Rhythmic Insight

Automated Beat Detection and BPM Analysis Framework

by Sven Fuchs and Joshua Reichmann

This project plan outlines the necessary steps to complete the project on time. It includes a brief description of the content, solution requirements, necessary sub-steps, and a schedule.

December 21, 2023

1   Brief description

The 'Rhythmic Insight' project is an academic undertaking that focuses on developing a MATLAB-based application to analyze audio tracks and determine their beats per minute (BPM). The project is primarily concerned with extracting musical rhythm from integrated music files, using a range of digital signal processing techniques such as Discrete Wavelet Transforms (DWT) and auto-correlation.

The aim of this project is to investigate automated beat detection and demonstrate the suitability of MATLAB as a platform for conducting musical analyses. Users can input their music files into the application, which will analyze the audio signals to identify potential beat progressions and calculate the tempo of the track. The software is designed to process audio input in segments, applying a series of mathematical operations to isolate the rhythmic components and determine the beats per minute (BPM) for each segment.

A crucial aspect of this project is the utilization of median calculation to derive the overall BPM across all measured segments. This method is expected to improve the reliability and accuracy of the BPM measurement, especially in tracks with varying tempos or complex rhythmic structures. Additionally, the application will offer users a graphical representation of the auto-correlation of the processed signal, providing a visual interpretation of the rhythmic patterns and tempo fluctuations.

The project plan will outline the phases of design, implementation, testing and deployment of the software. It will also address potential challenges and propose strategies to mitigate them. The project aims to deliver an efficient and functional tool for BPM detection, contributing to the field of musical analysis and demonstrating the capabilities of MATLAB for signal processing applications.

2   Aims of the project

The final aims of the 'Rhythmic Insight' project should encapsulate the broad goals of the software while remaining attainable for a student group. The following are some general aims for the software:

1. **Accurate BPM Detection**: The aim of this project is to develop an algorithm that can precisely detect the BPM of various music genres. The target is to achieve a high level of accuracy, which can be considered *appropriate* for academic projects. It is important to note that the goal is not perfection, but rather a consistent and reliable analysis.

2. **Handling of Varied Musical Structures**: The software must be capable of processing both simple and complex rhythmic structures, including straightforward beats and more intricate patterns found in genres with fluctuating tempos and intricate rhythms.

3. **User-Friendly Interface**: Design a user interface that is intuitive and easy for users to navigate. The interface should allow users to upload audio files, initiate analysis, and view results in a clear and understandable format.

4. **Efficient Processing**: The objective is for the software to efficiently process audio files, optimizing for reasonable analysis times without sacrificing accuracy. It should be able to analyze a standard-length track in a practical time frame for users.

5. **Adaptability and Scalability**: The software should be designed with adaptability in mind, allowing for future enhancements and additions. It should be structured in a way that new methods or improvements can be integrated without extensive overhauls.

6. **Educational Value**: The project should have educational value by providing clear insights into digital signal processing, rhythm analysis, and software development. Thorough documentation should explain the methods, algorithms, and design choices made.

7. **Robustness and Reliability**: The software should be designed to be robust, capable of handling various input types and qualities with minimal errors or failures. It should consistently produce accurate results across multiple runs on the same input.

8. **Testing and Validation**: Conduct comprehensive testing on a variety of music tracks to validate the software's performance. Document the testing process and results to provide transparency and understanding of the software's capabilities and limitations.

These aims provide a broad framework for developing the 'Rhythmic Insight' software. The project aims to create a useful, educational, and reliable tool for detecting BPM and analyzing music.

3   Roadmap

The 'Rhythmic Insight' project comprises a series of progressively complex objectives aimed at developing a comprehensive understanding of musical tempo and rhythm through signal processing techniques. The following are the outlined objectives for the project:

1. Basic Beat Detection in Simple Rhythms:

   - **Objective**: To develop an initial capability of the software to detect the BPM of tracks with simple, consistent beats such as those found in techno music.
   - **Approach**: Implement an algorithm to analyze the energy of the audio signal and identify peaks corresponding to beats. This will involve setting a threshold to distinguish between the beats and other parts of the audio signal.

2. Enhancement of Beat Detection Accuracy:

   - **Objective**: To refine the beat detection process for greater accuracy, enabling the software to detect beats reliably across a wider range of simple rhythmic patterns.
   - **Approach**: Improve the energy analysis algorithm to adapt to different energy levels and incorporate a smoothing mechanism to reduce false positives and negatives.

3. Introduction of Auto-Correlation for Complex Rhythms:

   - **Objective**: To extend the software's capabilities to handle more complex rhythms, such as those found in jazz or classical music, which may have varying tempos and more intricate beat structures.

- **Approach**: Implement an auto-correlation function to analyze the time intervals between beats, accommodating for variations and irregularities in the rhythm.

4. Multi-Level Signal Decomposition:

   - **Objective**: To analyze tracks with multiple instruments and layered rhythms, extracting and isolating the beat from a complex mixture of sounds.
   - **Approach**: Use Discrete Wavelet Transforms (DWT) to decompose the audio signal into various frequency components and analyze each one for rhythmic information.

5. Temporal Dynamic Analysis:

   - **Objective**: To detect changes in tempo and rhythm over time within a single track, identifying transitions and variations.
   - **Approach**: Implement a sliding window technique to perform beat detection over short, overlapping segments of the track, allowing the detection of changes in tempo and rhythm throughout the piece.

6. User Interface Development:

   - **Objective**: To create an intuitive and user-friendly interface that allows users to easily input their audio files and understand the analysis provided by the software.
   - **Approach**: Develop a (*optional*: graphical) user interface (GUI) that provides visual feedback, such as waveforms and tempo graphs, and allows for easy navigation and operation of the software.
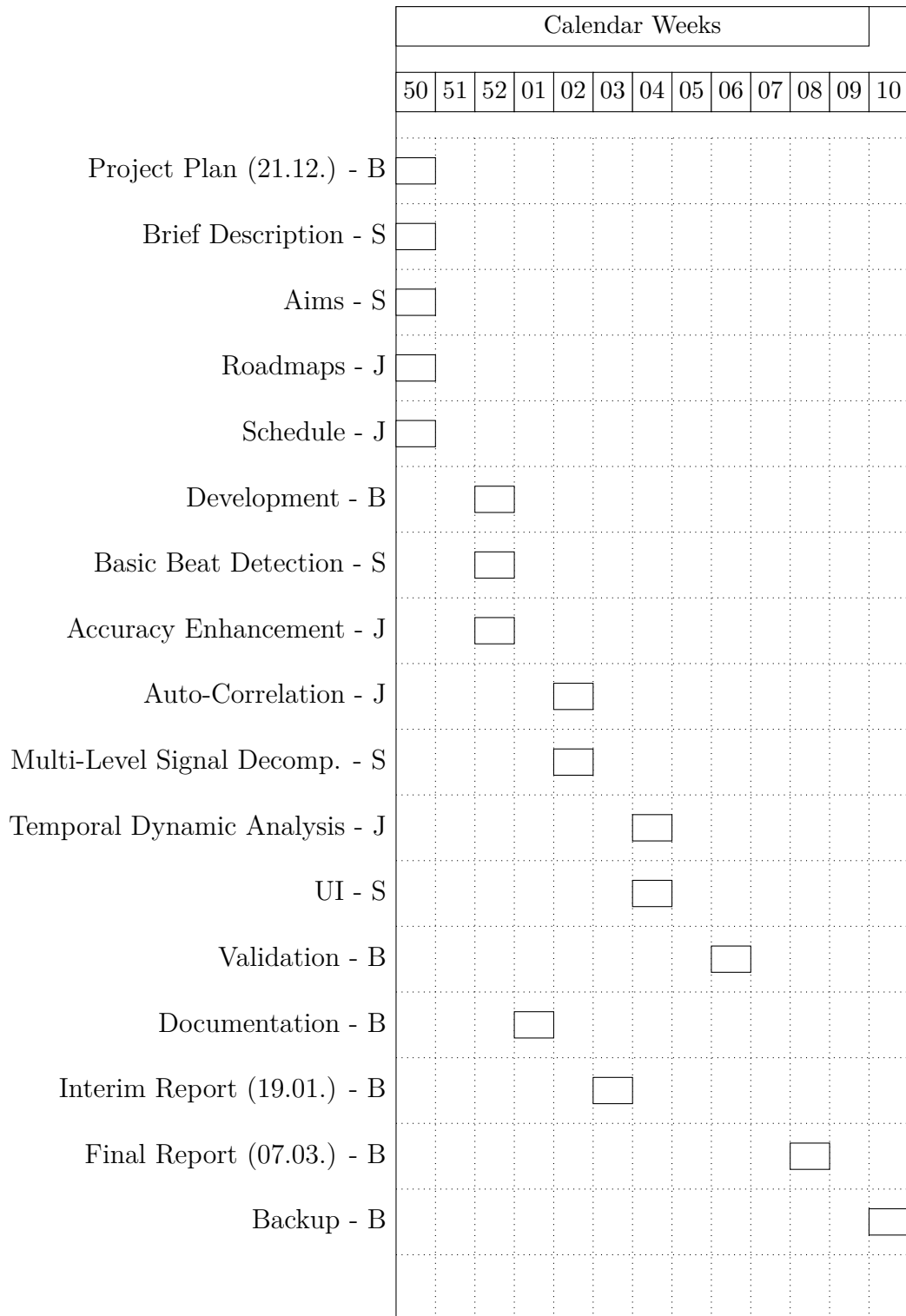
7. Validation and Testing:

   - **Objective**: To ensure the reliability and accuracy of the BPM detection across a variety of music genres and recording qualities.
   - **Approach**: Conduct extensive testing using a diverse set of audio tracks, comparing the software's BPM output with manually verified values and adjusting the algorithms as necessary to improve accuracy.

The 'Rhythmic Insight' project aims to create a versatile and reliable tool for analyzing musical tempo and rhythm, contributing valuable insights and methodologies to the field of digital music analysis.

4   Schedule

To manage and track the progress of the 'Rhythmic Insight' project, a Gantt chart is presented below. The chart outlines the timeline, key milestones, and dependencies of various tasks, providing a visual roadmap for the project's development from inception to completion.

	Calendar Weeks												
	50	51	52	01	02	03	04	05	06	07	08	09	10
Project Plan (21.12.) - B	▭												
Brief Description - S	▭												
Aims - S	▭												
Roadmaps - J	▭												
Schedule - J	▭												
Development - B			▭										
Basic Beat Detection - S			▭										
Accuracy Enhancement - J			▭										
Auto-Correlation - J					▭								
Multi-Level Signal Decomp. - S					▭								
Temporal Dynamic Analysis - J							▭						
UI - S							▭						
Validation - B									▭				
Documentation - B				▭									
Interim Report (19.01.) - B						▭							
Final Report (07.03.) - B											▭		
Backup - B													▭

B = both, J = Joshua, S = Sven

The Gantt chart above serves as a strategic planning tool to ensure that all project components are addressed in a timely and orderly manner. It will be instrumental in monitoring progress, managing resources, and achieving the set objectives within the designated time frame. Regular reviews and updates to the Gantt chart will be conducted to reflect any changes or developments as the project advances.