ELEC5305 Project Proposal

Comparative Study of Music Synthesis Techniques

Additive and FM Synthesis with Spectral Analysis

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Project Overview

This project explores music synthesis as an application of audio signal processing. The central problem is how different synthesis methods influence the spectral characteristics and perceptual quality of generated sounds. While real instruments have complex harmonic structures, digital synthesis techniques attempt to recreate such timbral richness through mathematical modeling.

The proposed solution is to implement and compare Additive Synthesis and Frequency Modulation (FM) Synthesis in MATLAB. By analyzing their spectral outputs and perceptual qualities, this study aims to highlight the strengths, limitations, and potential applications of each method in modern audio processing.

Beyond theoretical interest, music synthesis has significant practical applications in electronic music production, sound design for film and games, and hearing research. Understanding how additive and FM synthesis differ provides insight into why certain timbres are more efficient to generate or more perceptually convincing. This comparison also reflects broader themes in signal processing: trade-offs between precision and efficiency, and between control over parameters and emergent complexity. By systematically analyzing these methods, the project aims not only to reproduce sounds but also to uncover principles that guide modern synthesizer design and digital audio workstation workflows.

Background and Motivation

Music synthesis has been a central topic in both digital signal processing (DSP) and electronic music since the mid-20th century. Early synthesizers relied heavily on additive synthesis, which constructs complex tones by combining multiple sinusoidal harmonics (Wikipedia, Additive synthesis, 2025). This approach directly reflects Fourier theory, where any periodic waveform can be expressed as a sum of sinusoidal components. Although additive synthesis provides precise control over harmonic structure, it can be computationally expensive when modeling instruments with many overtones (Reid, An Introduction To Additive Synthesis, 2000).

Later developments introduced frequency modulation (FM) synthesis, which generates complex and evolving spectra by modulating the frequency of a carrier oscillator with a modulating oscillator (Wikipedia, Frequency modulation synthesis, 2024). Unlike additive synthesis, FM achieves timbral richness using only a small set of parameters, making it far more efficient in practice (Reid, An Introduction To Frequency Modulation, 2000). This efficiency explains the commercial success of FM synthesis in iconic instruments such as the Yamaha DX7, which became one of the most influential digital synthesizers of the 1980s.

Existing research compares additive and FM synthesis from both spectral and perceptual perspectives. Additive synthesis is often favored in theoretical contexts and for precise sound design because of its explicit control over harmonics (Reid, An Introduction To Additive Synthesis, 2000). In contrast, FM synthesis is praised for its ability to produce dynamic, musically rich tones with limited computational resources (Smith, ND).

I chose this topic for three reasons:

1. It connects directly to core DSP knowledge from ELEC5305, including Fourier analysis, harmonic modeling, and envelope shaping.
2. It allows both quantitative evaluation and qualitative demonstration.
3. It offers a balance of feasibility and creativity, with scope for extensions such as hybrid synthesis, real-time implementation, or comparison against recorded instrument timbres.

Proposed Methodology

The project will be implemented in MATLAB using the Signal Processing Toolbox. The methodology is divided into several main components:

Additive Synthesis Implementation

Additive synthesis will be realized by generating tones as the sum of harmonically related sinusoids, reflecting the Fourier decomposition principle (Wikipedia, Additive synthesis, 2025). Amplitude scaling will be applied to approximate the harmonic envelopes of simple instruments such as clarinet or flute, where higher harmonics typically decay in energy (Reid, An Introduction To Additive Synthesis, 2000). Temporal shaping will be introduced through ADSR (Attack–Decay–Sustain–Release) envelopes, enabling simulation of instrument dynamics and articulation (Synclavier, 2019). This approach provides explicit control over harmonic structures, allowing precise manipulation of timbre.

FM Synthesis Implementation

FM synthesis will be implemented following the classic carrier–modulator formulation (Wikipedia, Frequency modulation synthesis, 2024):

$$x(t) = Asin(2\pi f_c t + Isin(2\pi f_m t))$$

where f_c is the carrier frequency, f_m the modulation frequency, and I the modulation index. By varying the modulation index and frequency ratio, different spectral distributions and timbral evolutions can be generated (Reid, An Introduction To Frequency Modulation, 2000). This efficiency in producing complex tones from a small parameter set makes FM synthesis particularly attractive for comparison against additive methods.

Data sources

This project does not rely on external speech or music corpora. Instead, all audio material will be generated synthetically within MATLAB using additive and FM algorithms. For validation and comparison, I will select several recordings of real instrument tones as reference signals to filter and compare them from Music App.

Spectral Analysis

Spectral analysis will be conducted to compare the harmonic richness of the synthesized signals. Magnitude spectra and spectrograms will be computed using FFT and STFT, providing insights into harmonic spacing, spectral centroid, and bandwidth (Smith, ND). These measures will reveal how additive synthesis emphasizes explicit harmonic control, while FM synthesis generates emergent sidebands with distinct spectral signatures.

Evaluation

- Objective Evaluation: Quantitative measures will include spectral centroid, bandwidth, and harmonic distortion to characterize timbre differences. Computational efficiency will also be assessed by measuring processing time for additive versus FM synthesis.
- Subjective Evaluation: Informal listening tests will be conducted to judge perceived similarity to natural instruments and overall musical quality. These perceptual impressions complement the spectral analysis and provide a holistic evaluation.

This methodology ensures that both theoretical spectral properties and perceptual outcomes are captured, enabling a balanced and rigorous comparison of additive and FM synthesis.

Expected Outcomes

The project is expected to deliver both practical implementations and analytical insights into the comparative study of additive and FM synthesis. The main outcomes are:

MATLAB Codebase

- A well-documented MATLAB implementation of additive and FM synthesis, including ADSR envelope modeling and parameter control.
- The code will be modular, allowing other students or researchers to extend the framework for hybrid

synthesis or real-time applications.
- Code will be hosted on GitHub for transparency and reproducibility.

Spectral Analysis Plots
- Time-domain waveforms, magnitude spectra, and spectrograms will be generated for both additive and FM signals.
- These plots will illustrate differences in harmonic control (explicit harmonics in additive synthesis vs emergent sidebands in FM synthesis).
- Quantitative measures such as spectral centroid, bandwidth, and harmonic distortion will be included as indicators of timbral quality.

Demonstration Audio Files
- Audio samples will be synthesized using both additive and FM techniques and shared as WAV files.
- These demonstrations will highlight perceptual differences, allowing listeners to experience how synthesis methods influence timbre and richness.
- Selected audio files will be integrated into the final video presentation as part of the evaluation.

Comparative Discussion
- A structured discussion on the trade-offs between additive and FM synthesis:
  - Control: Additive provides explicit harmonic manipulation, whereas FM relies on emergent complexity.
  - Efficiency: FM synthesis achieves timbral richness with fewer parameters and lower computational cost.
  - Perceptual Quality: Subjective evaluation will indicate which method listeners find more natural or musically appealing.
- The discussion will contextualize results against findings in literature, reinforcing theoretical and practical understanding.

Timeline

Week	Task
6–7	Literature review and dataset collection
8–9	Initial implementation and testing
10–11	Optimization and evaluation
12–13	Final report and GitHub documentation

Reference:

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