**CCT College Dublin**

**Assessment Cover Page**

*To be provided separately as a word doc for students to include with every submission*

|  |  |
| --- | --- |
| **Module Title:** | Research and Professional Ethics |
| **Assessment Title:** | Using Deep Learning to Classify and Analyse Musical Instruments Based on Spectrograms and Audio Features |
| **Lecturer Name:** | Rory Byrne |
| **Student Full Name:** | Obinna Igbodika |
| **Student Number:** | 2022551 |
| **Assessment Due Date:** | 26/05/2023 |
| **Date of Submission:** | 28/05/2023 |

**Declaration**

|  |
| --- |
| By submitting this assessment, I confirm that I have read the CCT policy on Academic Misconduct and understand the implications of submitting work that is not my own or does not appropriately reference material taken from a third party or other source. I declare it to be my own work and that all material from third parties has been appropriately referenced. I further confirm that this work has not previously been submitted for assessment by myself or someone else in CCT College Dublin or any other higher education institution. |

**Using Deep Learning To Classify And Analyze Musical Instruments Based On Spectrograms And Audio Features**

**INTRODUCTION**

In recent years the field of music information retrieval (MIR) has witnessed significant advancements with deep learning methods for audio, analysis gaining substantial attention from scholars and practitioners This has opened up exciting possibilities for the classification and analysis of musical instruments based on audio features and spectrograms. The ability of deep learning algorithms to automatically extract features from audio signals offers a promising avenue for more precise and robust models in instrument classification and analysis. Traditionally instrument classification has relied on hand crafted features and rule based systems, often limited in their ability to capture the intricate nature of audio data. Although with recent advancements in deep learning algorithms, researchers now have the opportunity to build models that can learn and extract features automatically from audio signals. This shift has sparked a renewed interest in exploring the potential of deep learning for instrument classification and analysis. The objective of this study is to develop a deep learning based model framework for classifying and analyzing musical instruments, utilizing both audio features and spectrograms. To achieve this we will train the model, on a large dataset consisting of audio recordings from various musical instruments. The performance of the proposed model will be evaluated using multiple metrics to ensure its accuracy and effectiveness. The outcomes of this research, investigation hold great potential for advancing the field of music information retrieval. The accurate classification and analysis of musical instruments can have various applications including music information retrieval systems, audio content analysis and automatic transcription. Additionally, the findings from this study will contribute to the development of more precise and robust models, ultimately enhancing the accuracy and reliability of instrument classification and analysis. By leveraging deep learning algorithms and exploiting the rich information contained within spectrograms and audio features we aim to overcome the limitations of traditional approaches in instrument classification. This research will not only contribute to the advancement of music analysis but also have implications for other domains such as music recommendation systems and genre identification. In conclusion, the fusion of deep learning techniques and audio analysis provides a promising avenue for accurately classifying and analyzing musical instruments. Through the development of a deep learning based model framework trained on a comprehensive dataset we aim to advance the field of music information retrieval, and contribute to the growth of more precise and robust models. The potential applications of this research span various domains, making it an exciting and important area of investigation in the field of audio analysis and machine learning.

**AIMS**

* To develop a deep learning model capable of accurately classifying different musical instruments based on their spectrograms and audio features.
* To investigate which combination of spectrogram and audio features yields the best classification accuracy for different musical instruments.
* To compare the performance of different deep learning models, such as convolutional neural networks and recurrent neural networks, in classifying musical instruments based on spectrograms and audio features

**RELATED WORK**

The paper presents an empirical study on feature analysis for classical instrument recognition using machine learning techniques. The authors analyze three major feature extraction schemes and evaluate their performance using classifiers undergoing cross-validation. The results reveal significant redundancy between and within feature schemes commonly used in practice. The study shows that the MFCC feature scheme gives the best classification performance and that some MPEG-7 features are not reliable for robust classification results. The authors suggest further feature analysis research to optimize feature selection and achieve better results for the instrument recognition problem. They propose investigating new feature schemes and mechanisms to combine feature schemes to improve classification performance. The paper highlights the importance of feature analysis and selection for instrument recognition tasks and provides relevant information for future research in this area. Overall, the study contributes to advancing the understanding of feature analysis and selection for classical instrument recognition, and the findings have implications for improving the accuracy of machine learning-based classification systems. Overall, this paper provides relevant information on the importance of feature analysis and selection for instrument recognition tasks, highlighting the need for further research in this area. The findings suggest that the MFCC feature scheme is most effective for classification tasks and that the current feature schemes used in practice are highly redundant. The paper also identifies possible areas for improvement, such as investigating new feature schemes and mechanisms to combine feature schemes to improve classification performance.

An interdisciplinary research field also focused on retrieving information from music. One of the cornerstone problems in MIR is musical instrument retrieval (MIR), specifically instrument classification. The IRMAS (Instrument Recognition in Musical Audio Signals) dataset has been used extensively for this purpose, as it includes a wide variety of musical clips recorded from various sources over the last century, with varying audio quality. Previous research has employed various supervised learning algorithms for this classification task, with SVM (Support Vector Machine) classifiers outperforming other state-of-the-art models with an accuracy of 79%. Unsupervised techniques such as Hierarchical Clustering have also shown promising results. Evaluation metrics used to assess the performance of the models include Precision, Recall, F1 score, Accuracy, and Confusion Matrix. It was observed that the classifier is unable to distinguish between flute and organ accurately due to their spectral envelopes being mostly identical in nature. There is scope for future research in this field, including using the same approach on a different dataset, exploring the idea of classifying Indian instruments, and studying and extracting more features using signal processing techniques to improve the accuracy of instrument classification. Overall, the development of robust MIR systems will contribute to a myriad of applications, including Recommender systems, Genre Identification, and Catalogue Creation, making the entire music catalogue manageable and accessible with ease.

Algorithm for automatically identifying all instruments present in an audio excerpt using sets of individual convolutional neural networks (CNNs) per tested instrument. The motivation for this work was the need for a flexible model where any instrument could be added to the previously trained neural network. The proposed solution split the model into separate processing paths, one per instrument to be identified, allowing the use of models with various architecture complexity for different instruments, adding new sub models to the previously trained model, or replacing one instrument for another. The study started with a review of tasks related to musical instrument identification, including the input type, algorithms employed, and metrics used. The model architecture was designed to produce outputs focused on specific patterns in the MFCC signal depending on the examined instrument, opposite to state-of-the-art methods, where a single convolutional part obtains one pattern per all instruments. The proposed framework is very flexible, allowing the use of instrument models with various complexity and the opportunity to extend the model with more instruments by adding new sub models in the proposed architecture. The model achieved high efficiency, with the metric values ranging from 0.86 for the guitar to 0.99 for drums.

The proposed model has several advantages over existing methods, such as the ability to identify various instruments, as it is not limited to a specific set of instruments. This flexibility is particularly valuable in real-time systems. The model could also use other neural network structures, such as sample-level filters, and try other approaches to music feature extraction, such as including the derivation of rhythm, melody, and harmony and determining their weights by employing the exponential analytic hierarchy process (AHP). The model could also be tested with audio signals other than music, such as the classification of urban sounds. In conclusion, the proposed model is a flexible and efficient solution for the automatic identification of musical instruments in an audio excerpt. The model's ability to add new sub models in the architecture, use instrument models with various complexity, and extend the model with more instruments makes it highly adaptable and valuable in real-time systems. Future work will explore the creation of a new dataset that will contain musical instruments that are underrepresented in music repositories and test the proposed model with audio signals other than music. The proposed model has the potential to significantly contribute to the field of automatic instrument identification and classification.

A common approach to applying CNNs to audio recognition tasks is employing a spectrogram image as the feeding data. However, this loses phase information. In this paper, the authors propose using multiresolution recurrence plots (MRPs) to analyze time-series data in a two-dimensional space without losing phase information. The authors combine spectrogram images with MRPs using a multi-column network to improve classification performance over a system that uses only a spectrogram.

To evaluate the proposed method, the authors created a dataset classifying four different types of pianos using a single note. The dataset comprised four seconds of 88 single notes from each of the four different pianos without any audio compression or pitch shifting. The authors used ten-fold cross-validation to evaluate the performance of their proposed method.

The authors evaluated the performance of MRP-based classification, spectrogram-based classification, and the combined results using multi-column CNNs. The results showed that incorporating MRPs with spectrogram image data improved the classification performance. Using only network-1, the classification performance was higher than the baseline. However, spectrogram-based network-2 showed an even more improved performance than network-1. When combining MRPs with spectrogram image data using a multi-column network, the classification performance improved further.

In conclusion, the proposed method for musical instrument classification using CNNs and MRPs provides a significant improvement over traditional method. The combination of MRPs and spectrogram images using a multi-column network allows for the extraction of characteristic timbre of musical instruments that cannot be extracted using a phase-blinded representation such as a spectrogram. The proposed method shows promise for more challenging timbre classification for musical instruments.

In the field of music transcription, accurately deciphering the intricate details of polyphonic music signals has long been a challenge. However, a recent research paper titled "Multi-Instrument Music Transcription Based on Deep Spherical Clustering of Spectrograms and Pitchgrams" by Tanaka et al. proposes a novel method that tackles this problem head-on. The paper introduces a clustering-based approach that estimates piano rolls of various musical instrument parts from complex polyphonic music signals, even when the musical instruments are undefined. The researchers' methodology consists of three key components: a feature extraction part, a feature embedding part for obtaining piano roll space and timbre space, and an estimation part based on deep spherical clustering. To address the limitation of dealing with undefined musical instruments, the team employs an instrument-independent neural multi-pitch estimator to estimate a condensed pitchgram. The pitchgram is then separated into distinct musical instrument parts using the deep spherical clustering technique. To improve transcription performance, the researchers propose a joint spectrogram and pitchgram clustering method that considers both timbral and pitch characteristics of musical instruments. The experimental results presented in the paper demonstrate the effectiveness of the proposed method. In the transcription of unknown instruments under open conditions, the proposed method outperforms the state-of-the-art classification-based approach. Moreover, the F-measure score for unknown instruments is comparable to that of known instruments, whereas the classification-based method experiences a significant decrease in performance. The proposed method also achieves accuracy equivalent to the classification-based approach in transcribing known instruments under both conditions. The estimated piano rolls obtained using the proposed method exhibit promising results, effectively conducting pitch estimation and instrument assignment. Although some errors are present in certain cases, the overall performance of the method is commendable. The researchers highlight several areas for future exploration. One important direction is to automate the process of matching estimated piano rolls with instrument part labels, which is currently done manually. Additionally, the researchers suggest considering the possibility of multiple instruments sharing the same time-frequency bin by introducing the von Mises-Fisher (vMF) distribution into the hyper spherical latent space and employing soft clustering based on this distribution. In conclusion, the research presented in this paper contributes significantly to the field of music transcription by providing a clustering-based method capable of transcribing arbitrary musical instrument parts. The integration of timbral and pitch characteristics enhances the accuracy and adaptability of the proposed approach. The results warrant further research, particularly in automating the matching process and exploring soft clustering techniques using the vMF distribution in the latent space.

The recognition of predominant instruments in ensemble recordings poses a significant challenge, especially when distinguishing closely-related instruments such as alto and tenor saxophones. In their paper, "Jazz Solo Instrument Classification with Convolutional Neural Networks, Source Separation, and Transfer Learning," Juan S. Gómez, Jakob Abeßer, and Estefanía Cano from the Semantic Music Technologies Group at Fraunhofer IDMT in Germany propose an innovative approach to improve instrument recognition. Their study aims to make contributions to the field of Music Information Retrieval (MIR), benefiting tasks such as automatic music transcription, source separation, and music recommendation. The researchers build upon a hybrid deep neural network, which combines convolutional and fully connected layers to learn spectral-temporal patterns indicative of specific instruments.

To mitigate the overlap among multiple instruments, they evaluate two pre-processing steps harmonic/percussive and solo/accompaniment source separation algorithms. By isolating the desired instrument from the mixture, they aim to enhance instrument recognition performance. Additionally, they employ transfer learning techniques to fine-tune a pre-existing instrument recognition model for the classification of six jazz solo instruments. The results indicate that both source separation and transfer learning techniques significantly improve instrument recognition performance, particularly for smaller subsets of highly similar instruments. The researchers found that the combination of solo/accompaniment source separation and transfer learning leads to better generalization to unseen data in jazz solo instrument classification. These findings demonstrate the potential of applying deep learning models to discriminate between highly similar instruments and extend their application to other timbre-related recognition tasks.

The systematic evaluation of source separation algorithms as pre-processing steps, along with the application of transfer learning techniques, contributes to the advancement of instrument recognition in ensemble recordings. The study provides insights into improving timbre description and instrument classification, particularly in jazz ensemble recordings. Furthermore, the findings suggest the potential utilization of the proposed system for content-based metadata clean-up and enrichment of jazz archives. However, the researchers acknowledge the need for further research and emphasize the importance of expanding the dataset used in the study (JAZZ dataset). By increasing the dataset size, the generalizability of the system can be enhanced. Future investigations may explore the application of the proposed methods in performer identification and other timbre-related recognition tasks. In conclusion, Gómez, Abeßer, and Cano's study presents an effective approach to jazz solo instrument classification by combining convolutional neural networks, source separation, and transfer learning. Their research offers valuable insights and improvements to instrument recognition in ensemble recordings, paving the way for advancements in MIR and its related fields.

Music Instrument Classification (MIC) plays a vital role in various applications such as music recommendation, automatic mixing, and music discovery. However, the lack of annotated training data poses a significant challenge for achieving high-performance results. In this article, titled "Music Instrument Classification Reprogrammed," Hsin-Hung Chen and Alexander Lerch from the Music Informatics Group at Georgia Institute of Technology propose a novel technique called "reprogramming" to address the scarcity of annotated data for MIC. They demonstrate that reprogramming can effectively leverage the power of pre-trained deep neural networks originally designed for different tasks, resulting in state-of-the-art performance with significantly reduced training parameters.

The researchers adopt the concept of transfer learning and introduce the reprogramming paradigm to the field of Music Information Retrieval (MIR). They select a pre-trained state-of-the-art audio classification model, the Audio Spectrogram Transformer (AST), and extend it through input pre-processing and label mapping. The study aims to explore various forms of input and output reprogramming to enhance the compatibility of the pre-trained model with MIC tasks. The authors hypothesize that by modifying the input data and mapping the output labels, the reprogrammed model can adapt to the specific requirements of MIC.

Through extensive evaluation and analysis, the researchers demonstrate that reprogramming achieves remarkable performance in MIC tasks, surpassing state-of-the-art systems. The study provides evidence that reprogramming can be a promising technique for tasks impeded by data scarcity. By effectively utilizing a pre-trained model's representation, the reprogrammed system shows comparable or even superior performance while requiring significantly fewer training parameters. This approach addresses the limitation of data availability and reduces the complexity of training, making it applicable to various fields beyond MIR. In conclusion, the study by Chen and Lerch introduces the concept of reprogramming to address the lack of annotated data in Music Instrument Classification. Their methodology, which modifies the input and output of a pre-trained model, proves successful in achieving state-of-the-art results. The researchers highlight the potential of reprogramming in other MIR tasks and emphasize its low training complexity. They suggest exploring variations of input reprogramming beyond CNN or U-Net structures and testing the algorithm with different pre-trained models from both audio and non-audio domains. The promising outcomes and the reduced training complexity warrant further research into reprogramming as a transfer learning approach in MIR and other fields with limited data.

A proposed method for music emotion recognition based on a convolutional neural network (CNN). The method aims to improve the efficiency and accuracy of music emotion classification by combining low-level audio features with time-domain and frequency-domain features extracted using a convolutional recurrent neural network (CRNN) and bidirectional long short-term memory (Bi-LSTM) network.

The proposed method utilizes the mel-frequency cepstral coefficient (MFCC) and residual phase (RP) as weighted and combined low-level audio features. These features are then input into the CRNN to extract time-domain, frequency-domain, and sequence features from the spectrogram. Additionally, the low-level features are input into the Bi-LSTM network to capture sequence information. The extracted features from both networks are fused and input into a softmax classification function with a center loss function to classify music into four emotion categories.

Experiments conducted on an emotion music dataset show that the proposed method achieves a recognition accuracy of 92.06% and a loss function value of approximately 0.98, outperforming other methods. The method offers a new approach for music emotion recognition by combining different types of features and leveraging deep learning techniques.

The passage also discusses the importance of music emotion recognition in various fields such as music database management, retrieval, recommendation, and therapy. It highlights the limitations of manual emotion labeling and the need for automatic recognition methods. Previous research in this area is mentioned, including studies on emotion recognition using lyrics or audio analysis, multimodal fusion techniques, and machine learning-based approaches.

The experiments conducted in the study use an emotion music dataset consisting of 2906 songs with four emotion classes: anger, happiness, relaxation, and sadness. The dataset is divided into training, verification, and test sets, with the first 30 seconds of each song used for analysis. The passage presents the results of different experiments, such as selecting the optimal audio time period, analyzing the influence of iteration times on loss values, comparing different convolutional networks, and evaluating emotion classification using confusion matrices.

Overall, the proposed method shows promising results in music emotion recognition and provides a new approach for extracting and combining various features for improved classification accuracy.

The classification of music genres plays a crucial role in effectively organizing and retrieving large collections of music. However, achieving reliable accuracy in music classification has remained a challenge. Traditional methods employing handcrafted features have struggled to capture the unique characteristics of music, necessitating the exploration of dynamic and effective alternatives. In this context, the combination of a Convolutional Neural Network (CNN) and variants of Recurrent Neural Networks (RNN) has been relatively underexplored. This study aims to address this gap by proposing a hybrid architecture that combines a CNN with Long Short-Term Memory (LSTM), Bidirectional LSTM (Bi-LSTM), Gated Recurrent Unit (GRU), and Bidirectional GRU (Bi-GRU) variants of RNN. The performance of the proposed architecture is evaluated using two different feature extraction techniques: Mel-spectrogram and Mel-frequency cepstral coefficient (MFCC).

The authors conducted experiments using the GTZAN dataset, which consists of 1000 music clips categorized into ten genres. The dataset was preprocessed by converting the 30-second clips into 3-second durations for meticulous evaluation. Feature extraction was performed using Mel-spectrogram and MFCC methods. Mel-spectrogram represents a 2D signal obtained through bandpass filters and a digital filter bank, while MFCC involves analyzing audio signal acoustics such as rhythm, pitch, tonality, intensity, and timbre. The proposed hybrid architecture, incorporating CNN and the respective RNN variants, was then applied to classify the music genres.

The results showed that the hybrid architecture of CNN and Bi-GRU, utilizing Mel-spectrogram features, achieved the highest accuracy of 89.30%. On the other hand, the hybridization of CNN and LSTM, using MFCC features, attained an accuracy of 76.40%. These findings suggest that the proposed hybrid model is effective in music genre classification. The study contributes to the field by demonstrating the benefits of combining CNN and RNN variants, along with the importance of selecting appropriate feature extraction techniques. The authors also compared their model's performance with other state-of-the-art methods and found comparable results.

The hybrid architecture and feature extraction techniques presented in this study provide insights into improving music classification. However, further research is warranted to explore the proposed methodology on additional datasets, such as FMA, for tasks such as instrument recognition or artist identification. Additionally, it would be valuable to investigate the potential applications of the hybrid model beyond music classification, such as in music recommendation systems or online access platforms.

Overall, this study successfully addresses the challenges of music classification by proposing a hybrid CNN and RNN variant model. The experimental results, coupled with the comparative analysis, highlight the effectiveness of the proposed approach. By advancing the understanding of deep learning techniques in music analysis, this research contributes to the development of efficient systems for organizing and retrieving music collections.

In today's digital era, with the rise of music streaming platforms like Spotify, Apple Music, and Deezer, automatic instrument recognition in sound recordings has become increasingly important. However, distinguishing between similar instruments such as the cello and violin or the flute and clarinet remains a challenging task for both machines and humans. In this research paper titled "Instrument Classification using image-based Transfer Learning," authors Utsav Shukla, Utkarsh Tiwari, Vaibhav Chawla, and Shailendra Tiwari aim to address this challenge by identifying four similar string instruments (acoustic guitar, cello, violin, and electric guitar) in audio recordings.

The researchers employed two popular deep learning architectures, 1D MLPs (Multi-Layer Perceptrons) and 2D CNNs (Convolutional Neural Networks), to classify the sounds. They compared the performance of these architectures on different audio features, namely Mel-frequency cepstral coefficients (MFCC), constant-Q transform (CQT), Mel Spectrogram, and a self-curated 1-dimensional feature that combines multiple audio features. Additionally, they explored the use of image-based transfer learning models such as Inception and VGG, which have shown significant advancements in image classification tasks.

The study's main contribution involved creating a subset of the IRMAS dataset, called IRMAS-String, specifically focusing on string instruments. The researchers conducted comprehensive experiments using various audio features and deep learning architectures for instrument classification. Their results indicated that utilizing pretrained image models, particularly Inception V3, led to improved accuracy compared to other architectures. They observed an increase in accuracy by converting stereo audio samples to mono using the Librosa package's to\_mono function. The study demonstrated the advantage of transfer learning in audio classification tasks and highlighted the effectiveness of MFCC and the self-curated 1D feature for instrument recognition.

The research paper successfully achieved its objectives of comparing the performance of different audio features and model architectures in instrument classification tasks. The findings suggested that using image-based transfer learning models and specific audio features, such as MFCC, yielded promising results. The study's outcomes hold relevance in various domains, including music transcribers, home assistants, and recommendation systems. However, further research is warranted to explore the combination of different features and evaluate their collective performance. Additionally, investigating preprocessing techniques like source separation and noise reduction could further enhance the efficiency of the models in instrument recognition.

Overall, the study sheds light on the potential of leveraging image-based transfer learning and deep learning architectures in the field of instrument classification. By addressing the challenges associated with distinguishing similar instruments, this research contributes to the development of accurate and efficient music classification systems.

In the Internet age, music has transcended borders and holds a universal appeal, expressing thoughts, emotions, and resonating with people from different cultures and regions. As technology revolutionizes various fields, including music production and education, researchers have started exploring the application of intelligent music recognition technology in music teaching. This article aims to investigate the use of deep learning, specifically the Long Short-Term Memory (LSTM) network, to distinguish and generate various genres of music. By analyzing the role of machine learning and deep learning in music, the study designs an algorithm model for intelligent music generation, providing a theoretical foundation for further research in this area.

The study utilizes a massive dataset of music to test the designed music style discrimination and generation model. The model's architecture consists of four hidden layers with 1,024, 512, 256, and 128 neurons, respectively. The classification accuracy of jazz, classical, rock, country, and disco music genres is evaluated, with a focus on jazz classification, which yields the best results at 77.5% accuracy. Additionally, the generated music scores are compared with the original music spectrum, demonstrating a close alignment. The researchers employ deep neural networks, particularly LSTM, for music analysis and processing, as they are more capable of handling large-scale data and extracting meaningful features.

The experimental results indicate that the designed algorithm model can effectively distinguish between music signals and generate diverse genres of music. The classification accuracy for different music genres exceeds 60%, outperforming the traditional restricted Boltzmann machine method. The findings highlight the potential of deep learning algorithms, specifically LSTM networks, in music generation and classification tasks. The algorithm's ability to accurately capture and reproduce music characteristics paves the way for advancements in intelligent music teaching. The study's outcomes have implications for quality education and the integration of technology in music pedagogy.

This research contributes to the field of music education psychology by shedding light on the psychological changes that occur during music teaching. It emphasizes the importance of understanding individual behavioral and psychological cognition in the teaching process. The use of intelligent music signal identification and generation technology has the potential to enhance teaching effectiveness and provide a rich learning experience. Further research can focus on refining the algorithm model to improve accuracy, exploring additional music genres, and investigating the impact of intelligent music teaching on student learning outcomes. Continued research in this area will support the advancement of music education and the integration of technology in pedagogical practices.

**VALIDITY**

Accurate: This component is relevant as the deep learning model's output needs to be statistically sound and secure. The accuracy of the model's output is critical to the success of the classification and analysis of musical instruments.

Relevant: This component is important because the information collected through spectrograms and audio features should directly relate to the problem definition identified, which is the accurate classification of musical instruments. The relevance of the features used in the model will determine its effectiveness in classifying different musical instruments

**Sampling Strategy**

For a data analytics project focused on classifying and analyzing musical instruments, a non-probability sampling strategy, specifically snowballing and judgment sampling, has been chosen. This approach offers several advantages, such as flexibility in data collection, targeting specific elements of the population, and leveraging expert knowledge. Snowballing involves gradually expanding the sample by asking participants to refer others who meet the desired criteria, while judgment sampling allows for selection based on expert judgment and domain knowledge. These methods align with the project's objectives of developing a deep learning model for instrument classification and ensure a diverse and comprehensive dataset. Non-probability sampling enables efficient and effective data collection by targeting experts and musicians who can provide high-quality audio recordings and valuable insights. Overall, this sampling strategy enhances the accuracy and effectiveness of the deep learning model and contributes to music information retrieval and analysis.

**Primary Research Methodology**

For the data analytics project focused on classifying and analyzing musical instruments, qualitative research methods, specifically in-depth interviews, have been chosen as the primary research methodology. In-depth interviews allow for a comprehensive understanding of instrument classification by exploring the experiences, perspectives, and insights of experts and musicians. These interviews provide rich qualitative data, capturing detailed aspects of instrument classification that may not be captured by quantitative methods alone. The flexibility of in-depth interviews enables tailored questioning and exploration of specific areas of interest, accommodating the diversity within the field of music. Furthermore, these interviews foster a personal connection, encouraging participants to share their authentic perspectives and insights. Overall, the choice of in-depth interviews as the primary research methodology will enhance the accuracy and reliability of the deep learning model and contribute valuable insights to the field of music information retrieval and analysis.

**Ethics**

Ethical considerations are essential in a data analytics project on classifying and analyzing musical instruments. Key considerations include privacy and data protection, fairness and bias mitigation, transparency and explainability, impact on individuals, and responsible dissemination of findings. It is crucial to obtain informed consent, handle data securely, and communicate the purpose and scope of data collection to participants. Mitigating bias involves diverse participant selection and regular assessment of the dataset. Transparency is fostered through clear documentation and explanations of the deep learning model. Consideration of stakeholders' perspectives and needs is crucial, as well as responsible dissemination through open-access platforms. By addressing these ethical considerations, the project can contribute to the field while respecting individuals' rights and societal well-being.

**METHODOLOGY**

The methodology section of this project outlines the approach and techniques employed to accomplish the task of classifying and analyzing musical instruments based on spectrograms and audio features. The primary objective is to design a robust deep learning model that can accurately identify and differentiate between various musical instruments, thereby contributing to the advancement of music information retrieval and classification systems. This section provides a comprehensive overview of the steps taken to achieve this goal, from data preprocessing and feature extraction to model architecture and evaluation metrics.

The methodology encompasses a multi-faceted approach, integrating state-of-the-art techniques in deep learning, signal processing, and machine learning. The design decisions are guided by the need to address challenges such as spectral similarities between instruments, data variability, and the extraction of discriminative features from audio recordings. By combining these techniques, we aim to achieve a high-performing model capable of classifying musical instruments with a high degree of accuracy.

The following subsections elaborate on the key components of the methodology, including data preparation, feature extraction, deep learning model architecture, training and evaluation, and the rationale behind the chosen approaches. Through a detailed exploration of each phase, this methodology provides insights into the workflow and considerations that underpin the development of an effective musical instrument classification system.

**DATASET**

The foundation of this project lies in the utilization of the IRMAS dataset, a collection of musical audio excerpts meticulously annotated with the primary instrument(s) present in each recording. This dataset serves as the cornerstone for evaluating the efficacy of our proposed methodology. The dataset was previously employed for assessment in a study titled "A Comparison of Sound Segregation Techniques for Predominant Instrument Recognition in Musical Audio Signals" by Bosch et al. (2012), showcased in the proceedings of the International Society for Music Information Retrieval (ISMIR).

IRMAS stands as a pivotal resource for training and validating methods aimed at the automatic recognition of predominant instruments within musical audio. The diverse set of instruments encompassed by IRMAS includes cello, clarinet, flute, acoustic guitar, electric guitar, organ, piano, saxophone, trumpet, violin, and human singing voice. Notably, this dataset diverges from its precursor, compiled by Ferdinand Fuhrmann, in a few key aspects. The dataset undergoes meticulous data preparation, including stereo audio conversion, to ensure compatibility with the project's objectives. The subsequent sections delve into the methodology's intricate components, encompassing feature extraction, model architecture, training, and evaluation

**FEATURE EXTRACTION**

The heart of our feature extraction methodology lies in the utilization of spectrograms, providing a profound visual representation of audio signals frequency content over time. By deconstructing audio into its constituent frequencies, spectrograms unveil the dynamic evolution of these frequencies across time. This transformative representation adeptly captures variances in timbre, harmonics, and other pivotal sonic attributes.

For the purpose of our study, the generation of spectrograms is paramount. Each audio excerpt within our dataset is processed to create spectrograms. These spectrograms function as intricate maps that detail how the frequency components unfold throughout the duration of the audio. Consequently, they offer a window into the tonal nuances that distinguish one instrument from another. These spectrograms establish a bedrock for our ensuing feature extraction endeavors.

In tandem with spectrograms, we delve into the extraction of Mel-frequency cepstral coefficients (MFCCs) from the raw audio data. This process involves a series of steps that transforms the continuous audio signal into numerical representations. These numerical MFCC values hold a wealth of information about the spectral characteristics of the audio.

The process of extracting MFCCs begins with segmenting the audio into short time frames. Each frame is then subjected to a Fourier transform to convert it from the time domain to the frequency domain. Subsequently, the power spectrum is mapped to the Mel scale, which is closely aligned with human auditory perception. This Mel-frequency representation is then subjected to a discrete cosine transform (DCT), yielding the final MFCCs. Each MFCC coefficient encapsulates a different aspect of the audio's spectral content, contributing to a holistic portrayal of its timbral intricacies.

As an integral step, the extracted MFCC coefficients are organized into a structured data frame. This data frame serves as a structured repository that houses the MFCC values for each audio excerpt, effectively creating a digital representation of the audio dataset. Each row corresponds to an audio clip, with the columns containing the MFCC coefficients for that clip. This structured format enables streamlined data management and facilitates seamless integration with machine learning algorithms.

The journey of our feature extraction doesn't halt with MFCCs. Building upon this foundational audio representation, we transform the MFCCs back into spectrograms. This inverse transformation allows us to visually perceive the timbral and spectral transitions present within the audio. By aligning numerical MFCC data with its spectrogram counterpart, we bridge the gap between the mathematical and visual domains, offering a comprehensive perspective on audio characteristics.

In this multifaceted approach, the numerical MFCC values not only serve as crucial inputs for machine learning but also empower the visualization of audio attributes. The conversion from MFCCs to spectrograms completes the feedback loop, enriching our understanding of the intricate connections between mathematical representations and sonic qualities.

In summary, our feature extraction process combines the visually informative power of spectrograms with the numerical precision of MFCCs. While spectrograms offer a panoramic view of frequency changes over time, MFCCs distill complex audio into concise numerical representations. These numerical values, carefully organized into data frames, enable seamless integration with machine learning models. Through the extraction of MFCCs, their conversion into spectrograms, and their organization in structured data frames, our methodology unlocks a holistic understanding of the diverse sonic landscapes inhabited by different musical instruments.

**Model Architecture**

Our quest to classify musical instruments using deep learning led us to design a robust and accurate model architecture. Leveraging both spectrograms and extracted audio features, our architecture utilizes the power of Convolutional Neural Networks (CNNs) to process spectrograms, coupled with other models for handling audio features. In this section, we elucidate the high-level blueprint of our model, the exploration of alternative techniques, and our journey toward optimizing accuracy. Our primary deep learning architecture centers around a CNN tailored for processing spectrograms. Spectrograms, capturing the temporal and spectral nuances of audio, serve as rich data inputs for the model. The architecture comprises layers for convolution, pooling, and fully connected (dense) layers. Convolutional layers convolve over spectrogram data, effectively learning high-level features. Pooling layers aid in reducing the spatial dimensions while retaining important information.

Each convolutional layer is followed by an activation function, often Rectified Linear Units (ReLU), which introduces non-linearity to the model. To prevent overfitting, a Dropout layer is strategically inserted, randomly deactivating neurons during training. Batch normalization ensures stable training dynamics by normalizing activations, and MaxPooling layers capture essential information while reducing computational complexity. The final layers consist of fully connected (dense) layers, culminating in the output layer with neurons corresponding to the number of instrument classes. A softmax activation function generates class probabilities, facilitating accurate predictions.

While our primary architecture exploits spectrograms, we extended our exploration to incorporate models utilizing the extracted MFCC features. Support Vector Machine (SVM), Decision Tree, and Random Forest models were considered for comparison. SVM, a powerful classification technique, exploits hyperplane separation to categorize data points. It offers variations like linear, polynomial, and radial basis function (RBF) kernels. SVM, a versatile classification algorithm, was deployed using the MFCC features we had extracted. The linear kernel, capable of separating linearly separable data, and the RBF kernel, adept at capturing complex relationships, were particularly promising. Given the intricate distinctions among musical instruments, the RBF kernel seemed better suited. In our pursuit of accuracy, we embraced a multifaceted evaluation approach. Our model's success isn't solely gauged by overall accuracy, as it may not fully represent class imbalances or false positives. Instead, we examined precision, recall, F1 score, and the confusion matrix. Precision captures the ratio of true positive predictions to all positive predictions, offering insights into false positives. Recall denotes the ratio of true positives to all actual positives, illuminating false negatives. The F1 score harmonizes precision and recall, providing a comprehensive metric.

In our pursuit of constructing a comprehensive instrument classification system, we delved into the realm of decision trees and their more robust counterpart, random forests. These techniques offered both interpretability and the power of ensemble learning, rendering them fitting candidates for our intricate task of music instrument recognition.

A decision tree is a hierarchical structure that makes decisions based on feature values. It's analogous to a flowchart, where each internal node represents a feature, each branch signifies a decision, and each leaf node represents an outcome. Decision trees excel at handling non-linear relationships and are adept at classifying multi-class data, making them well-suited for our diverse range of musical instruments.

In the context of our music instrument classification, decision trees break down the complex decision-making process into a sequence of straightforward choices. Each split considers a particular feature to segregate data into subsets. This hierarchical approach aligns with the distinct characteristics of musical instruments. For instance, the decision tree might identify a crucial feature like the spectral envelope or harmonic content to distinguish between a flute and a guitar.

Building upon the foundation of decision trees, random forests elevate accuracy and robustness through ensemble learning. A random forest comprises multiple decision trees, each trained on a different subset of the data and features. The outputs of individual trees are aggregated to yield a more accurate and stable prediction.

In our instrument classification task, the random forest's ensemble nature mitigates the risk of overfitting and enhances generalization to unseen data. By aggregating the decisions of multiple trees, random forests reduce the impact of noisy or inconsistent data points. This is particularly valuable when dealing with the nuances of music audio data, where variances can stem from diverse recording conditions and musical interpretations.

One compelling aspect of decision trees and random forests is their inherent interpretability. Decision trees offer a clear insight into how a model arrives at a decision. By tracing the path from the root node to the leaf node, we can discern the sequence of features and their thresholds that led to a classification.

Additionally, random forests provide a quantification of feature importance. This assessment highlights which features played the most significant role in distinguishing instruments. Understanding feature importance is not only valuable for interpreting the model's decisions but also aids in refining future feature extraction and model design.

As we ventured into using decision trees ,random forests and SVM, our focus extended beyond mere accuracy. The imbalance in our dataset, with varying numbers of audio samples for different instruments, necessitated a nuanced evaluation. To address this, we employed a confusion matrix, which provided a detailed breakdown of true positive, true negative, false positive, and false negative predictions.

In addition to the confusion matrix, we adopted the F1 score and precision as key evaluation metrics. The F1 score harmonizes precision (minimizing false positives) and recall (minimizing false negatives), offering a balanced assessment. Precision, on the other hand, highlights the ratio of true positive predictions to all positive predictions, effectively minimizing false positives. These metrics ensure that our model's accuracy is not biased by class imbalances and false predictions.

**Transforming MFCC to Spectrograms: Unveiling the Sonic Landscape**

While the extracted Mel-frequency cepstral coefficients (MFCC) provide valuable insights into the audio features of our musical instruments, we extended our exploration by delving into the realm of spectrograms. Spectrograms, in essence, offer a richer and more holistic perspective of audio signals, revealing the intricate nuances of frequency content over time. By visualizing the spectrogram, we can gain a deeper understanding of the evolution of sound components, transcending the confines of individual MFCC coefficients.

**The Visual Symphony of Spectrograms:** Spectrograms break down audio signals into a grid of time versus frequency, with color intensity indicating the amplitude of different frequency components. This visual representation allows us to witness the dynamic interplay of various frequencies across time, providing an invaluable tool for analyzing tonal characteristics, harmonics, and transient elements within the music.

Unlike MFCC, which compresses audio information into a limited set of coefficients, spectrograms present a comprehensive snapshot of the frequency content. This enables us to capture both subtle variations and sudden shifts in musical timbre and texture. Spectrograms serve as an ideal foundation for neural network models, as they encapsulate the essence of the audio signal and empower models to discern intricate patterns and relationships.

**Leveraging Spectrograms for Neural Networks: ANN and CNN Models:**

With a profound understanding of spectrograms, we harnessed their potential in constructing robust neural network models for music instrument classification. We embarked on building two distinct architectures: Artificial Neural Networks (ANN) and Convolutional Neural Networks (CNN). These architectures tap into the essence of spectrograms to decipher the complex audio information encoded within.

**Artificial Neural Networks (ANN):** ANNs are versatile models designed to mimic the human brain's decision-making process. In the context of music instrument classification, ANNs can identify intricate patterns and relationships among features extracted from spectrograms. ANNs consist of interconnected layers, including input, hidden, and output layers. Each neuron processes input and passes it to subsequent layers through weighted connections. ANNs are adept at recognizing patterns but might lack the spatial awareness to discern finer spectral nuances.

**Convolutional Neural Networks (CNN):** CNNs, on the other hand, exhibit remarkable prowess in spatial recognition, making them ideally suited for image-like data such as spectrograms. Inspired by the human visual system, CNNs employ convolutional layers to extract features from local regions of the input. These features capture spatial hierarchies, enabling CNNs to identify complex patterns that ANNs might overlook.

**Model Construction and Evaluation:**

In our pursuit of constructing ANN and CNN models, we would partition our dataset into training, validation, and testing subsets. This division ensures that our models are not only trained on a diverse range of data but also tested on unseen samples. As we proceed with model training, the confusion matrix will be our guiding light, providing insights into the distribution of correct and incorrect predictions across instrument classes.

Furthermore, we'll harness the Receiver Operating Characteristic (ROC) graph to visualize the trade-off between sensitivity and specificity. This graph empowers us to make informed decisions about model threshold settings, ultimately enhancing our model's classification accuracy.

**In Summary**

By transitioning from MFCC to spectrograms and embracing neural network models like ANN and CNN, we aim to unearth the profound complexities embedded within audio signals. Spectrograms provide a visual symphony of audio dynamics, enriching our feature representation. ANN and CNN architectures capitalize on this representation, leveraging their unique strengths to decode the intricate world of musical instruments. As we venture into the realm of neural networks, our journey is underscored by the pursuit of accuracy, interpretability, and an unwavering commitment to unveiling the resonant essence of music.

Top of Form

Bottom of Form

**Concluding Thoughts**

Incorporating decision trees and random forests into our classification pipeline brought interpretability, robustness, and meticulous evaluation to our music instrument recognition endeavor. The hierarchical structure of decision trees aligned with the intricate distinctions among musical instruments, while the ensemble nature of random forests bolstered accuracy and generalization. Through these methodologies, we embarked on a journey to construct a versatile model that not only delivers accurate predictions but also aids in unraveling the intricate tapestry of musical timbre.

Top of Form

Bottom of Form

**Concluding Thoughts**

Our deep learning architecture, marrying the potency of CNNs with alternative techniques like SVM, Decision Trees, and Random Forest, showcases a thorough exploration of classification paradigms for instrument recognition. By exploiting both spectrograms and MFCC features, our methodology takes advantage of visual and numerical representations of audio characteristics. As we navigate this interdisciplinary realm, our model emerges as a versatile tool in the realm of music instrument classification, offering a harmonious blend of accuracy, interpretability, and comprehensive evaluation metrics.

**IMPLEMENTATION**

In our implementation, we made several key decisions to streamline the preprocessing of our musical instrument dataset. Among these, the careful renaming of audio files and the thorough format verification were crucial steps that contributed to the efficiency and effectiveness of our project. Let's delve into why these decisions were made and how they impacted the overall implementation.

In the initial stages of handling a dataset as diverse as the IRMAS collection, organization is paramount. Renaming the audio files served multiple purposes. The original filenames might be diverse, inconsistent, and not directly indicative of the content they represent. Renaming them according to a standardized format, using instrument labels provided a consistent naming convention across the dataset. With a clear and informative naming structure, locating and referencing specific audio files during implementation, training, and evaluation became much more straightforward.

Renaming files programmatically according to instrument labels saved manual effort and mitigated the risk of human errors. Organizing files by instrument labels enhanced the dataset's integrity, allowing us to effortlessly manage and track the data's evolution.

Working with a well-defined and uniform file format is essential for consistent processing. Our choice of using WAV (Waveform Audio File Format) files was driven by several considerations. WAV files are known for their lossless audio quality. This fidelity was crucial for preserving the nuances and subtleties of musical instruments during preprocessing and analysis. Many audio processing libraries and frameworks readily support WAV files. This compatibility simplified the extraction of features, generation of spectrograms, and model training.

**CONCLUSION**

In the field of music information retrieval (MIR), ongoing studies are focusing on instrument recognition and classification. Researchers are exploring different approaches, such as analyzing and selecting features, using machine learning algorithms like convolutional neural networks (CNNs), and utilizing various data representations. These studies highlight the need for more accurate and reliable MIR systems, which requires diverse and extensive datasets for training and testing.

The research in MIR has important implications for applications like music recommendation systems and genre identification. CNNs, a type of machine learning algorithm, have shown promise in improving the accuracy and reliability of MIR systems. However, their performance heavily depends on the quality and quantity of training data. Therefore, it is crucial to gather more diverse and comprehensive datasets to train and test these algorithms effectively.

Another important aspect of MIR is the development of effective methods for feature analysis and selection. These methods aim to extract relevant and distinctive features from the audio signal, enabling accurate classification and recognition. The ongoing research in MIR demonstrates the potential for advancing music analysis, music production, and sound engineering. However, there is still much work to be done in developing robust and accurate MIR techniques that can handle the diversity and complexity of music. To achieve progress in this field, future research should focus on creating larger and more diverse datasets, improving feature analysis and selection methods, and exploring different machine learning algorithms. By addressing these challenges, we can enhance the accuracy and reliability of MIR systems, leading to better music analysis and facilitating applications in various domains.

**REFERENCE**

1. Racharla, K., Kumar, V., Jayant, C. B., Khairkar, A., & Harish, P. Predominant Musical Instrument Classification based on Spectral Features. Indian Institute of Technology, Kharagpur India.
2. Deng, D., Simmermacher, C., & Cranefield, S. A Study on Feature Analysis for Musical Instrument Classification. Dept. of Information Science, University of Otago.
3. Solanki, A., & Pandey, S. (2019). Music instrument recognition using deep convolutional neural networks. 1 • Sachin Pandey.
4. Heittola, T., Klapuri, A., & Virtanen, T. Musical instrument recognition in polyphonic audio using source-filter model for sound separation.
5. Li, P., Qian, J., & Wang, T. Automatic instrument recognition in polyphonic music using convolutional neural networks.
6. Nam, J., Choi, K., Lee, J., Chou, S.-Y., & Yang, Y.-H. Deep Learning for Audio-Based Music Classification and Tagging.
7. Park, T., & Lee, T. Musical instrument sound classification with deep convolutional neural network using feature fusion approach.
8. Gururani, S., Summers, C., & Lerch, A. Instrument activity detection in polyphonic music using deep neural networks.
9. Tanaka, K., Nakatsuka, T., Nishikimi, R., Yoshii, K., & Morishima, S. Multi-Instrument Music Transcription Based on Deep Spherical Clustering of Spectrograms and Pitchgrams.
10. Gómez, J. S., Abeßer, J., & Cano, E. Jazz Solo Instrument Classification with Convolutional Neural Networks, Source Separation, and Transfer Learning. Proceedings of the 19th ISMIR Conference.
11. Chen, H.-H., & Lerch, A. Music Instrument Classification Reprogrammed. Music Informatics Group, Georgia Institute of Technology.
12. Ashraf, M., Abid, F., Ud Din, I., Rasheed, J., Yesiltepe, M., Yeo, S. F., & Ersoy, M. T. A Hybrid CNN and RNN Variant Model for Music Classification
13. Shukla, U., Tiwari, U., Chawla, V., & Tiwari, S. (Year). Instrument Classification using image-based Transfer Learning.
14. H., Zhang, Y., & Zhang, Q. The Use of Deep Learning-Based Intelligent Music Signal Identification and Generation Technology in National Music Teaching. Frontiers in Psychology
15. Li, P., Qian, J., & Wang, T. (2015). Automatic Instrument Recognition in Polyphonic Music Using Convolutional Neural Networks.
16. Kostek, B. (2004). Musical instrument classification and duet analysis employing music information retrieval techniques.
17. Elbir, Ahmet, et al, 2018, "Music Genre Classification and Recommendation by Using Machine Learning Techniques
18. Yang, Rui, et al., 2020, "Parallel recurrent convolutional neural networks-based music genre classification method for mobile devices.
19. McFee, Brian, et al, 2015, "librosa: Audio and music signal analysis in python
20. Corrêaa, Débora C. and Francisco Ap Rodriguesa., 2018, "A Survey of Symbolic-Based Music Genre Classification
21. Weninger F, Schuller B. Audio recognition in the wild: static and dynamic  
    classification on a real-world database of animal vocalizations.
22. Choi K, Fazekas G, Sandler M, Cho K. Transfer learning for music classification  
    and regression tasks.
23. Cotton CV, Ellis DPW. Spectral vs. spectro-temporal features for acoustic event  
    detection
24. Khamparia A, Gupta D, Nguyen NG, Khanna A, Pandey B, Tiwari P. Sound  
    classification using convolutional neural network and tensor deep stacking  
    network.
25. Salamon J, Bello JP. Deep convolutional neural networks and data  
    augmentation for environmental sound classification.
26. Zhu, B., Wang, Y., Patel, R., & Li, Y. (2018). Learning environmental sounds with multi-scale convolutional neural network. In Proceedings of the International Joint Conference on Neural Networks.
27. Geiger, J.T., & Helwani, K. (2015). Improving event detection for audio surveillance using Gabor filterbank features.
28. Saldanha EL, Corso JF. Timbre cues and the identification of musical instruments. J. Acoust. Soc. Am. 1964
29. Heittola, T., Klapuri, A., & Virtanen, T. (Year). Musical instrument recognition in polyphonic audio using source-filter model for sound separation.
30. Han, Y., Kim, J., & Lee, K. (2017). Deep convolutional neural networks for predominant instrument recognition in polyphonic music.
31. Pons, J., Slizovskaia, O., Gong, R., Gómez, E., & Serra, X. (2017). Timbre analysis of music audio signals with convolutional neural networks.
32. Bhalke, D.G., Rao, C.B. Rama, & Bormane, D.S. (2016). Automatic musical instrument classification using fractional Fourier transform based-MFCC features and counter propagation neural network.
33. Li, J., Han, L., Li, X., Zhu, J., Yuan, B., & Gou, Z. (2022). An evaluation of deep neural network models for music classification using spectrograms. Multimedia Tools and Applications
34. Quazi, G.R., Mohammed, N., Sadia, Z.P., & Sabrina, A. (2021). Comparative analysis of three improved deep learning architectures for music genre classification.
35. Bhat, A.S., Amith, V.S., Prasad, N.S., & Mohan, D.M. (2014). An efficient classification algorithm for music mood detection in western and Hindi music using audio feature extraction.
36. Li, T., Ogihara, M., & Li, Q. (2003). A comparative study on content-based music genre classification
37. Jensen, K. (1999). Pitch independent prototyping of musical sounds
38. Muhammad, G., & Alghathbar, K. (2009). Environment recognition from audio using MPEG-7 features
39. Baniya, B.K., Lee, J., & Li, Z.N. (2014). Audio feature reduction and analysis for automatic music genre classification.
40. Scheirer, E.D. (1998). Tempo and beat analysis of acoustic musical signals.
41. Zheng, E., Moh, M., & Moh, T.-S. (2017). Music genre classification: A n-gram based musicological approach.
42. Sigtia, S., & Dixon, S. (2014). Improved music feature learning with deep neural networks.
43. Wang, Z., Muknahallipatna, S., Fan, M., Okray, A., & Lan, C. (2019). Music Classification using an Improved CRNN with Multi-Directional Spatial Dependencies in Both Time and Frequency Dimensions.
44. Maccagno, A., Mastropietro, A., Mazziotta, U., Scarpiniti, M., Lee, Y., & Uncini, A. (2019). A CNN Approach for Audio Classification in Construction Sites.
45. Bosch, J.J., Janer, J., Fuhrmann, F., & Herrera, P. (2012). A Comparison of Sound Segregation Techniques for Predominant Instrument Recognition in Musical Audio Signals.
46. Piczak, K.J. (2015). Environmental sound classification with convolutional neural networks. In Machine Learning for Signal Processing (MLSP)
47. Rajesh, S., & Nalini, N.J. (2020). Musical instrument emotion recognition using deep recurrent neural network
48. Bosch, J.J., Janer, J., Fuhrmann, F., & Herrera, P. (2012). A comparison of sound segregation techniques for predominant instrument recognition in musical audio signals.
49. Elsayed, G.F., Goodfellow, I., & Sohl-Dickstein, J. (2019). Adversarial reprogramming of neural networks.
50. Gong, Y., Chung, Y.A., & Glass, J.R. (2021). AST: Audio spectrogram transformer. In Interspeech.
51. Gururani, S., Lerch, A.: Semi-supervised audio classification with partially labeled
52. Gururani, S., & Lerch, A. (2021). Semi-supervised audio classification with partially labeled data.
53. Bhalke, D., Rao, C., & Bormane, D.S. (2016). Automatic musical instrument classification using fractional Fourier transform based-MFCC features and counter propagation neural network. Journal of Intelligent Information Systems.
54. Ye, & Yang, J. (2021). A deep neural network model for speaker identification. Applied Sciences.
55. Naranjo-Alcazar, J., Perez-Castanos, S., Zuccarello, P., Antonacci, F., & Cobos, M. (2020). Open set audio classification using autoencoders trained on few data. Sensors.
56. Ronneberger, O., Fischer, P., & Brox, T. (2015). U-net: Convolutional networks for biomedical image segmentation.
57. Choi, K., Fazekas, G., Cho, K., Sandler, M., & Cunningham, S. (2017). A tutorial on deep learning for music information retrieval
58. Wu, W., Xia, Z., Qian, Y., Li, Z., & Li, Z. (2018). Music genre classification using independent recurrent neural network.
59. Fulzele, P., Bhadane, M., Kasar, T., & Kulkarni, S. (2018). A hybrid model for music genre classification using LSTM and SVM.
60. Duan, Z., Han, J., & Pardo, B. (2014). Multi-pitch streaming of harmonic sound mixtures. IEEE/ACM Transactions on Audio, Speech, and Language Processing.