Audio wirelessly controlled Remote Control Car

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***Abstract*— This report presents the design and implementation of an audio wirelessly controlled remote control car. The audio signals must be within the human audible range (20-20kHz). The designed solution utilizes a website to transmit audible frequencies that are received by a microphone module which is then passed through a fourth-order bandpass filter to reduce noise. The processed signals are sent to the microprocessor where the Fast Fourier Transform is used to obtain the frequency of the input signal. The obtained frequency is used to send a specific command to the DC motors of the remote-control car through an H-bridge. The designed solution is successful, but the noise immunity of the design can be improved as false signals occasionally trigger control commands.**

Keywords*— *Bandpass filter, Fast Fourier Transform, DC motors

I. Introduction

This report presents the design of an audio wirelessly controlled Remote Control (RC) car that was developed by a team of three electrical engineering students. This project does not have many practical benefits but allows students to grasp the fundamentals of communication and signal processing.

Section 2 outlines the assumptions, constraints, and success criteria of the project. Section 3 provides additional information that was utilized. Section 4 outlines the design process and methodologies used. Section 5 outlines the testing and evaluation of the design and identifies key weaknesses of the design. Section 6 outlines the improvements that can be made to the design.

II. Project Specifications

The design of the RC car was based on the project specifications outlined by the assumptions, constraints, and success criteria made by the engineering group. These assumptions, constraints, and success criteria are outlined below.

A. Assumptions

- No limit to the number of components required.
- No budget constraint
- Range of wireless link between 5 to 10m.
- Must be able to race against a maximum of 5 other RC cars. Therefore, noise immunity is vital.
- Can utilize a Bluetooth speaker or phone to generate the audio signals.

B. Constraints

- The maximum voltage supplied to the motor is 5V.
- No modifications to the RC car's chassis can be made.
- The link between driver and car must be within the human audible range (20-20kHz).
- Completion of project within six weeks.

C. Success criteria

The success of the RC car design will be determined by the driver's ability to control the RC car accurately using audio signals within the human audible range (20-20kHz). Additionally, the RC car must possess a high level of noise immunity to prevent interference from other drivers' signals. Therefore, noise immunity is crucial for its overall performance. The maximum error of the detected frequencies must be lower than 50 Hz to keep the frequency range to a minimum. The minimum range of detected audio signals should be at least five meters.

III. Background

A. Existing solutions

The Arduino project presented by Dr. Clyde Lettsome approximates the frequency of the loudest sound detected by the microphone module [1]. The analog sound is sampled by the Arduino where a Fast Fourier Transform (FFT) is used to approximate the maximum frequency of the digitized data [1].

The controlling of the DC motors was inspired by Surajit Majumdar's work by utilizing an H-bridge to improve the accuracy and control of the DC motors [2].

IV. Design and Implementation

The high-level block diagram for the final design is shown in Appendix A Figure 1. Each subsystem is discussed below, and the bill of materials is shown in Appendix B Table 1.

A. Microphone module

The microphone module used is the MAX9814 to detect audio signals. This module is utilized as it has an in-built audio amplifier and DC offset [3]. This combination reduces the number of components required on the RC car. The DC offset is a critical reason for utilizing this module as it allows for the microprocessor to sample and process the incoming signal because the microprocessor cannot read negative voltages. The gain feature of the microphone improves the range at which audio signals can be detected. The module can also be powered by the microcontroller's 5V rail. The cost of the microphone module is higher than if an audio amplifier is built but due to time constraints and space limitations of the RC car, the module is utilized.

B. Bandpass filter

The bandpass filter is required to reduce the noise of the audio signals from the microphone module. The circuit diagram of the filter is shown in Appendix A figure 2.

The design of an existing second-order Butterworth bandpass filter was adapted and used as it merged the low and high pass filters requiring only one operational amplifier [4]. The adapted bandpass filter designed in this project is two second-order active bandpass filters cascaded causing a fourth-order active filter. The Q-factor of each filter is set to 10. The gain of each second-order bandpass filter is 2. The range of frequencies the filter allows through is between 2.5kHz to 3.5kHz. The calculations for the bandpass filter's characteristics are shown in Appendix A figure 3 [4]. The bandpass filter circuit is powered by two 9V batteries due to two LM741s being used [5].

The active bandpass filter is used over a passive band pass filter because passive filters attenuate the entire signal. This would cause the range to be a major issue while the active filter would not propose this issue. The use of a Butterworth filter is due to the passband being maximally flat. Therefore, there are no fluctuations, possibly causing range issues. The setting of the Q-factor to 10 and fourth order causes a smaller frequency range to not be attenuated due to the narrowed bandwidth and -80 dB roll-off, improving the noise immunity as keeping the usable frequency range to a minimum is vital. This causes the interpretation of the input signals to be more accurate as the spacing of frequencies used for commands is smaller.

The bandpass filter was soldered onto a Veroboard, and a 3-D printed case was made. This was done to protect the filter during testing and use of the RC car.

C. Microprocessor and Fast Fourier transform

The ESP32 development board is used to perform the FFT and send commands to control the DC motors based on the resulting frequency detected. The ESP32 is used because of dual-core processing and larger memory compared to the Arduino Uno [6]. This separation of processing is vital to achieve a sufficient balance between the accuracy and speed of the FFT as it requires a large amount of processing power.

The FFT used has a total number of samples of 256 and a sampling frequency of 6500. The number of samples is set at 256 as this allows for the code to be executed quickly and with reasonable accuracy. The maximum absolute error produced was approximately 32Hz. Increasing the number of samples will slow down the code significantly and decreasing the samples will cause the error to increase. Therefore, 256 samples are sufficient. The maximum frequency the designed FFT can detect is 3250Hz due to its Nyquist sampling rate. Increasing the sampling frequency causes the code to slow down and errors to increase. The use of 3250Hz produced a sufficient balance between accuracy and speed. The frequencies lower than 2.5 kHz would not be detected by the microprocessor due to the bandpass filter. The ESP32 is powered by a power bank.

The triggering of a DC motor command requires a constant stream of at least 10 samples of a specific frequency to send out a specific command to the DC motors. This is done to reduce the effect of a frequency within the range of the commands to be triggered accidentally. Instead, a constant stream is required to trigger the corresponding command.

D. H-bridge and motor control

The dual L298N H-bridge motor driver module is used to power the two 9V DC motors of the RC car [7]. The internal circuitry of the module is powered by the 5V rail of the microprocessor. The power source for the motors is 4xAA rechargeable batteries.

The varying of the average voltage and direction of the motors is vital to obtaining highly accurate movements. Movements such as pivoting on the spot, forward, reverse, and varying degrees of left and right turns can be accomplished [7]. Therefore, the use of the module increases the power consumption and complexity of the design but increases accuracy in controls.

The 4xAA rechargeable batteries were utilized to remain in the constraint of a maximum of 5V going to the motors. The use of the 4xAA rechargeable batteries allows for more current to be available from the power source for a longer duration. Therefore, operating the DC motors at a lower voltage does reduce the maximum speed but allows for a longer duration of use.

E. Controller

The visual representation of the implemented controller is shown in Appendix A figure 4.

The controller is set up as a website where a smartphone, tablet, or laptop can access the controller. This allowed any device to be used as the controller but requires the device to have a constant internet connection. If a button is clicked a specific tone will be played, and the website was designed such that two buttons cannot be clicked at the same time. This was done as it would be redundant to have two tones playing simultaneously due to it not being interpreted as a combined motion. The maximum time a singular tone can be played is ten seconds. This is due to the audio samples from the online website [8]. The placement of the buttons is in a manner that is intuitive and easy to control.

Tones were chosen as the audio signal due to it being a consistent frequency. This allowed for the amplitude of the signal to be ignored and focused mainly on the frequency of the received audio signal.

F. Project Management

The work breakdown and time management are shown in Appendix B Table 2 and Table 3.

The team initially pursued voice recognition but lacked the expertise for machine learning. The voice recognition solution was also highly prone to noise. Therefore, the team collectively shifted to another simpler solution.

V. Testing and Evaluations

G. Range and Noise immunity

The maximum range the FFT can approximate the correct frequency while only using a cell phone speaker is approximately 15m. Therefore, the maximum range would increase if a speaker was utilized. This is sufficient to fulfill the maximum range of the success criteria.

The testing of the noise immunity was done using a song that has rapid changes in frequencies. The RC car does get false signals when the song is only playing but once the tone correlating to a certain command is played it dominates the FFT and is no longer affected by the noise. Therefore, the noise immunity is sufficient but can be improved to prevent these false signals from triggering the commands.

H. Fast Fourier Transform

Upon testing the FFT without the bandpass filter a major fault of this method was found. If a frequency higher than the set maximum frequency was played it would cause the received value to be random. This prevented other tones from being detected. Therefore, the use of the bandpass filter is vital because the testing of the FFT with the bandpass filter was immune to this effect.

The error received from the FFT after the audio signal is passed through the bandpass filter is a maximum absolute error of 32Hz. The maximum absolute error received from the FFT without the bandpass filter is 29Hz. Therefore, the error caused by the bandpass filter is negligible. The comparison is shown in Appendix B table 4.

I. Motor driver and DC motor control

The voltage supplied to L298N is approximately 4.8V at full charge while the motors at full power only receive approximately 3.8V. Therefore, the reduced voltage causes the motors to operate at a slower speed than expected. This can be resolved by using a higher-voltage power source.

There were also inaccurate movements of the RC car which was mainly with the forward command. The RC car had a very wide left turn instead of a forward movement. Therefore, the average voltage being supplied to the right motor was reduced while the left motor's average voltage was kept at a maximum. This balanced out the torque produced from the right and left motors allowing for a forward movement to be accomplished. Turning left and right were done in a similar manner instead of pivoting on the spot. This is due to the gradual left and right turns being easier to control.

VI. Improvements

The controller and code can be improved such that varying degrees of turns can be accomplished. This can be done using the gyroscope in smartphones and tablets to vary the frequency emitted and the code can map these frequencies where the mapped values vary the turns respectively. The noise immunity of the design can be improved such that a smaller range of frequencies is utilized and that false signals triggering commands are reduced. A higher order filter and higher Q factor can also be utilized to improve noise immunity.

VII. Conclusion

The final constructed prototype meets the success criteria to an acceptable degree. Each sub-system could perform its tasks efficiently and the noise immunity of the design was sufficient. Improvements to the bandpass filter, triggering system, and controller can be made.

References:

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Appendix A

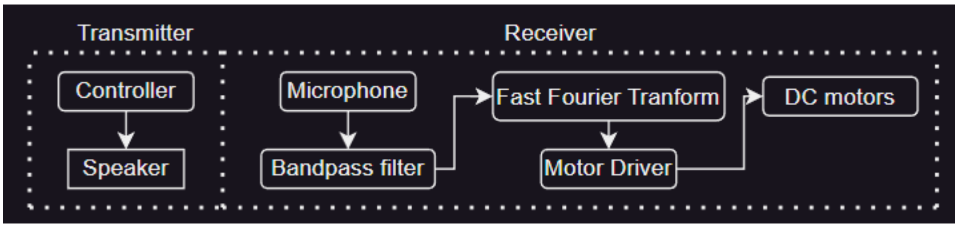

Figure 1 High-level flow diagram of the implemented design

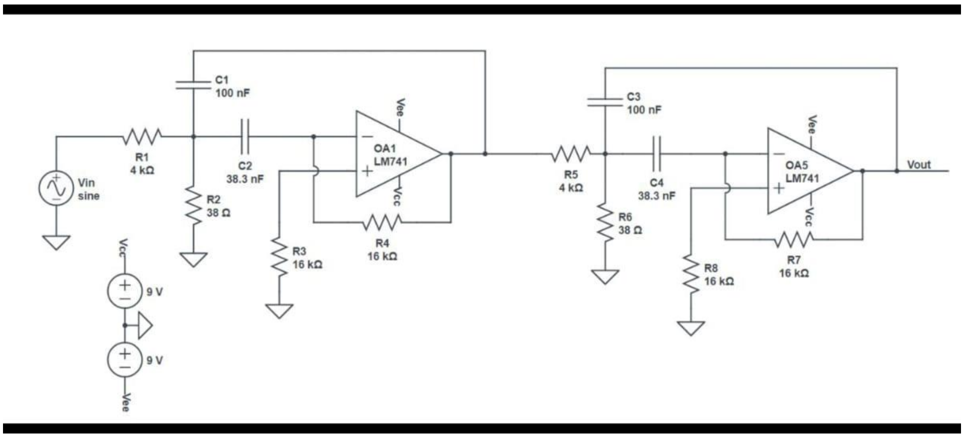

Figure 2 Cascaded second-order bandpass filters used in design [4]

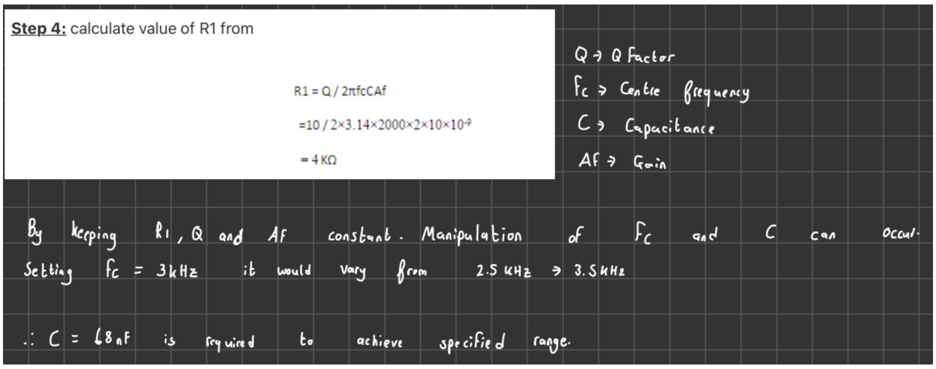

Figure 3 Calculations for a centre frequency of bandpass filter [4]

Figure 4 Website of controller layout that the driver used

Appendix B:

Table 1 Bill of materials of the designed solution

Component	Cost of Component
MAX9814 Microphone module	R98.26
ESP32 development board	R168.97
Dual L298N H-bridge Motor driver	R73.31
2x 9V battery clips	R16.22
Battey holder 4xAA	R46.90
Total cost: R403.66	

Table 2 Work distribution between participating engineers

Task	**Participant**
Research	Engineer 1, Engineer 2, Engineer 3
Bandpass filter	Engineer 2, Engineer 3
Fast Fourier Transform Code and Dc motor control	Engineer 1, Engineer 3
Controller	Engineer 1
Soldering	Engineer 3
Assembly	Engineer 1, Engineer 2, Engineer 3

Table 3 Ghant chart of the project timeline

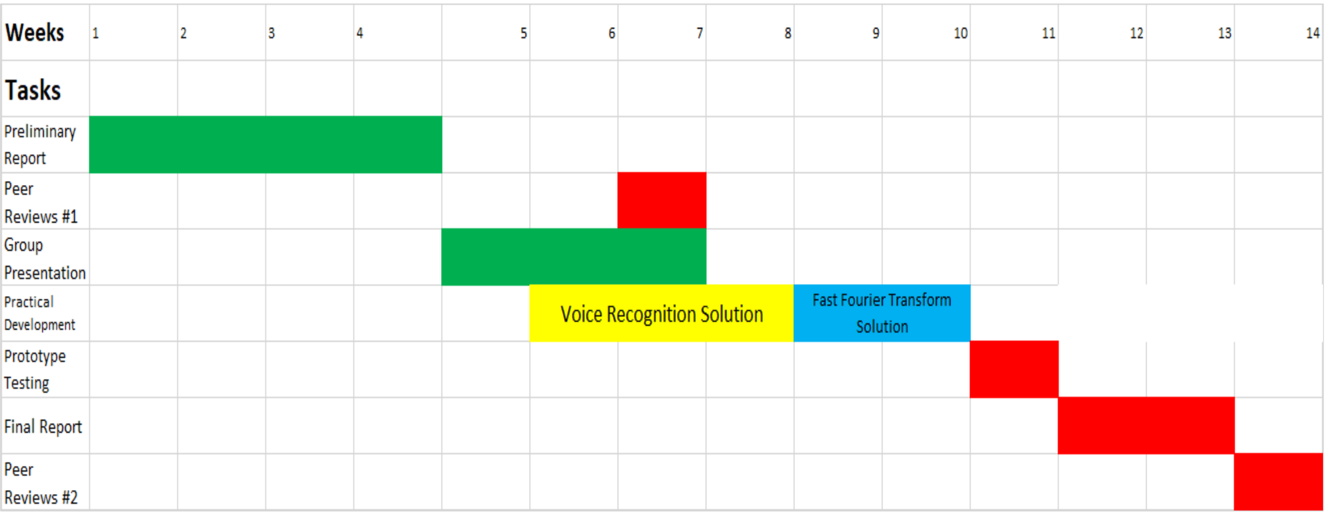

Table 4 Testing of FFT using ESP32 with and without the fourth-order bandpass filter

Command	**Transmitted Frequency (Hz)**	**Detected frequency by ESP32 without Bandpass filter (Hz)**	**Detected frequency by ESP32 with Bandpass filter (Hz)**
None	1000	1009	Nan
None	2000	2015	Nan
None	2500	2521	2521
Forward	2800	2826	2828
Right	2900	2929	2930
Left	3100	3127	3132
Stop	3200	3226	3228
None	3250	3250	3250
None	3500	2995	2996
None	4000	A random value between 2000 and 3000 Hz	Nan