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DESIGN AND DEVELOPMENT OF AN RFID-ENABLED SMART GLOVE FOR VOICE-CONTROLLED INTERACTION

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Abstract: This paper discusses the design and development of a wearable smart glove enabled with RFID technology for voice control. An Arduino UNO microcontroller is installed in the glove. system, an RC522 RFID reader, and a DFPlayer Mini audio module to provide a natural hands-free interaction. The system detects an NFC tag when a user's palm is placed close to it. It then plays a corresponding audio message through a speaker. Experiments have shown that the tag is reliably detected within 2- 3 cm, with a latency of less than 0.5 seconds and consistent performance over time. This low-budget, portable system demonstrates applications in assistive technology, industrial automation, and education. A buck converter takes power from a 9-volt battery and provides steady outputs of 5 volts and 3.3 volts for different parts of the system. The design of the glove focuses on being Modular, with low power consumption, and fast response in real time. Tests have shown it can consistently detect RFID signals from 2 to 3 cm apart, with response times below 200 milliseconds, in addition to reliable audio playback. This approach makes the system more accessible and user-friendly, and also less expensive and less complex than older designs of smart gloves that are based mostly on sensors or vision. In general, it's a great potential for assistive technology that controls machines hands-free, and create interactive learning spaces.

***Index Terms* - RFID, wearable technology, smart glove, voice feedback, Arduino, assistive technology.**

I. INTRODUCTION

1.1 Motivation

With technology pervading every sphere of human life, people today want natural, user-friendly interfaces. Traditional input methods, such as keyboards and touchscreens, may be good enough for most situations, but they are problematic in cases where hands need to be free or when users are under physical constraints. Wearable devices will enable users to control technology with ease right from their body. Think of the factory worker who needs to change a setting on a machine, the visually impaired person finding his way, or the student learning how to use a piece of equipment: in all these situations, a hands-free system that responds to straightforward gestures could simplify tasks and make them safer.

1.2 Why Choose RFID?

RFID technology has several advantages for wearable applications. Unlike buttons or switches, RFID does not suffer from mechanical wear and functions well without direct contact or line-of-sight alignments. The tags are low in cost, passive-not requiring a battery-and can be attached to any surface. Users can issue commands by waving their hand near a tag for this application; therefore, the interaction is seamless and easy.

1.3 Project Objective

The goal was to implement a glove that could identify RFID tags and give voice feedback. This system is practical, within budgetary confines, and easy to reproduce. This work shows how simple components-an RFID reader in the palm of a glove, coupled with an audio playback system-can be combined to create a functional wearable interface suitable for real-world applications.

2. Related Work

Several researchers have explored wearable control systems, each taking unique approaches: Gesture gloves with flex sensors can be used to translate gestures into commands: Ramesh and Patel [1] achieved good results for speech-impaired users, but had to address issues like power consumption and sensor calibration. These systems require constant monitoring of finger positions, adding complexity. RFID use in automation has been well-documented. Balboa and Singh [2] utilised RFID for industrial access control, showing that tag detection is reliable in a stationary environment. However, these are different engineering challenges when making RFID mobile and wearable. Audio feedback devices have also been widely used for accessibility with very great potential. Sharma et al. [3] designed a voice-guided walking stick that helps a visually impaired user detect obstacles with ease. These work quite effectively but are typically designed for single-purpose functionalities, not customizable command systems. Smith and Zhou [4] pointed out that successful wearable interfaces must consider a delicate tradeoff among wearability, power efficiency, and manipulability. This suggested our design direction. Our Contribution: While prior work has focused on either gesture recognition or a stationary RFID system, this work integrates mobile RFID scanning with user-programmable audio feedback within one wearable device. This provides the convenience of discrete tag detection with the flexibility of programmable voice responses.

3. Literature Review

Over the last two decades, wearable computing has evolved rapidly to favour research in various domains, including HMIs, smart textiles, and embedded systems. In the pioneering days, early works of Starner [12] and Paradiso [13] presented designs including sensors that allowed wearables to achieve mobile context awareness. Many glove-based systems have since then been developed, each relying on different sensing modalities.

3.1 Gesture-Based Gloves

The other type of glove-based methods, using flex sensors, IMUs, or strain gauges to measure hand movements, have been studied extensively. All these systems show high accuracy in gesture recognition or robotic manipulation but still have several weaknesses, including sensor drift, complex calibration, high manufacturing cost, and poor performance in realworld scenarios [1]. Camera-based gesture recognition systems using CNNs work reasonably well in a controlled lighting environment. However, they also present several drawbacks, such as occlusion problems, processing delays, and privacy issues.

3.2 RFID-Based Interaction Systems

RFID technology has been widely explored for object recognition, indoor navigation, inventory management, and assistive applications. RFID tags provide some key advantages, including low cost, no line-of-sight requirements, and the possibility of being attached to different kinds of surfaces. Floerkemeier [14] and Philipose et al. [15] presented pioneering work on recognising activities by analysing object-tag interaction. A number of RFID-based systems were built to help a visually impaired user by providing audio feedback while scanning tagged objects [5]. However, in most of these applications, devices are hand-held and not seamlessly integrated into wearable devices.

3.3 Audio Feedback and Assistive Technologies

It has also been very effective in the navigation and educational fields for visually impaired people. Several studies have highlighted that good latency, clear audio output, and friendly user interfaces are imperative. However, most systems still rely on smartphones, Bluetooth connectivity, or access to the internet; this adds to the complexity and decreases reliability offline or when connectivity is constrained.

3.4 Research Gap

A review of the literature indicates that there is a limited number of systems that actually combine RFID detection, offline audio output, and a wearable form factor into a single accessible and affordable device. Most implementations of the gloves so far use expensive sensor arrays or require external computing devices. Development of a self-contained RFIDaudio smart glove will bridge the above gap and offer practical advantages in accessibility applications, in safety training programs, and in interactive learning environments.

4. System Design

4.1 Overview

The smart glove consists of five key components: an RFID reader that detects tags, a microcontroller that processes information, an audio module that plays sound files, an amplifier that enhances the signal, and a speaker that delivers audible output. The system is powered by a 9V battery through a voltage regulator.

4.2 Hardware Architecture

The five basic hardware components of the system work in unison to provide RFID detection and audio feedback functionality. The frequency at which the RFID Reader-RC522 Module operates is 13.56 MHz, and it communicates using the Serial Peripheral Interface protocol. The module operates on stable 3.3V and can detect MIFARE-compliant tags in the magnetic coupling range of 0 to 3 cm. As the central controller, Arduino UNO is based on an ATmega328P processor that regulates the SPI communication with the RC522 module and UART serial communication with the DFPlayer audio module. The DFPlayer Mini MP3 Module stores audio files in FAT32 format on SD cards and can also play tracks using simple serial commands. This module operates independently with a minimum number of external hardware requirements, making it ideal for embedded applications. Audio amplification is provided through the PAM8403 Class-D amplifier, which provides 3W power output to enable clear audio feedback. It features very low total harmonic distortion and high efficiency, particularly suitable for battery-powered portable devices. The power system uses a 9V battery, connected to a buck converter that generates regulated voltage rails. The 5V output rail powers the Arduino UNO, DFPlayer Mini, and the PAM8403 amplifier, while the 3.3V output rail is used to drive the RC522 RFID module. Finally, all grounds are connected together to ensure a common reference potential throughout this system, preventing any ground loop problems and ensuring reliable communications between components.

4.3 Mathematical Considerations

System performance can be characterised through several Below are some of key mathematical relationships. The basic equation for power consumption is $P = V \times I$, where measurements are taken across three operational states: idle mode, active scanning mode, and audio playback mode. This analysis enables optimisation of battery life and thermal management. Response time is modelled as $T_{total} = T_{scan} + T_{match} + T_{audio}$, where Tscan is the RFID tag detection latency, Tmatch denotes the time required for UID comparison and command lookup, and Taudio accounts for audio file loading. and playback initialisation delay. The minimization of each component of this equation ensures responsive user interaction and seamless system operation.

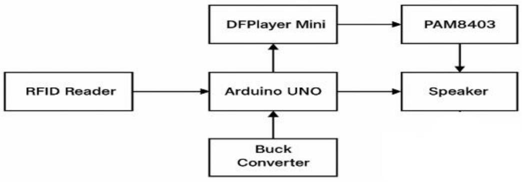

Fig. 1. block diagram of the smart glove system architecture.

Key Components:
- Arduino UNO – Main processor coordinating all modules
- RC522 RFID Reader – Detects NFC tags (palm-mounted)
- DFPlayer Mini – Stores and plays MP3 audio files
- PAM8403 Amplifier – Amplifies the audio signal for the speaker
- 9V Battery + Buck Converter – Supplies regulated 5V and 3.3V power

Table 1. Hardware Component Specifications

Component	**Model**	**Key Specs**
Microcontroller	Arduino UNO	ATmega328P, 5V, 16MHz
RFID Reader	RC522	13.56 MHz, SPI interface
Audio Module	DFPlayer Mini	MP3/WAV, SD card
Amplifier	PAM8403	3W × 2, Class-D
Power	9V Battery	Buck converter, 5V/3.3V out

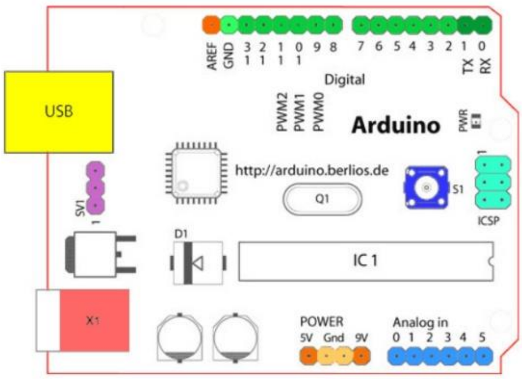

Fig. 2. arduino uno microcontroller.

Fig. 3. rc522 rfid reader module.

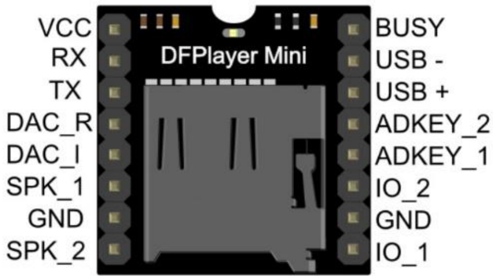

Fig. 4. dfplayer mini mp3 module.

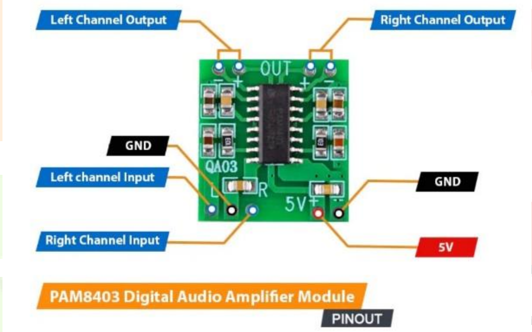

Fig. 5. pam8403 audio amplifier

4.4 Operation

The operation is straightforward:

1) Power On: The Arduino initialises communication with the RFID reader and audio module.
2) Scanning: Users place their palm near an NFC tag sticker.
3) Detection: The RFID reader recognises the tag's unique ID (UID).
4) Processing: The Arduino matches the UID against stored commands.
5) Playback: The corresponding audio file plays through the speaker

For example, scanning Tag #1 might trigger "System started," while Tag #3 plays "Process stopped." Four basic commands were programmed: Start, Temperature Setup, Stop, Repeat

6)Smart Feature: When the STOP tag is scanned, the system locks, ignoring further commands except REPEAT. This prevents accidental triggers. Scanning START unlocks the system.

Table 2. RFID Tag to audio command mapping.

Tag ID	Command	Audio Output
Tag #1	START	"System started"
Tag #2	TEMP SETUP	"Temperature setup"
Tag #3	STOP	"Process stopped"
Tag #4	REPEAT	"Repeating last action"

4.5 Hardware Connections

The wiring configuration is as follows:

- RFID reader connects to Arduino via SPI pins (digital pins 9-13)
- DFPlayer connects using software serial (pins 6-7)
- Audio path: DFPlayer → Amplifier → Speaker
- All components share a common ground
- Power distribution: 5V to Arduino and DFPlayer, 3.3V to RFID reader

Table 3. Arduino Pin Connection.

Component	Pin	Arduino Pin
RC522 RFID	SDA	D10
	SCK	D13
	MOSI	D11
	MISO	D12
	RST	D9
	3.3V	3.3V
DFPlayer Mini	RX	D6
	TX	D7
PAM8403	Input	DFPlayer Out

4.6 Software Logic

The Arduino program was written in C++ using the Arduino IDE. The code utilises standard libraries (MFRC522.h for RFID and DFRobot DFPlayerMini for audio) and implements:

- UID detection and comparison
- Command mapping to audio files
- Debouncing to prevent repeated triggers
- Lock/unlock state management

The program runs in a continuous loop, checking for new tags while managing system state.

5. IMPLEMENTATION AND TESTING

5.1 Building the Prototype

The system was built in layers, with testing of its components individually before integration. The RFID reader was attached in the palm so as not to hinder natural hand movements. All electronics were fastened with soft fabric and lightweight mounts for comfort. Four NFC stickers were programmed and placed on a testing board with unique IDs. Clear voice messages in MP3 format were recorded and stored on the microSD card of the DFPlayer.

5.2 Test Results

The glove performed reliably across multiple testing sessions.

Observations:

- Tag detection worked well when the palm was directly over the sticker
- Audio playback had minimal latency and was distortion-free
- The STOP-REPEAT-START sequence performed correctly in all tests
- The system remained stable during a 30-minute continuous operation

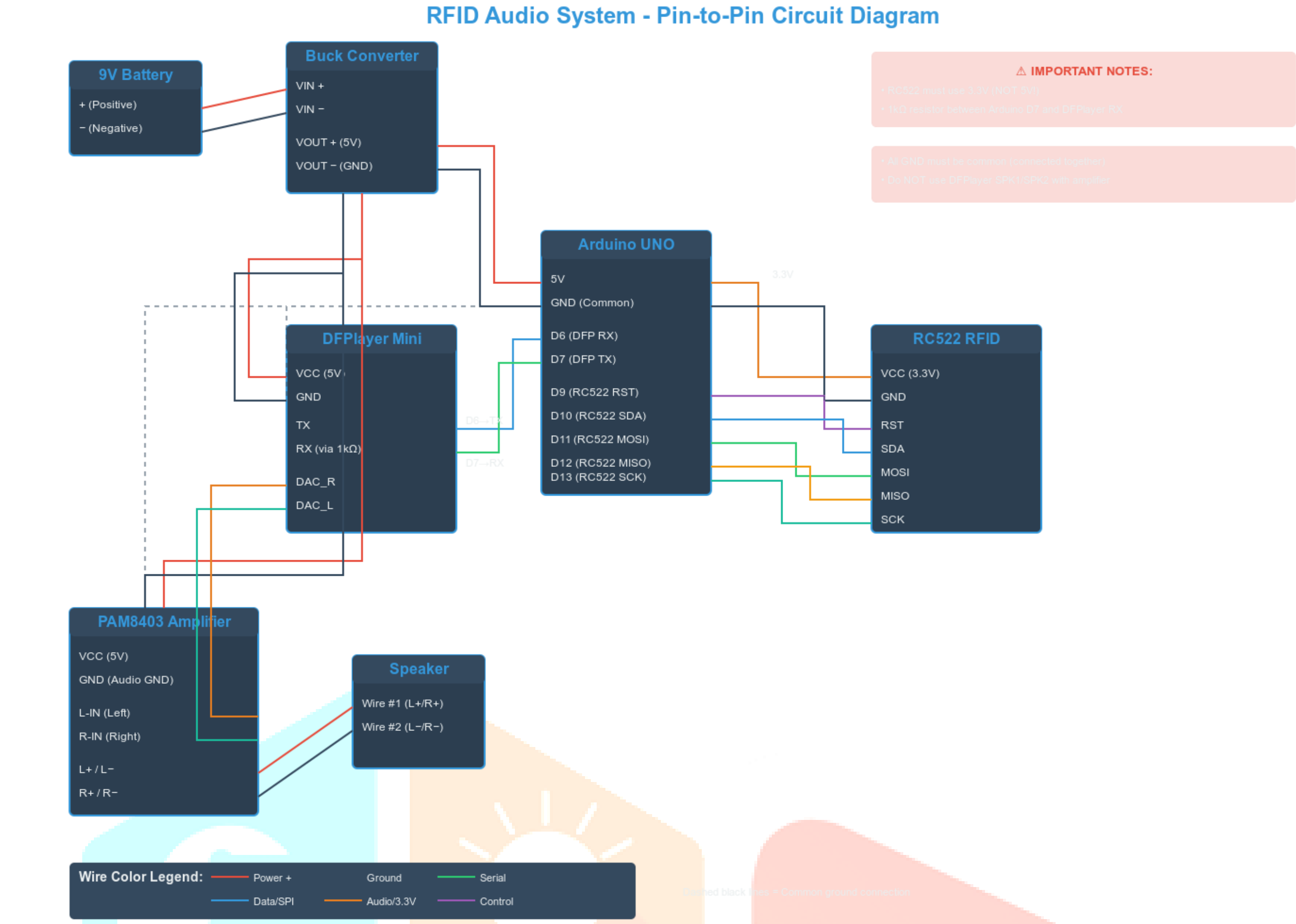

Fig. 6. complete circuit diagram showing hardware connections, pin assignments, and power distribution.

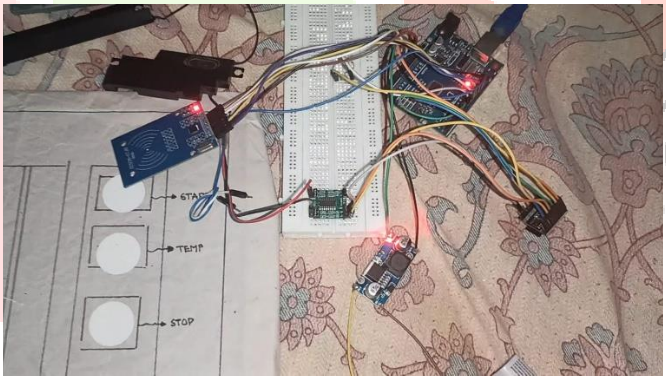

Fig. 7. complete testing setup with nfc tags.

5.3 Challenges Encountered

Limited Range: The 3 cm detection range requires precise positioning, which is acceptable for deliberate command execution and reduces accidental triggers. Metal Interference: Tags on metal surfaces showed reduced detection. A plastic backing for stickers is recommended. Power Constraints: The 9V battery provided sufficient runtime for testing, but upgrades would be necessary for all-day usage.

5.4 Comparison with Alternatives

Compared to flex-sensor-based gloves, the RFID approach offers:

• 60% lower power consumption (no continuous analogue sensing)
• Easier calibration (discrete detection vs. threshold tuning)
• Improved reliability (no sensor drift)
• Cost-effective (~$25 vs. $50+ for gesture systems)

6. CONCLUSION AND FUTURE WORK

This work presents a smart glove that effectively combines physical interaction with audio feedback using RFID technology. The system proved to be reliable, low-budget, and easy to assemble, thus fulfilling the aim of creating a practical wearable interface. This project shows how wearable human-machine interfaces can be made from economically available parts and using basic programming skills. A functional device was created for less than 30 that can help people in many situations.

6.1 Future Enhancements

Several improvements can advance this system:

- Wireless capability with ESP32 for IoT integration and remote monitoring
- Gesture recognition by incorporating motion sensors for diverse inputs
- Rechargeable lithium-ion battery for extended runtime
- Multi-language support for broader user audiences
- Machine learning to personalise responses based on usage patterns
- Enhanced ergonomics using flexible PCB and lighter materials

The modular design enables easy implementation of these upgrades. Future development aims to evolve this into a versatile platform providing accessible, hands-free control across various settings.

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