# Design And Implementation of a Remote-Controlled Race Car Utilising Wireless Audio-Transmission

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**Abstract:** The design and implementation of a remote-controlled race car which utilises the audible frequency range to communicate is presented. The design is centred around creating a reliable wireless communication system which is capable of operating within a noisy environment as well as to devise methods of driving a DC motor. The final prototype utilises Digital Signal Processing (DSP) to facilitate the communication as well as noise filtering and Pulse-Width Modulation (PWM) as a method to drive the motor to allow for differential steering. The design has been implemented and successfully constructed satisfying all testing parameters. Further design and testing is required to improve the maximum operating distance and noise immunity.

**Key words:** Wireless communication, PWM, filtering, modulation

## 1. INTRODUCTION

The designing and implementation of a Remote Controlled (RC) car comes with the challenges associated with implementing a wireless communication system. Namely, challenges relating to the attenuation of signals and signal interference [1]. Thus, the goal set out is to investigate the relevance of various wireless communication techniques to overcome these challenges when using audio signals for communication. When implementing the final design various considerations were made analysing the various benefits and shortcomings of each solution. Section 2 details the background, requirements and assumptions imposed as well as an analysis of existing solutions. Section 3 presents the design and implementation of the protype, whilst the testing and critical analysis of the design is given in Section 4

## 2. BACKGROUND

### *2.1 Specifications*

The design of the RC car requires the following specifications be met:

- Limited to 20Hz – 20KHz frequency
- Limited to 5 Volts to drive the motors
- The prescribed components cannot be upgraded
- The sound intensity should be with in a safe range

### *2.2 Assumptions*

The design process of the RC car requires that one have a good understanding of the obstacles the final solution should overcome. Thus, the following assumptions have been made to ensure the implemented design has no unforeseen shortcomings.

The nature of the testing track contains no obstacles that will interfere or obstruct the signals. Moreover, it is assumed that the distance of the track does not exceed the detection range of common microphones. The RC cars will be competing together, thus, resulting in the car receiving and needing to process multiple signals at once.

### *2.3 Success criteria*

The resulting design will be deemed successful should the implemented system complete the defined course producing a completion time. Moreover, the resulting design should be immune to noise arising from the environment as well as other communication devices present. The device should only respond to instructions from driver and not react to interference from other sources. Lastly the system should satisfy all specifications set out.

### *2.4 Existing solution*

Resources detailing the design of an RC car which utilises a wireless audio link for control is not abundantly available. However, there are resources available that individually discuss and present the key component of the design which cumulatively aid in the design process. Key resources pertaining to modulation schemes to encode data, DSP methods to extract data and methods of achieving high noise resiliency when transmitting data have been identified and discussed.

An investigation into radio-controlled RC cars gives one insight to the modulation schemes that commonly used, namely, the use of Frequency Shift Keying (FSK) [2] to facilitate communication as it is simple to implement to encode and decode data and is relatively noise immune. A research paper detailing the use of FSK-PWM for signal transmission verifies this as well as analyses and details the implementation of such a scheme [3]. These studies demonstrate the application of FSK and PWM using microcontrollers to precisely transmit data when communicating wirelessly.

A project utilising DSP to perform a spectral analysis on an incoming sound wave discusses the application of the Fast Fourier Transform (FFT) to extract data from an incoming sound wave [4]. The project utilises this to drive an output to a display, however, this can be easily adapted to drive a differential motor output. The use of the FFT in DSP allows for rapid prototyping when compared to the time need for prototyping when using analogue circuits.

Finally, a report discussing Dual Tone Multi Frequency (DTMF) and applications of the FFT in the transmission of data is considered [5]. This report further explains the use of the FFT in the context of communication as well as notes the noise resilient nature of DTMF. This is a result of the utilization of a complementary pair of mutually exclusive frequency groups to represent data. Thus, implementation of redundancy can used to improve reliability.

## 3. DESIGN AND IMPLEMENTATION

The final design implemented encompasses design decisions discussed in section 2.4 ensuring that the optimal solution accounts for the benefits and drawbacks of each design decision. The final design is broken down into 2 key components, the transmitter which is held by the driver and the receiver which is attached to the car. The transmitter is responsible for accepting the user input and transmitting the instruction as a sound wave. Whilst the receiver is responsible for reading in the soundwave, extracting the instructions, and relaying the instructions to the motors. A high-level overview of the process can be seen in figure 1.

### *3.1 Transmitter*

The transmitter is comprised of a frequency generator app, seen in figure 2, and a speaker. The app is used to produce a set of 4 frequencies each frequency is associated with an instruction. These instructions are as follows: start race, drive straight, turn left and turn right. These are the minimum frequencies required to complete the race. The frequency generator app is used instead of designing a frequency generator circuit as the app allows one to instantaneously switch to any frequency required, moreover, the app is capable of modulating multiple frequencies at a time. The app is simple to use, easily accessible, requires no further development time and is robust.

### *3.2 Receiver*

The receiver is comprised of 3 main components, namely, the sound detection circuitry, microcontroller and the motor driver circuitry.

#### *3.2.1 S*ound detection circuitry

This unit is comprised of two sound sensors, each responsible for the detection of sound waves. This unit represents the sound waves as an electrical signal which can then be read in by the microcontroller. Two microphones have been implemented to improve the sound detection of the receiver in any given direction. The sound sensors utilise electret microphones which have a polar pattern represented best by a hypercardoid. Thus, employing two sound sensors in opposing directions ensures that better coverage is achieved as seen in table 1.

#### *3.2.2 Microcontroller*

The Microcontroller is responsible for preforming the Analogue to Digital Conversion (ADC) on the input from the sound sensors, preforming the DSP using the Arduino FFT library and relaying the output instructions for the motors.

The microcontroller used is the Raspberry Pico, this has been chosen over the Arduino nano as the Pico has much greater clock frequency of 133 MHz allowing for more intricate digital filtering to occur. This allows the microcontroller to sample at a greater resolution whilst maintaining a fast response. The sampling frequency has been set to 30 KHz and the number of samples to 256. This allows for a greater operating range whilst maintaining a minimal error of 117 Hz.

The algorithm implemented on the microprocessor is depicted in the flow chart in figure 3 and proceeds as follows. The microcontroller preforms 12-bit ADC, for maximum resolution, on both microphone inputs. The two sets of sampled data are averaged to produce one set of data. This is done to optimise the code to ensure that we only need to run the FFT once per cycle. The averaged sampled data is windowed using the hamming function. This is done to limit the effects of spectral leakage on the FFT output. The FFT is computed on the windowed data using the Arduino FFT library as this library implements the most efficient FFT algorithm. The system checks if the system interrupt has been triggered to determine which set of frequencies to operate on. Two sets of frequencies have been implemented as a counter measure to the problem of clashing frequencies allowing the cart to switch to a different range of operating frequencies should there be interference. The system checks if the ‘start race’ frequency mentioned in section 3.1 has been played letting the system know if the race has begun. If the ‘start frequency’ has been played the system will check if the magnitudes of the frequencies for the instructions drive straight, turn left and turn right exceed the defined threshold indicating to the car to execute that instruction. The algorithm will loop until the race is complete.

*3.2.3 Motor driver circuitry*

The motor driver circuitry is comprised of the included h - bridge and dc motors. The h-bridge receives a PWM signal from the microcontroller to drive the motor. A custom motor driver circuit had been designed, however, the noise produced by the inductance of the motor affected the microcontroller's ability to perform accurate ADC as the reference volage would fluctuate.

## 4. TESTING AND CRITICAL ANALYSIS

Various test has been conducted to determine the performance of the system. The results of which are discussed below.

The operating distance of the car is an important metric to understand to capabilities of the car as signal attenuation has a great impact on the car's responsiveness. Figure 4 shows the attenuation of the signal at increasing distance. The lap time achieved by the car on testing day was 1 minute 45 seconds. This is a satisfactory result as the car was able to complete the track without any human intervention and lies within the average time achieved.

The noise immunity of the design is another metric of importance as this affects the driver's ability to exercise control over the car. The external interrupt for stitching frequencies proved an effective solution to combating colliding frequency channels, however, the averaging functions implemented in the algorithm did not provide enough immunity from environment noise.

The performance of the car is satisfactory as it was able to complete the tasks required on testing day, however, areas of improvement have been identified. It is noteworthy that the testing requirements changed on race day. The performance of the FFT was acceptable, however, the effect of spectral leakage is still prevalent and negatively impacted the cars ability to detect at long distance. Moreover, the poor efficiency of the h-bridge limited to speed of the car hindering the lap time. The work distribution for the design and implantation of this project is detailed in table 2.

Recommendations for improvements include the implementation of a DTMF scheme to improve noise immunity. Replace the FFT with a digital filter to limit the effects of spectral leakage and implement the FSK scheme to limit the filtering needing to be performed. The addition of a voltage regulator as well as a larger decoupling capacitor could eliminate noise when using a custom motor driver circuit.

## 5. CONCLUSION

The design of a remote-controlled race car utilising wireless audio-transmission has been successfully designed and implanted utilising DSP preformed on a microcontroller, satisfying the minimum requirements set out. However, further testing highlighted key areas of improvement in noise immunity, signal attenuation and motor performance. Implementation of the recommendations discussed would allow for a more robust design capable of improved performance and increased reliability.

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# Appendix

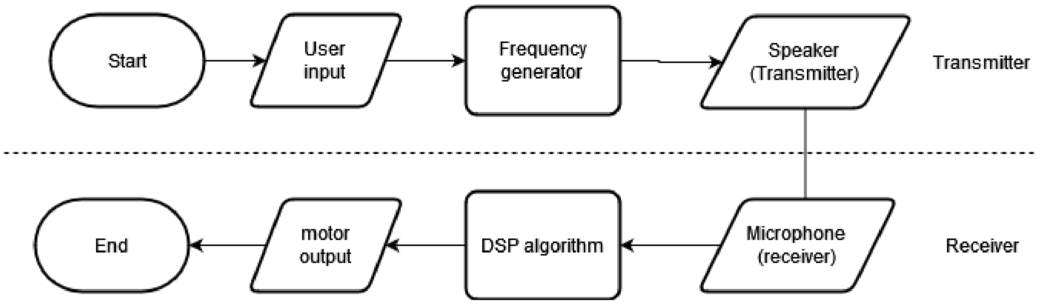


*Figure 1: High level overview of the design*

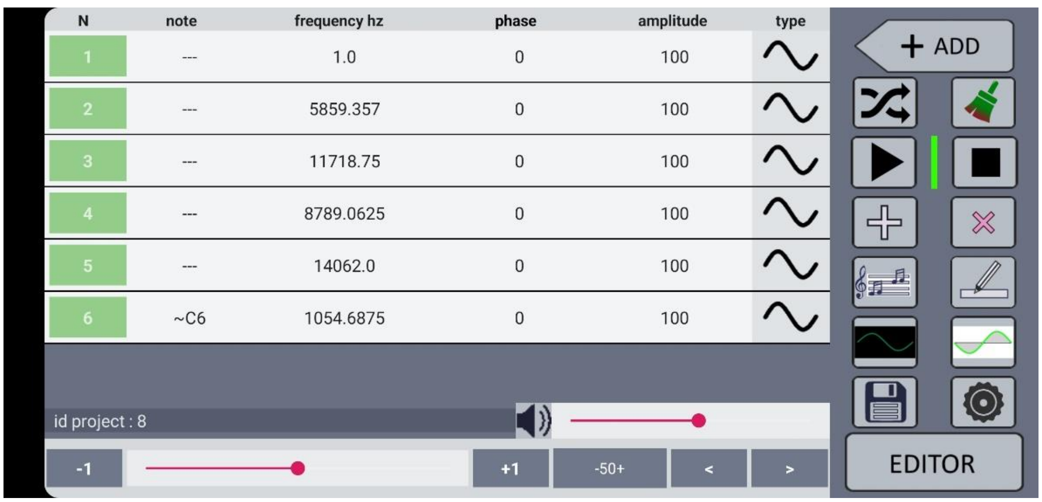


*Figure 2: App used for frequency generation.*

**Table 1 showing the relationship between the polar pattern of the microphone and the magnitude of sound detected at a fixed distance.**

| | 0 | 45° | 90° | 135° | 180° | 225° | 270° | 315° |
|---|---|---|---|---|---|---|---|---|
| Bi-directional mic | 2.45 | 2.87 | 2.98 | 2.77 | 2.3 | 2.69 | 2.89 | 2.85 |
| Single mic | 1.5 | 2.78 | 2.99 | 2.8 | 1.45 | 1.9 | 2.25 | 1.88 |

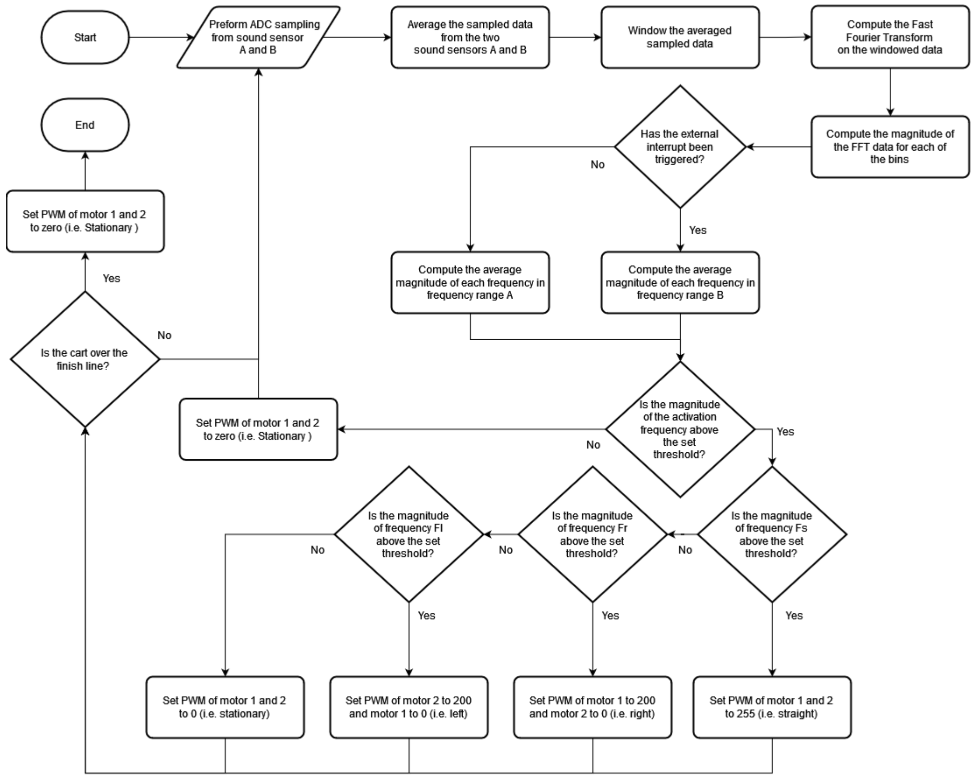


*Figure 3: Flow chat explaining the DSP algorithm implemented.*

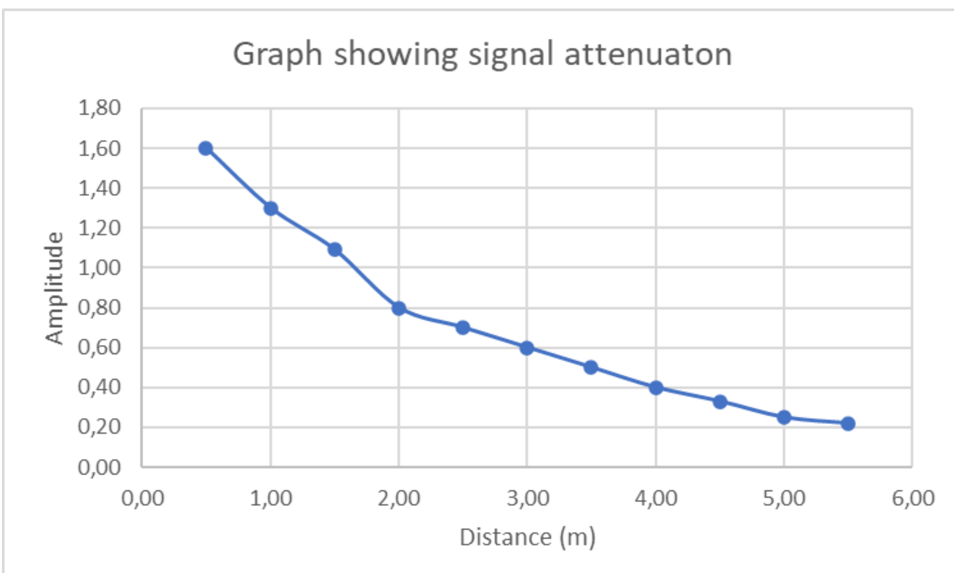


*Figure 4: Graph showing the attenuation of signals at increasing distance.*

**<u>Table 2 showing the work distribution throughout the project.</u>**

| | Group Member 1 | Group Member 2 | Group Member 3 |
|---|---|---|---|
| DSP design | 60% | 30% | 10% |
| Controls design | 40% | 40% | 20% |
| motor circuitry | 20% | 20% | 60% |
| Testing and prototyping | 60% | 20% | 20% |