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ASR Mobile Application with 6G Beamforming Simulation

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Abstract: ***Most speech analysis tools today either work only on desktops or need a constant internet connection, which makes them hard to use for students and researchers on the go. On the wireless side, understanding how 6G beamforming works is tough without expensive hardware. To tackle both these issues, we built a project that brings together three things in one package. First, a Flutter-based mobile app that lets users record audio, view waveforms, run offline speech-to-text using Whisper, and generate spectrograms and pitch graphs. Second, a Python-based 6G beamforming simulation that compares square and star antenna layouts using CNN-based beam prediction along with classical methods. Third, a simple ESP32 and servo hardware demo that physically shows how beam scanning and angle selection work. Testing showed that all three modules perform reliably and complement each other well for academic use.***
Keywords: Speech recognition, Beamforming simulation, Mobile application, Antenna geometry, Deep learning.

I. INTRODUCTION

In the last few years, phones have become powerful enough to handle tasks that used to need full-blown computers. Speech analysis is one such area where mobile apps can now do things like waveform display, pitch tracking, and even transcription right on the device. At the same time, wireless communication research is moving towards 6G, where smart antennas and beamforming play a huge role. But for most students, getting hands-on experience with beamforming is nearly impossible because the hardware is way too expensive.

That is exactly why we decided to combine these two areas into one project. We built a mobile speech analysis app using Flutter with offline Whisper-based recognition, paired it with a 6G beamforming simulation in Python, and added a small hardware demo using an ESP32 and servo motor to physically show how beam scanning works.

The project is therefore presented as an academic and research-oriented platform designed to facilitate experimental analysis, practical concept demonstration, and learning-based exploration in the fields of speech signal processing and 6G beamforming, with scope for future research and system improvements.

II. SYSTEM ARCHITECTURE

The whole project is split into three modules that work alongside each other. The speech analysis module handles the mobile side of things, the beamforming simulation takes care of the research side, and the hardware demo gives a physical feel to the beam selection concept.

A. Speech Analysis Module

The mobile app is built using Flutter and runs on Android devices. It lets users record audio, play it back with waveform visuals, and run offline speech-to-text using the Whisper model. On top of that, it can generate spectrograms, sonograms, pitch curves, and intensity plots. FFmpeg handles all the audio conversion and trimming work in the background. The whole thing works without needing any internet connection, which is a big plus for field use and classroom demos.

B. Beamforming Simulation Module

The simulation is written in Python and runs on Google Colab. It sets up a 64-element antenna array in either a square grid or a star shape, generates synthetic wireless channels for multiple users, and then uses a CNN model to predict which beam direction works best for each user. Classical methods like MRT and ZF are also run as baselines so we can compare how the learning-based approach stacks up against traditional ones.

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C. Hardware Demonstrator

The hardware part uses an ESP32 microcontroller connected to a servo motor and an ultrasonic sensor. The servo rotates through a set of angles, and at each position the sensor measures the distance to the nearest object. After scanning all directions, the system locks onto the angle with the strongest response. This mimics how a real beamforming system would sweep and select the best direction.

III. WORKING PRINCIPLE

On the speech side, the user opens the app, records audio or imports a file, and the waveform shows up right away. They can then run Whisper to get a text transcript with timestamps. If they want deeper analysis, they pick a segment and the app generates a spectrogram, sonogram, pitch track, or intensity graph using frame-based algorithms and FFmpeg processing under the hood.

On the simulation side, the user picks a geometry, the code builds the antenna array and generates channels, and the CNN predicts the best beam for each user. WMMSE then refines the digital precoding. On the hardware side, the ESP32 tells the servo to sweep through angles, reads the sensor at each stop, and then parks at the strongest direction.

Performs sequential angle-wise scanning to determine the optimal beam direction and automatically selects the strongest directional path based on measured signal values.

IV. HARDWARE AND SOFTWARE COMPONENTS

The main components used across the three modules include:

• ESP32 microcontroller for hardware demo control • Servo motor for directional sweeping • HC-SR04 ultrasonic sensor for distance measurement • Flutter framework for mobile app development • Whisper model for offline speech recognition • Python with PyTorch and NumPy for beamforming simulation.

V. ADVANTAGES OF THE PROPOSED SYSTEM

This project has several practical advantages:

• Works fully offline with no cloud dependency for speech analysis • Combines multiple analysis tools like waveform, spectrogram, pitch and intensity in one app • Compares different antenna geometries which let’s visual analysis of the importance in antenna’s geometry • Provides clear eclipse of Federated Average approach against Centralized Learning • Affordable and reproducible with commonly available parts • Near world simulation environment for accurate results considering various loss factors like building reflection, beam loss, natural calamities and more.

VI. APPLICATIONS

The system can be useful in several settings, such as:

• Classroom demonstrations for DSP and wireless communication courses • Student research projects exploring speech and antenna topics • Quick field-level speech recording and analysis without internet • Academic presentations explaining beamforming concepts visually

VII. RESULTS AND DISCUSSION

We tested all three modules and the results were encouraging. The mobile app recorded audio cleanly, displayed waveforms in real time, and the Whisper transcription worked accurately even without internet. Spectrograms and pitch graphs came out clear and matched what we expected. In the simulation, the CNN learned to predict beam directions for both square and star geometries, and the SNR sweep and user count sweep plots showed meaningful differences between the learning-based and classical approaches.

The hardware demo did exactly what we wanted. The servo swept through the angles smoothly, the ultrasonic sensor picked up objects at each direction, and the system locked onto the strongest angle every time.

VIII. CONCLUSION

In this project, we put together a mobile speech analysis app, a 6G beamforming simulation, and a physical beam scanning demo into one coherent package. Each part works well on its own, and together they form a solid academic platform. The speech app handles recording and analysis offline, the simulation compares antenna geometries with real depth, and the hardware makes the whole thing tangible. Future work could include adding a camera feed, richer acoustic features, and tighter app-to-hardware communication.

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IX. FUTURE SCOPE

There are quite a few ways this project can grow in the future. On the speech side, we could add more advanced features like MFCC extraction, formant tracking, and voicing confidence scores to make the analysis richer. The beam prediction model could be improved with better training data and a more refined CNN architecture so that its accuracy holds up more consistently across different antenna setups and user counts.

On the hardware side, replacing the basic ultrasonic proxy with a proper signal strength measurement setup would result in more accurate analysis. We could also build a dashboard that shows the beamforming simulation results right inside the mobile app or on a connected screen. Adding wireless communication between the app and the ESP32 would tie everything together into a fully integrated live demonstration.

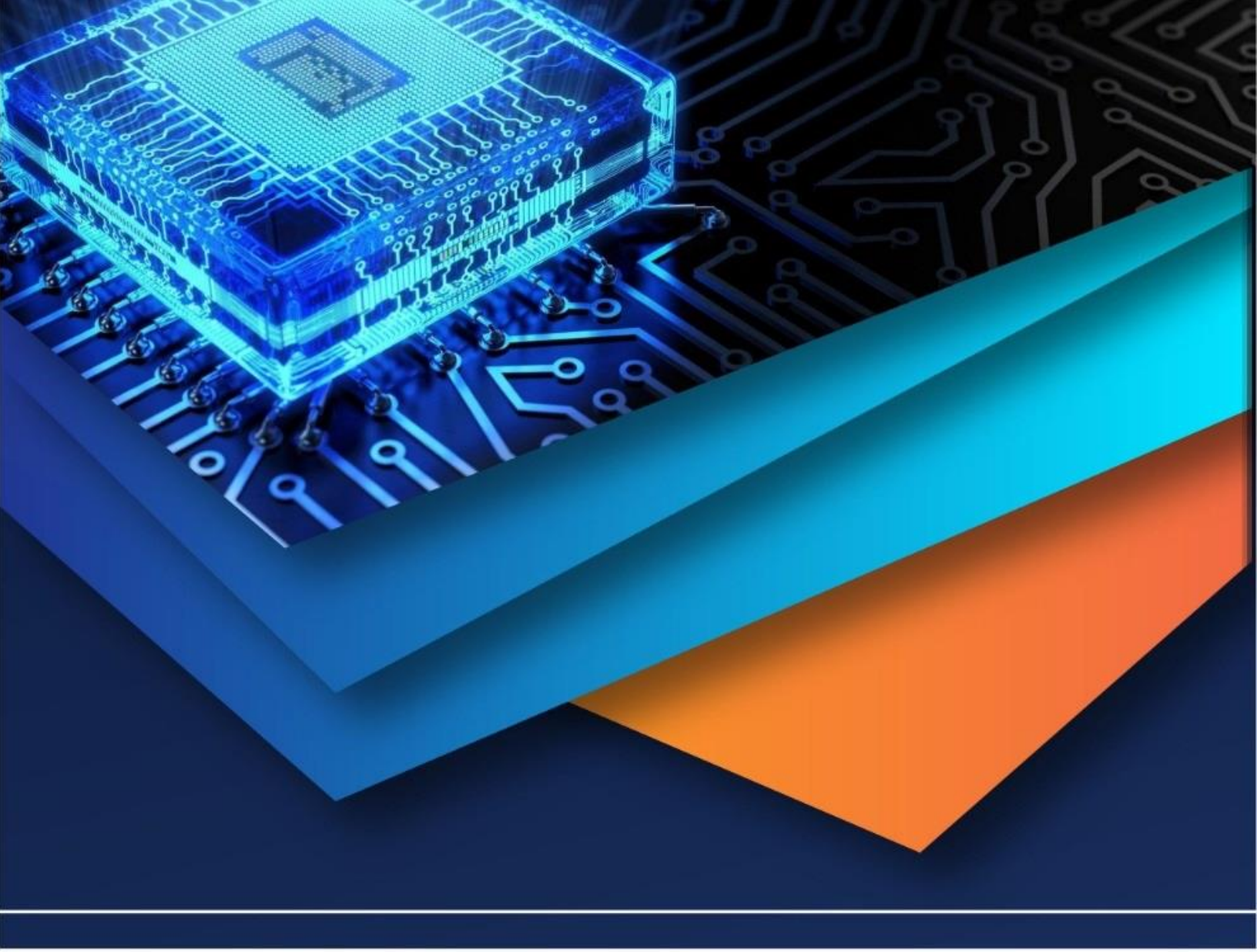
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