Devices (Simulated)**:
    - LED bulb (simulated as a 10W LED in Proteus).
    - Small fan (simulated as an LED or motor model, <50W equivalent).
    - Solenoid-based smart lock (simulated as an LED or relay, low-power).

- Small heater (simulated as an LED or relay, <500W equivalent).

Specifications:

- **Hardware**:
  - **Microcontroller**: Arduino Uno (ATmega328P, 16 MHz, 32 KB flash, 2 KB SRAM).
  - **Bluetooth Module**: HC-05 (Bluetooth Classic, 9600 baud default, configurable PIN).
  - **Relay Module**: 6-channel, 10A/250V AC per channel (simulated as LEDs in Proteus, opto-isolated in real hardware).
  - **Power Supply**: 5V USB input (1A min) for Arduino and HC-05. No battery backup in simulation (optional 9V battery or 5V power bank for real hardware).
  - **Indicators**: Virtual terminal in Proteus for feedback (e.g., "Received: light on"). Optional LEDs (green for success, red for error) for real hardware.
  - **Enclosure**: Simulated in Proteus as a virtual circuit; real hardware uses a pre-made ABS plastic box (IP54, ~100x100x50 mm, wall-mountable).
  - **PCB**: Not used in simulation; real hardware uses a custom 2-layer FR4 board (1.6 mm thickness) for Arduino and HC-05 integration.
- **Software**:
  - **Firmware**: C/C++ in Arduino IDE, using Serial library for Bluetooth communication and string parsing.
  - **Bluetooth Stack**: HC-05's SPP (Serial Port Profile) for communication with MIT App Inventor app.
  - **App**: MIT App Inventor (Android) for sending commands and password authentication. Supports English and Amharic via text buttons.
  - **Optional**: Future support for MQTT or cloud integration possible with additional hardware (e.g., ESP8266/ESP32).
- **Bundled Devices (Simulated Specs)**:
  - **LED Bulb**: Simulated as a 10W, 800-lumen LED (E27 base, 220V equivalent).
  - **Fan**: Simulated as a <50W, 3-speed, 12-inch blade tabletop fan (220V equivalent).
  - **Smart Lock**: Simulated as a solenoid-based lock, 12V DC (5W max, 220V adapter in real hardware).
  - **Heater**: Simulated as a <500W ceramic heater with overheat protection (220V equivalent).
- **Size**:
  - Controller: Simulated in Proteus; real hardware ~100x100x50 mm (excluding HC-05 antenna).
  - Devices: Bulb (standard E27), fan (~300x300x400 mm), lock (~150x50x30 mm), heater (~200x150x100 mm).
- **Environmental**:
  - Operating temperature: 0–40°C (suitable for Ethiopian homes).
  - Humidity: 20–80% non-condensing.
- **Compatibility**:
  - Relays support 220V, 50Hz appliances up to 10A in real hardware. Simulated devices (LEDs) pre-tested in Proteus for plug-and-play integration.

Feasibility:

- **Technical**:
  - **Processing**: Arduino Uno's ATmega328P handles Bluetooth communication and relay control adequately for four devices, though limited by 2 KB SRAM (careful string handling required for Amharic UTF-8).
  - **Bluetooth**: HC-05's 9600 baud rate supports text commands (English/Amharic). PIN configuration (e.g., "5678") adds pairing security in real hardware.
  - **Power**: 5V USB is widely available; simulation assumes stable power, real hardware may need a 9V battery for portability.
  - **Relays**: 10A rating supports all bundled devices (<500W). LEDs simulate relays in Proteus.
- **Cost**: Estimated ~8,000–10,000 ETB for real hardware (Arduino Uno: ~1,500 ETB, HC-05: ~1,000 ETB, relay module: ~1,000 ETB, devices: ~4,500 ETB, enclosure/PCB: ~1,000 ETB). Lower than imported kits (~20,000 ETB). Simulation costs are negligible (software licenses only).
- **Time**: ~2 months for simulation development and testing in Proteus with MIT App Inventor. Real hardware prototyping adds ~1 month (total ~3 months with a skilled team).
- **Risks**:
  - **Proteus Limitations**: HC-05 model doesn't simulate AT commands or PIN pairing. Mitigated by assuming PIN is set and using password authentication ("secure123").
  - **Amharic String Handling**: Arduino Uno's limited SRAM may cause issues with UTF-8 Amharic strings. Mitigated by trimming strings and using Serial.readStringUntil('\n').
  - **Component Availability**: Arduino Uno and HC-05 widely available; relays and simulated devices use standard Proteus models.
  - **Security**: Password authentication mitigates unauthorized access in simulation; PIN change applies to real hardware.

4. Development Roadmap

Plan:

Weeks 1-3: Hardware selection (controller + devices), schematic design, voice setup.
Weeks 4-9: Build prototype, integrate and test all 8 scenarios with bundled devices.
Weeks 10-14: Optimize voice accuracy, power, error handling.
Weeks 15-18: Add BLE setup, finalize enclosure, document.

Milestones:

Week 3: Design complete.
Week 9: Functional prototype with devices.
Week 14: Optimized prototype.
Week 18: Final prototype.

5. Budget and Resource Allocation

Resources:

Team: 4 developers (embedded systems skills).
Core Controller Cost (ETB):
- **Arduino Uno**: 1,500 ETB
- **HC-05 Bluetooth Module**: 1,000 ETB
- **6-Channel Relay**: 1,200 ETB
- **5V USB Power**: 300 ETB
- **LEDs + Resistors**: 60 ETB
- **PCB + Misc.**: 1,200 ETB
- **Enclosure (pre-made plastic box)**: 360 ETB
- **Subtotal (Controller)**: 5,620 ETB

Bundled Devices Cost (ETB):
- **10W LED Bulb**: 300 ETB
- **Small Fan (<50W)**: 1,200 ETB
- **Basic Smart Lock (Solenoid)**: 3,600 ETB
- **Small Heater (<500W)**: 2,400 ETB
- **Subtotal (Devices)**: 7,500 ETB

Total Product Cost: 5,620 + 7,500 = 13,120 ETB
Additional Testing Costs: 600 ETB (spare components for controller, e.g., extra Arduino Uno, HC-05, relays).
Grand Total (Product + Testing): 13,120 + 600 = 13,720 ETB
Source: Self-funded, local grants, or university funding.

Justification: The Arduino Uno-based system with HC-05 Bluetooth control provides a cost-effective, secure solution with password authentication and MIT App Inventor app integration. Bundled devices ensure a complete smart home solution, simulated in Proteus for rapid prototyping. The total cost (~13,720 ETB) remains competitive against imported kits (~20,000 ETB), leveraging widely available components and simplified development in a simulation environment.

6. Launch Strategy

Deployment:

Demo on Ethiopian tech forums, Telegram, ICT Expo Ethiopia; collaborate with Addis Ababa University.
Testing: In local homes (220V, noise, temperature) using bundled devices.
Documentation: English/Amharic guide (GitHub); include setup for bundled devices.
Power: 5V USB for controller, battery backup for outages; devices use 220V.
Maintenance: Modular controller design, BLE firmware updates; devices replaceable.
Security/Privacy: Offline processing, secure BLE.
Localization: English/Amharic commands, local accent support. Scenarios & Implementation Scenarios:

- "Lights on/off": Relay 1 (10W LED bulb).
- "Fan on/off": Relay 2 (small fan).
- "Door lock/unlock": Relay 3 (smart lock).
- "Heater on/off": Relay 4 (small heater).

Flow: Microphone captures audio.
Wake word ("Hey Home") triggers listening.
Speech-to-intent (e.g., "heater on" → HEATER_ON).
ESP32 toggles relay (e.g., Relay 4). Green LED blinks for feedback.