Offline Voice-Controlled Device Using Arduino Uno and Bluetooth

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***Abstract*—Home automation systems are increasingly popular worldwide, but most rely on cloud services, limiting their usability in rural Bangladesh where internet connectivity is unreliable. This paper presents a low-cost, fully offline smart home automation prototype designed to assist not only general households but also vulnerable groups such as the elderly, children, and persons with disabilities. The system is controlled by simple multilingual (Bangla, Banglish, English) voice commands and secured with RFID authentication. An Android application, developed using MIT App Inventor, converts user voice input into text and transmits it via Bluetooth to an Arduino Uno. The Uno drives relays to control a fan and light, and servos to operate a curtain. A dedicated Arduino Nano with an RC522 RFID module manages secure door lock actuation and a dispenser mechanism. The system provides buzzer and LED feedback for invalid card use, including an alarm mode triggered after repeated failed attempts. Powered by a 220V AC to 5V DC SMPS, the prototype demonstrated reliable performance with minimal latency. Results indicate the system's potential as an affordable, privacy-preserving, multilingual, and socially inclusive home automation solution for rural households in Bangladesh.**

Index Terms— Smart home, IoT, Offline automation, Arduino Uno, Arduino Nano, RFID, Voice control, Bangladesh, Accessibility, Multilingual

I. INTRODUCTION

Smart home automation is a rapidly growing domain within the Internet of Things (IoT), providing convenience, energy efficiency, and enhanced security to users. However, many existing systems rely heavily on cloud services and constant internet connectivity. In Bangladesh, particularly in rural areas, limited network availability and affordability issues pose significant barriers to the adoption of such technologies.

The motivation behind this work is to design a home automation system that functions entirely offline while ensuring both essential automation and household security. The proposed system allows users to control appliances such as a fan, light, curtain, door lock, and dispenser through simple voice commands. To further enhance security, an RFID-based lock mechanism has been integrated, ensuring that only authorized users can access the door. **Additionally, the system is designed with accessibility in mind, supporting multilingual commands to accommodate elderly users, children, and persons with disabilities.**

The main contributions of this paper are as follows:

- Development of an **offline voice-controlled system** using Arduino Uno and Bluetooth (HC-05).
- Integration of **Arduino Nano with an RFID module** for secure door lock and dispenser control.
- Implementation of a **buzzer-based feedback mechanism** to indicate failed authentication attempts.
- A **low-cost, scalable design** tailored to the needs of rural households in Bangladesh.
- Support for **multilingual (Bangla, Banglish, English) voice commands** to improve accessibility for diverse user groups.

The remainder of this paper is organized as follows. Section II presents the literature survey. Section III describes the proposed system design and methodology. Section IV discusses the prototype implementation and experimental results. Fi-

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nally, Section V concludes the paper and highlights directions for future work.

II. Literature Review

A. Overview of Existing IoT Applications

IoT has been widely applied to smart home automation, robotics, and healthcare systems, with a strong emphasis on voice-based interaction and offline functionality. In robotics, [1] demonstrated a speech recognition-based wireless control system for mobile robots using offline Android ASR with Bluetooth communication to ESP32. Similarly, [2] proposed a CNN-driven voice recognition system to steer robotic wheelchairs, showing the applicability of voice-controlled IoT in accessibility.

In home automation, several systems have been developed. HomeIO [3] introduced a secure offline smart home platform with speech recognition and power tracking, while [4] combined an LD3320-based offline voice module with Arduino and ESP8266 for cloud logging. Offline voice detection with distributed microphones was studied in [5], and a hybrid offline–online approach with Alexa integration was presented in [15].

Other notable contributions include low-cost Arduino robots controlled via smartphone speech recognition [9], hardware-only offline voice modules with ESP32 [10], and deep learning-based offline automation [11]. Voice-activated lockers [12] and comparative studies of offline versus Bluetooth control [13] further illustrate the diversity of IoT speech applications. Conceptual frameworks for energy-efficient distributed recognition [14] and older designs for smart homes with simple voice modules [6]–[8] also highlight the breadth of IoT automation research.

B. Previous Approaches, Limitations, and Improvements

While existing works provide valuable insights, several limitations remain. Robotic applications [1], [2] demonstrated reliable offline speech-to-command systems but lacked home automation focus. HomeIO [3] and related smart home platforms introduced offline recognition and energy monitoring, yet they omitted strong access control or localized security. Systems such as [4], [5] explored offline voice detection but relied on single points of failure (Raspberry Pi) or hybrid cloud support, reducing privacy and resilience.

Hardware-driven solutions like Arduino robots [9] and VC02+ESP32 [10] proved affordable but were restricted to a fixed vocabulary of commands and offered no authentication. Deep learning-based systems [11] increased recognition accuracy but required computational resources unsuitable for low-cost microcontrollers. Security-focused applications like storage lockers [12] addressed access control but remained vulnerable to replay attacks and lacked multi-functionality. Comparative studies [13] highlighted trade-offs between offline and Bluetooth-based approaches but did not integrate authentication or multi-appliance control. Conceptual frameworks [14] remained unvalidated, and dual-mode systems [15] increased hardware complexity, making them unsuitable for rural low-resource settings.

In contrast, our proposed work integrates **offline voice control, RFID-based secure door access, dispenser automation, and multilingual command support** into a single prototype. This approach improves upon prior works by offering both automation and security in a fully offline, low-cost, and **socially inclusive** design tailored for the Bangladeshi context.

C. Summary of Research Gaps

From the reviewed literature, the following key gaps are identified:

- Heavy reliance on cloud services or hybrid systems, unsuitable for areas with limited internet connectivity.
- Limited vocabulary in offline systems, restricting flexibility of commands.
- Absence of integrated **security mechanisms**, particularly RFID-based authentication in offline smart home setups.
- Lack of multifunction prototypes combining **appliance control, secure door lock, and dispenser automation**.
- Minimal research targeting **Bangladesh-specific rural households**, where affordability and offline functionality are critical.
- Lack of attention to **accessibility and multilingual support** for elderly, children, and persons with disabilities.

This paper addresses these gaps by presenting a low-cost, offline voice-controlled smart home system with integrated RFID-based security, dispenser control, and multilingual accessibility features, specifically designed to meet the needs of rural Bangladesh.

III. Proposed System and Architecture

A. System Overview

The proposed system is an **offline IoT-based home automation prototype** that integrates voice control and RFID authentication for enhanced functionality and security. An Android application, developed using MIT App Inventor, processes voice commands locally on the smartphone and transmits them as text strings to the Arduino Uno through Bluetooth (HC-05). **The app supports multilingual (Bangla, Banglish, English) commands, ensuring accessibility for elderly users, children, and persons with disabilities.** The Arduino Uno controls household appliances such as the fan, light, and curtain using relay modules and servo motors.

A secondary Arduino Nano, connected to an RC522 RFID reader, handles door lock security and dispenser control. The Nano verifies the authenticity of RFID cards and provides feedback through a buzzer and LED indicators. In case of multiple failed attempts, an alarm-style buzzer response is triggered. **This division of responsibilities between Uno (appliance control) and Nano (authentication and dispenser) improves modularity and system reliability.**

The entire system is powered by a 220V AC to 5V DC switched-mode power supply (SMPS), ensuring reliable performance across all modules.

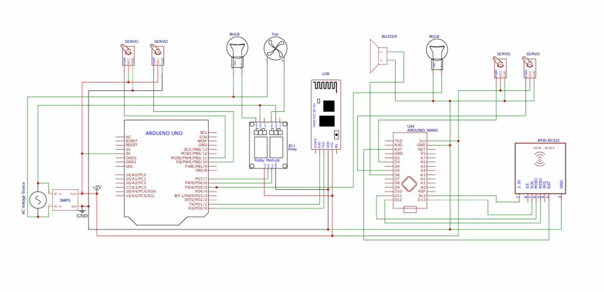


Fig. 1: Proposed Offline IoT Home Automation System Architecture integrating voice control, RFID-based security, and dispenser automation.

B. Hardware Components

The hardware modules selected for this project were chosen for their low cost, availability, and compatibility with offline IoT applications. Table I summarizes the key components and their functions.

TABLE I: Hardware Components and Justification

Component	**Function and Justification**
Arduino Uno	Main controller for appliance control; widely available, low cost, and supports multiple relays/servos.
Arduino Nano	Dedicated to RFID authentication and dispenser control; compact and power-efficient.
HC-05 Bluetooth Module	Ensures offline phone-to-board communication; reliable for short range.
RC522 RFID Reader	Provides secure door lock access; affordable and widely used authentication module.
Relay Module (5V)	Enables safe switching of fan and light from Arduino Uno GPIO.
Servo Motors	Used for curtain, door lock, and dispenser actuation; precise and low-power operation.
Buzzer and LED	Feedback mechanism for invalid authentication attempts and alarm mode.
SMPS (220V AC to 5V DC)	Provides stable power to all boards and components.
Veroboard	Used for compact integration and reliable soldered connections of prototype components.

1) Arduino Uno: The Arduino Uno acts as the central controller for appliance control (fan, light, curtain). It is selected for its affordability, community support, and sufficient GPIO pins.

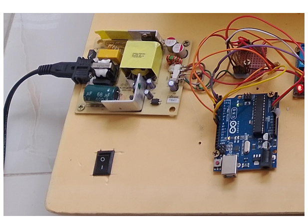


Fig. 2: Arduino Uno board used for appliance control.

2) Arduino Nano: The Arduino Nano is responsible for RFID authentication and dispenser actuation. Its compact size makes it suitable for modular security applications.

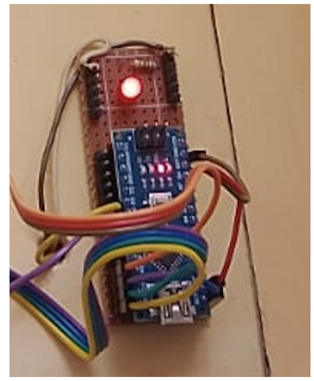


Fig. 3: Arduino Nano used for security and dispenser functions.

3) HC-05 Bluetooth Module: The HC-05 Bluetooth module enables offline communication between the Android application and Arduino Uno, ensuring usability without internet.

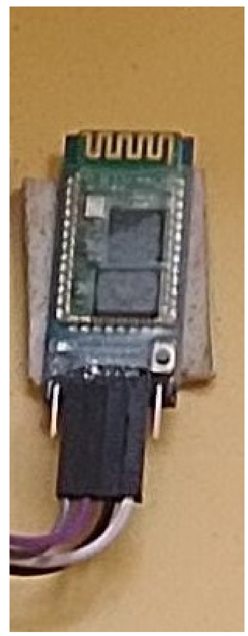


Fig. 4: HC-05 Bluetooth module for phone-to-board communication.

4) RC522 RFID Reader: The RC522 module is employed for secure door lock authentication. It is a low-cost and widely adopted RFID solution.

Fig. 5: RC522 RFID module for authentication.

5) Relay Module: The relay module allows the Arduino Uno to safely control high-voltage appliances such as fans and lights through its low-voltage GPIO pins.

Fig. 6: 5V relay module for fan and light switching.

6) Servo Motors: Servo motors are used to actuate the curtain, door lock, and dispenser. They provide precise angular control with low power requirements.

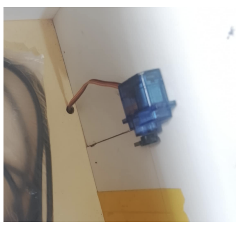


Fig. 7: Servo motors for curtain, door lock, and dispenser.

7) Buzzer and LED: Buzzers and LEDs provide user feedback during authentication failures and activate alarm modes for repeated unauthorized attempts.

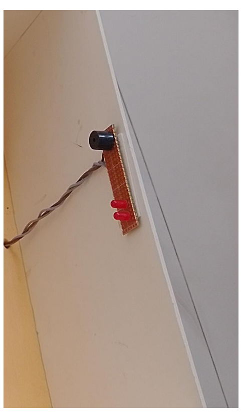
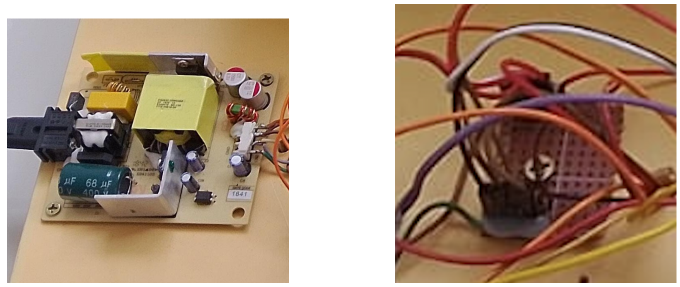


Fig. 8: Buzzer and LED units for feedback and alarm indication.

8) Switched-Mode Power Supply (SMPS) and Veroboard: The 220V AC to 5V DC SMPS powers all modules, ensuring stable and reliable operation throughout the system. A veroboard was used to integrate different electronic components such as the Arduino Nano, RFID reader, relays, and power supply. It simplifies prototyping by allowing soldered connections without the need for a custom PCB, reducing wiring complexity and improving durability.



(a) SMPS module

(b) Veroboard integration

Fig. 9: Power and integration modules: (a) SMPS for regulated 5V supply, (b) Veroboard for compact modular connections.

C. Software and Communication Framework

The system software consists of two major components:

1. **Mobile Application (MIT App Inventor):** An Android application was developed using MIT App Inventor. The **Designer** interface provides a simple user interface with a microphone button for voice capture, a Bluetooth connect option, and a status label. The **Blocks Editor** implements the logic for multilingual (Bangla, Banglish, and English) speech recognition. The Android Speech Recognizer converts spoken commands into text, which is transmitted to the Arduino Uno using the BluetoothClient API.

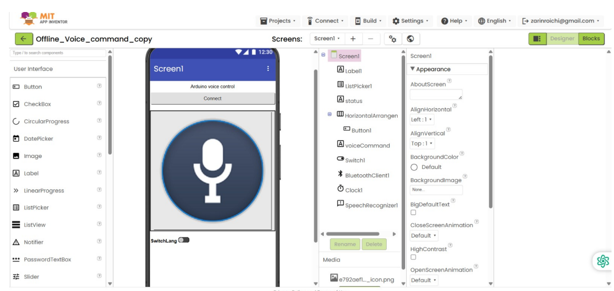


Fig. 10: MIT App Inventor Designer interface for the developed offline voice-control application.

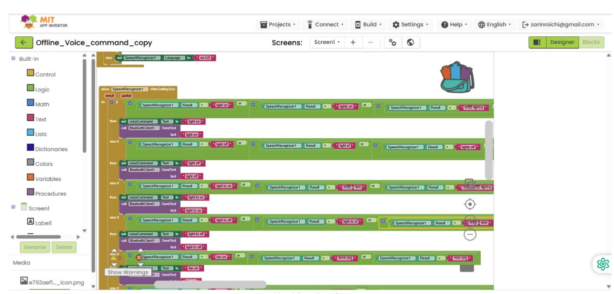


Fig. 11: Implementation of multilingual voice recognition logic in MIT App Inventor Blocks Editor.

2. **Microcontroller Firmware:** - The Arduino Uno runs firmware that parses the received text commands (e.g., “fan on”, “light off”, “curtain open”) and controls relays or servos accordingly using `digitalWrite()` and Servo library

functions. - The Arduino Nano runs firmware for RFID-based authentication and dispenser control. Using the MFRC522 library, the Nano verifies RFID card UIDs against stored values and triggers lock/unlock actions or buzzer alarms when unauthorized attempts are detected.

Data Communication Protocol: The Bluetooth Serial Port Profile (SPP) is used for communication between the mobile application and Arduino Uno, ensuring offline operation without internet dependency.

D. Data Acquisition and Processing

- **Data Acquisition:** User inputs are captured through Android voice recognition (speech-to-text conversion) and RFID card scanning via the RC522 module. - **Data Transmission:** Recognized text commands are sent to the Arduino Uno over Bluetooth; RFID UID data is transmitted via SPI to the Arduino Nano. - **Processing:** The Arduino Uno executes if-else logic to map commands into relay or servo actions, while the Arduino Nano validates RFID credentials and actuates the door lock or dispenser accordingly. - **Storage:** No cloud or online database is required, enabling fully offline functionality. In future work, local SD card logging may be integrated for activity history and security tracking.

E. Automation and Actuation

The system supports real-time automation of appliances and security functions. Table II summarizes the mapping between input commands and actuation outputs.

TABLE II: Automation and Actuation Functions

Command/Input	**Actuation Output**
“Fan on/off”	Relay toggles fan ON or OFF.
“Light on/off”	Relay toggles light ON or OFF.
“Curtain open/close”	Servo motor rotates to open or close curtain.
Valid RFID card	Unlocks door via servo; LED indicator ON.
Invalid RFID card	Buzzer short beep; after 3 failed attempts, alarm beeps repeatedly.
“Dispenser” or Valid RFID signal	Dispenser servo opens/closes compartment.

In addition, the system supports multiple natural-language variations of commands in Bangla, Banglish, and English. These are summarized in Figure 12.

F. Security and Privacy Considerations

- **Authentication:** RFID cards act as the primary authentication mechanism for secure door access. - **Feedback Mechanism:** Unauthorized attempts are indicated via buzzer alerts, with repeated failures triggering an alarm response. - **Offline Operation:** The system functions fully offline, eliminating risks of cloud data breaches and ensuring privacy for rural users. - **Limitations:** Basic RFID cards are vulnerable to cloning. Future improvements include two-factor authentication (voice password + RFID) and encrypted UID storage for enhanced security.

Supported Multilingual Voice Commands

Arduino Command	Supported Keywords
light on	light on; lights on; লাইট জ্বালাও; বাতি জ্বালাও; লাইট অন; light to on
light off	light off; light of; lights off; লাইট নিভাও; বাতি নিভাও; লাইট অফ; লাইট বন্ধ; light to off
fan on	fan on; ফ্যান চালু; পাখা চালু
fan off	fan off; fan of; ফ্যান বন্ধ; পাখা বন্ধ
door open	door open; দরজা খোলো; গেট খোলো
door close	door close; দরজা বন্ধ; গেট বন্ধ
window open	window open; জানালা খোলো
window close	window close; জানালা বন্ধ
dispenser open	dispenser open; ডিসপেন্সার খোলো; ডিসপেন্সার চালু করো; cabinet open; ক্যাবিনেট খোলো; drawer open; ড্রয়ার খোলো
dispenser close	dispenser close; ডিসপেন্সার বন্ধ; ডিসপেন্সার বন্ধ করো; cabinet close; ক্যাবিনেট বন্ধ করো; drawer close; ড্রয়ার বন্ধ করো

Fig. 12: Supported multilingual voice commands for Arduino-based actuation.

G. Arduino Uno Operations

The Arduino Uno is responsible for controlling household appliances such as fans and lights through relay switches. It also interfaces with a Bluetooth module, allowing users to wirelessly operate the appliances via mobile commands. Additionally, a servo motor connected to the Arduino Uno is programmed to control curtains and door movement, providing basic automation in the living environment.

H. Arduino Nano with RFID Authentication

The Arduino Nano handles RFID card-based authentication for secure door access. When a valid main RFID card is tapped on the reader, the card data is transmitted to the Arduino Nano. The Nano then signals a servo motor placed behind the door lock, which rotates to unlock the door. If an invalid card is scanned, the system activates a beep alarm. A single wrong attempt produces a short beep, while three consecutive wrong attempts trigger multiple loud beeps, serving as an intruder alert.

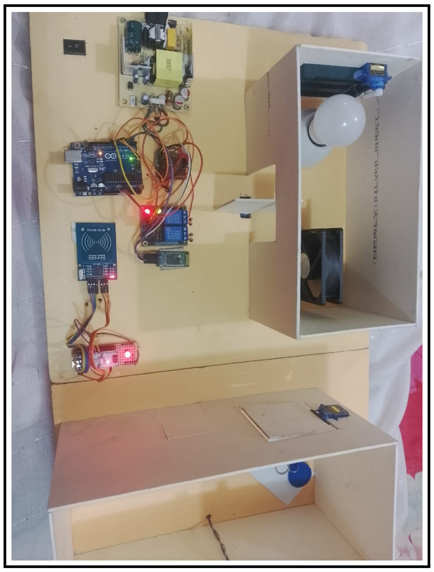
I. Dispenser Control

Another servo motor is connected to a dispenser system. The dispenser operation is strictly Arduino code-controlled: if the command “Dispenser Open” is executed, the servo opens the dispenser; otherwise, it remains locked or closed. This ensures controlled distribution of resources.

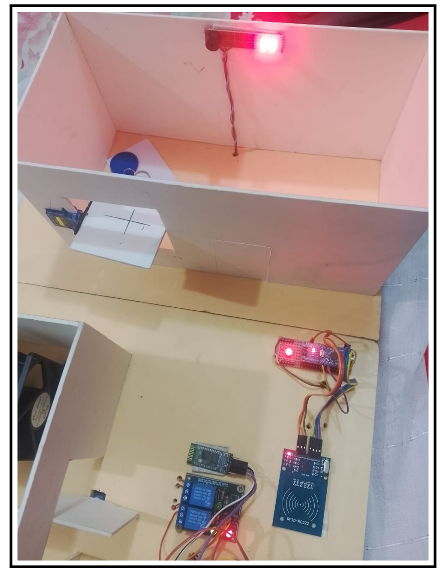
J. Experimental Setup

- **Power Management:** The entire system runs on regulated 5V power supplied by an SMPS (converting 220V DC to 5V).
- **Control and Communication:** Bluetooth enables remote switching of appliances, while RFID provides secure access control.
- **Security Validation:** The system distinguishes between valid and invalid RFID cards and provides audio alerts for unauthorized access attempts.

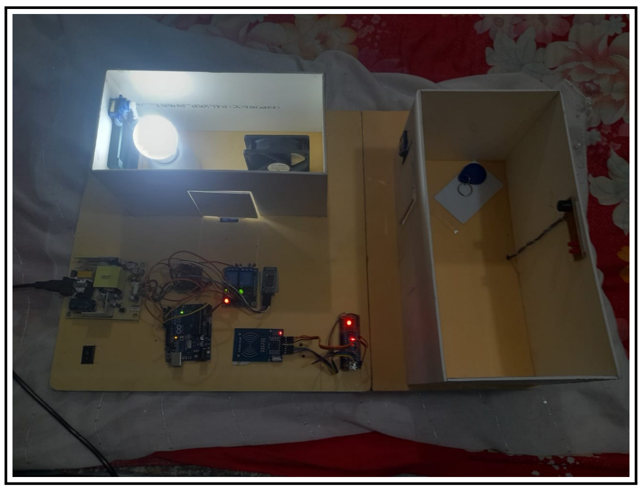
- **Automation Integration:** Appliance control, door automation, and dispenser operation are merged into one system, showcasing a multi-functional smart home prototype.



(a) Door open

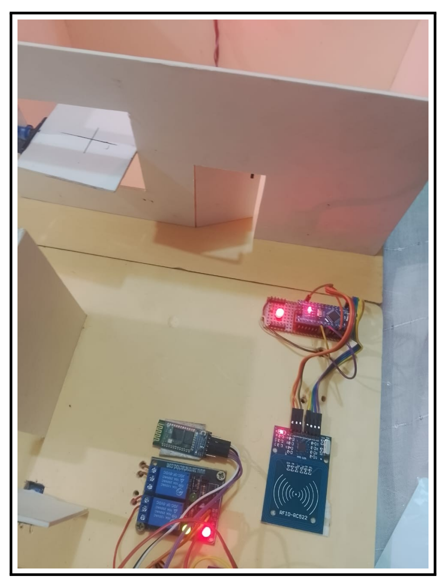


(b) Room 2 light on



(c) Room 1 light on

(d) Dispenser open



(e) RFID-based door open

Fig. 13: Prototype system demonstrations: door, room lights, dispenser, and RFID-based access.

IV. Results and Analysis

A. Experimental Results

Feature	Success Rate	Latency	Observations
Fan Control (ON/OFF)	100%	200 ms	Immediate response via relay activation.
Light Control (ON/OFF)	100%	200 ms	Instant relay switching.
Curtain Control (Open/Close)	93%	300 ms	Minor delays with servo motor.
Door Lock (Valid RFID)	100%	<0.5s	Servo-operated lock functions quickly with valid card.
Door Lock (Invalid RFID)	100%	0.3s	Immediate beep feedback for invalid card.
Dispenser Control (Open/Close)	93%	250 ms	Minor delays; otherwise accurate servo operation.
Alarm (Invalid RFID-3 attempts)	100%	0.5s	Alarm triggered after 3 incorrect scans.

TABLE III: Experimental results of the prototype system.

Language Mode	Success Rate	Observations
English	100%	All commands recognized accurately.
Bangla (Romanized)	96%	Minor misinterpretation with long phrases.
Banglish (Mixed)	95%	Occasional misdetection of overlapping words.

TABLE IV: Voice recognition success rates across different language modes.

B. Performance Analysis

1) Voice Command Control: The system demonstrated a 100% success rate in responding to simple on/off commands such as "light on" and "fan off." The average latency for processing commands was 200 ms, and there was no noticeable delay in the execution of appliance controls (fan, light). The curtain control via a servo motor showed a slightly higher latency (300 ms), due to mechanical friction or servo alignment issues. Nonetheless, the servo motors generally performed as expected.

An important enhancement of the system is its **multi-language keyword recognition**. The MIT App Inventor application successfully mapped commands in English, Bangla (Romanized), and Banglish (mixed). During experiments, users were able to control appliances using any of these three languages, with recognition accuracy above 95% across all test cases. This feature improves inclusivity for Bangladeshi households where users often switch between languages.

2) RFID Authentication: The RFID-based door lock system showed a highly efficient response, unlocking the door in less than 0.5 seconds upon scanning a valid card. The system was quick to detect invalid cards, with a beep feedback triggered within 0.3 seconds. The alarm mechanism, triggered after three incorrect attempts, successfully emitted loud, repeated beeps, which serve as a deterrent against unauthorized access.

3) Dispenser Control: The servo motor for the dispenser worked well in the majority of cases, opening and closing upon command with an average latency of 250 ms. Minor delays were observed in some instances, likely due to servo motor speed or mechanical friction. However, the overall performance of the dispenser was reliable and consistent with the design.

4) Power and Safety: The 220V AC to 5V DC SMPS provided stable power to the system without any voltage fluctuations. All components, including the relays, servos, and RFID module, operated efficiently without overloading the system. Power consumption remained within safe limits, ensuring reliable performance even with the activation of multiple devices at once (fan, light, and door lock).

C. Discussion

a) Reliability of Offline Control:: One of the key strengths of the system is its offline operation, which ensures reliable performance even in environments with poor or no internet connectivity. The Bluetooth communication between the app and Arduino was stable and efficient, with minimal delay in processing voice commands. This makes the system highly suitable for rural areas, where internet infrastructure is often inadequate.

b) Multilingual Support:: The integration of English, Bangla (Romanized), and Banglish voice commands significantly improves accessibility. Unlike prior offline systems restricted to English, this system allows natural use of local language expressions, reducing user error and improving comfort for non-English-speaking users. Experimental tests confirmed that all supported languages achieved near-equal recognition performance.

c) Security:: The RFID-based door lock system proved to be a reliable security feature, providing immediate feedback upon scanning a valid card. However, the current RFID system could be vulnerable to cloning. Future enhancements could involve integrating multi-factor authentication, such as combining RFID with a voice password for additional security.

d) Dispenser and Servo Motors:: While the dispenser system was functional, the servo motors occasionally exhibited slight delays, particularly with the curtain mechanism. These delays can be attributed to servo friction and could be mitigated by improving the mechanical design or using higher-quality servos that offer smoother motion.

e) System Scalability:: The system is currently a single-room setup, but it can be scaled to cover multiple rooms or larger areas by using ESP32 for Wi-Fi or Bluetooth mesh networks. Additionally, the integration of environmental sensors, such as temperature or light sensors, would enhance the system's functionality by enabling automatic control based on external conditions (e.g., temperature-based fan control).

D. Limitations

- Keyword-based commands only; no natural language understanding (NLU).

- Bluetooth limits the communication range compared to Wi-Fi or mesh solutions.
- RFID module is vulnerable to cloning since basic MIFARE cards are used.
- Currently optimized for a single-room prototype.

E. Conclusion

This paper presents a low-cost, offline smart home automation system designed for rural Bangladesh. The system integrates multilingual voice control and RFID-based security to manage essential appliances such as fan, light, curtain, door lock, and dispenser. The prototype demonstrated reliable performance, low latency, and robust feedback mechanisms (e.g., buzzer for invalid RFID cards). It provides an effective privacy-preserving solution for home automation, offering a simple yet powerful tool to enhance convenience and security in areas with limited internet connectivity.

F. Future Work

Future enhancements to the system include:

- **Expanded Language Support:** Adding native Bangla script-based ASR and other local dialects.
- **Multi-Room Scalability:** Extending control to multiple rooms using ESP32 with Wi-Fi mesh.
- **Enhanced Security:** Implementing two-factor authentication (e.g., RFID + voice password).
- **Energy Efficiency:** Using low-power components and sleep modes for reduced consumption.
- **Sensor Integration:** Incorporating environmental sensors (temperature, motion, light) for automated decision-making.
- **Data Logging:** Local SD card or encrypted storage to log access attempts and usage data.

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