The Use of Forensic Musicology in Criminal Investigations

Zaroon; Jumana Rashid; Anwaar Iftikhar; Hamid Bashir; Rukhsana Parveen*

CAMB, University of the Punjab, Lahore, Pakistan

*Corresponding author: Rukhsana Parveen

CAMB, University of the Punjab, Lahore, Pakistan.
Email: rukhsana.camb@pu.edu.pk

Abstract

Forensic musicology is the scientific study of music in a legal context. It can be used to help identify the composer of a piece of music, to determine the ownership of a copyright, or to resolve disputes over the use of musical works. Forensic musicologists may also be called upon to give expert testimony in court cases involving questions of music.

Forensic musicology is a relatively new field, and there are no formal educations or training requirements for becoming a forensic musicologist. However, most forensic musicologists have advanced degrees in music theory, musicology, or a related field, and many also have experience working as professional musicians. Forensic musicologists use their knowledge of musical composition, history, and performance to answer questions raised in legal cases.

Forensic musicologists typically collaborate with attorneys, judges, and other legal professionals to provide expert testimony or analysis in court cases. In some cases, they may also be asked to testify in front of a grand jury or give depositions. Forensic musicologists may also be consulted by law enforcement agencies to help identify unknown pieces of music or to authenticate recordings. This review will focus on the application of forensic musicology in civil and criminal cases.

Keywords: Forensic; Forensic musicology; Music; Legal

Introduction

Forensic musicology gained significant popularity as a discipline in the late years of the twentieth century [1]. There are many potential applications of forensic musicology used in different fields today. Many countries around the world are currently demonstrating a deep extent of utilizing voice analysis. This trend is especially far more noticeable in developed countries [2]. The significance of voice recognition and analysis cannot be undermined as they play a pivotal role in solving so many criminal cases every year [3]. Criminology aside, forensic musicology has played a critical part in infringement cases involving the music industry [4].

Forensic musicologists have been called to courthouses over many decades to check the similarities between two pieces of music. These connoisseurs analyze the similarities between the music pieces and give a verdict on whether the two music pieces are similar or not. In cases with substantial evidence of similarity or infringement, these forensic musicologists have to testify in open court as well. This practice came to be in use fairly recently. The practice before was nowhere near this professional. Forensic musicologists create legal evidence that is based on logic and reason. The evidence that these experts can create holds a vi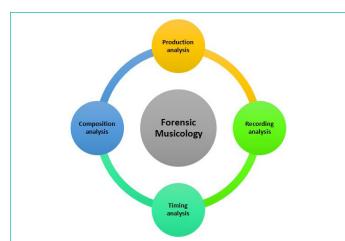sual significance. This might be one of the many reasons why courts in different countries have started viewing different music samples as violations of copyright [5,6].

A term that is currently being used frequently in copyright laws is 'reverse engineering'. This term refers to the use of previous work done in the early years and presenting that work or a form of it in the recent version. More efficient legal regulations are being put into place regarding this how to cover this aspect of copyright laws with forensic musicology. Forensic musicology is a study that evolves every day. New techniques are being tested and applied to increase the effectiveness and efficiency of the system and the results that are produced as a result of forensic musicology [7]. Since forensic musicology is playing its role for almost two hundred years the disciples of forensic musicology has only been recognized consistently since the late 20th century. Recent emergence of it has contributed to the dearth of academic study on its method, history and important figures.
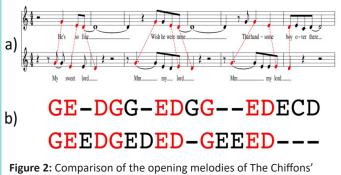
Importance of Forensic Musicology

The ongoing transition of the music business to digital recording and distribution has enhanced the expertise that legal professionals need from specialists. A wide range of legal con-

Figure 1: Analysis in music circulates around the following major areas.

Figure 2: Comparison of the opening melodies of The Chiffons' He's So Fine (top) and George Harrison's My Sweet Lord (bottom) [42].

cerns, including the identification and authentication of published works and musical recordings, performance rights, and legal rulings involving copyright infringement are supported by expert testimony for forensic musicology. Even though there have been legal instances concerning music and performance infringement since the 19th century, there is no established approach in the field of forensic musicology that allows for an objective forensic assessment [8].

To understand and realize the importance of forensic musicology, a basic understanding of the working of voices and sound is mandatory. This understanding will further lead to understanding the frequency, and pitch of the sound, and finally, getting to know the complex processes such as Automatic Speaker Recognition (ASR), forensic voice comparisons, and so on. Vibrations in the atmosphere produce the sound that we hear, and the frequency of a sound is a measure of how fast +or slow it makes the air vibrate around it [1].

For two voices to belong to the same person, there should be considerable similarities between the two. Otherwise, the alternative is that the voices belong to different people if they do not share similarities. Apart from the similarities, the voice should be clearly and categorically distinct in nature. The complexity of the human voice makes it extremely difficult to pinpoint one voice to one person based on similarities and distinctiveness. The same person may sound different in a cold or any other health issue that affects the voice [9].

Forensic musicology has been used to distinguish between the different music types in countries such as Africa where there is an amalgam of so many cultures with different traditions and music types. By use of forensic musicology, experts have been able to clearly define the boundaries and have been able to distinguish between the many types of music in differ-

ent cultures of Africa. Forensic musicology therefore is helping in the detection of following areas in music [10].

Voice Recognition

Voices and faces both contain intricate stimuli that provide vital social information. Both play a role in the recognition and differentiation of certain individuals. These parallels raise the possibility that speech recognition technology may have evolved similarly to facial recognition technology in certain ways [11].

Voice Recognition is the ability of a machine how well it perceives a spoken command by a person and how the machine interprets this information. This technology has been utilized by some of the biggest tech industries of today, such as Amazon, Microsoft, and Apple. These companies have applied the technique of voice recognition and made custom software for their tech devices. For instance, Apple has made Siri, Amazon has Alexa and Microsoft has Cortana. Recent years have seen a significant convergence between the methods and techniques used to develop man-machine interaction based on the word and the data statistical modelling paradigm (such as HMM-based acoustic modelling, n-gram-based language modelling, and concatenative speech synthesis). Of course, over the course of nearly three decades, these techniques have actually improved the quality and performance of the system, leading to this convergence of modelling paradigms [12].

For a computer to recognize anything, the signal has to be digital in nature. In that regard, the audio is initially converted to a digital form by a process known as analog to digital conversion. These conversions of speech patterns are stored in the computer on the hard drive. Pattern recognition is used by a comparator to check these speech patterns [13].

The acoustic characteristics of voice also reveal a speaker's identity in addition to their views and intents. The ability to identify people from their sounds has been studied in lab settings. Voice recognition, however, includes two components: (1) the ability to identify the voice of a known individual, and (2) the ability to familiarize a voice, that is, to encode a voice and retain some feature of it in long-term memory [14].

Automatic Speaker Recognition is an application of forensic musicology with immense scope and significance in not only an investigative approach but also the reporting of evidence. When we take an example of a case that is normally encountered by law enforcement officials on a routine basis, one such where a victim has received a call of a threatening nature [15]. In this scenario, a suspect list is made by comparing the voice on the call with that of the criminals. This sample voice on the call is called the trace [16]. Automated speaker-recognition systems have become a crucial tool for identity verification in many e-commerce applications, as well as in everyday commercial encounters, forensics, and law enforcement [17]. By analyzing a variety of acoustic, prosodic, and grammatical aspects of speech in a method known as structured listening, human professionals skilled in forensic speaker recognition may execute this task even better. Forensic speech scientists and linguists have been working on techniques for forensic speaker recognition for many years in an effort to help eliminate any prejudice or previous notions about the reliability of an unknown audio sample and a reference template from a suspected suspect [18].

Forensic voice comparisons come in handy in criminal cases where physical evidence is absent or sufficiently minimal. In case of a ransom call from a hostage situation where there is

no physical evidence such as DNA or fingerprints to go on, the only lead available is the voice of the caller. By running this trace with the database of voices present, there is the formation of a list of potential suspects. Further analysis of this sample recording can yield even a single entity where it is highly likely that the caller and suspect are one and the same person [19].

Study of Tampered and Original Sounds

Before 1950s and even in some cases now sounds and voices are analyzed by experts known as linguists. These professionals are trained in linguistics, which is the scientific study of speech as well as language. This type of voice analysis is called linguistic analysis. This field has been upgraded and different linguistic features are examined and compared in this study by the experts. The whole sample speech or trace is broken down into chunks. These separate chunks are carefully listened to by linguists. This part of the analysis is known as the auditory analysis since it deals with specific sounds.

Copy-move, deletion, insertion, substitution, and splicing are all methods of faking audio. As copy-move forgery entails shifting a portion of the audio to another point inside the same stream, its applicability are constrained in comparison to other methods. On the other side, integrating recordings from various speakers, devices, and surroundings may be involved in the deletion, insertion, replacement, and splicing of forged audio [20]. Different systems have been suggested to study the tampered verses original sound such as one suggested system's main goal is to resolve the following problems with high accuracy and a high categorization rate:

1.   Determine the difference between authentic audio and audio that has been altered by combining recordings made using the same microphone in various settings.

2.   Environment categorization of authentic and fake audio produced via splicing. Regardless of speaker or content (i.e., text), detect counterfeit audio.

3.   Reliable authentication using briefly fabricated audio [21].

Studying sound and making a comparison using these different developed software and tools have helped courts to study cases with legal and visual evidence [22]. This could help a judge to see how songs look onto a paper that he could clearly differentiate between original and tempered sounds [23].

Music as a Weapon

Acoustic weapons have been developed since the end of the past century as part of a non-lethal weapon invention. According to theories put forward by many experts over the years, the effect sound has on the body and its functions have been focused majorly. Sound and music have also been linked as a means of eradicating the subjectivity of a person during interrogation. Every article in the US press that has been linked to the use of music to torture prisoners or detainees has culminated in a reaction from the virtual side as well in the platform known as the blogosphere [24]. The Joint Non-Lethal Weapons Task Force's founding in 1997 in US is working for the Department of Defense have been developing "acoustic weapons," which accounted for a third of the Task Force's budget from 1998 to 1999. Whereas theorists of the interrogation chamber concentrate on the ability of sound and music to destroy subjectivity, those of the battlefield place more emphasis on the physical impacts of sound [25].

In the Yugoslavian wars that took place in the 1990s, music was seen as a symbol of differences in ethnicities. It was seen as a means of violence. Experts have ruled that understanding music and the reaction and address of the public to this could have made sense of the ethnic conflict that rose during the wars. During the wars, music has been used as a weapon and means of torture in prison. It was used to invoke feelings of fear and anxiety in the prisoners by making it take the shape and form of a cleansing ritual. That being said, some ethnic groups also took strength from music and boosted their morale in the tough and challenging times of the wars [26]. In many ways, lower- and middle-class opinions and frustrations with people, things, and governments that exercise authority over the masses are fairly accurately reflected in popular music.

The second part of the 1960s saw groups headed by the young that fundamentally contested preexisting forms of political and cultural authority. This was when the desire for social change and the challenge to authority reached its highest degree of intensity. All this is reflected in the music of that era [27]. Popular music and social movements have a link that has not gotten as much attention as its significance merits. More research is critically required since, in addition to frequently lagging behind other disciplines in its attempts to comprehend the nature and significance of popular media, especially popular music and the different protest movements of 1960s [28].

Frequency-Based Testing for Identification of Distinct Types of Sound

There is a lot of information that can be gathered by the voice of a person. This voice can tell the origin, the birthplace of a person along with the area of the upbringing of that person. Different areas and people have different languages, accents, and dialects. Not surprisingly, the voice of a person is revealing about the heritage and culture as well. The differences in the shape and size of vocal cords along with the upbringing in how to use them cause people's voices to differ from each other [29].

Experts use spectrograms to analyze voices between people. Spectrograms are visual images of speech sounds that are made by specialized software. This process of analysis by looking at spectrograms is termed acoustic analysis. By looking at two spectrograms from different individuals saying the same word, there will be many differences seen in both, even though the word both of them said was the same [30].

If the spectrogram appears brighter, it can be deduced that there was more sound energy in terms of frequency at that particular time. An increase in sound energy will cause increased brightness to appear on the spectrogram. Spectrograms can reveal differences in how individuals from varying backgrounds speak the same words of a language. One person saying a word will not appear exactly as the spectrogram of another individual saying the same word. The human voice is far too complex, much like fingerprint and DNA [31].

There are variations in voice parameters and signals even in individuals of the same culture, and ethnicity. Children such as siblings share similar genetic markers and the same environmental parameters. Even in these conditions with so many similarities, they still will not share the same cadence of voice [32].

Some features that are part of a routine linguistic analysis include looking at the voice quality, pitch, and wording as well as grammar usage, timing, and rhythm of the voice. The level of

fluency is also a parameter that is used by experts during their analysis. The vowels and consonant sounds made by a person are also looked at by experts. The accent of the speaker is also an important feature to look at.

Apart from the use of spectrograms, experts have other techniques to analyze voice samples as well. Audio pieces of evidence are not submitted as such in court hearings. Experts use two techniques to validate the authenticity of the audio clip as well as the message being delivered in it by two main categories of forensic multimedia. These include content authentication to confirm the contents of the sample. The other category used is noise reduction to deliver the message loud and clear and without any doubts about the perceived notions [33].

A court verdict holds tremendous value therefore, many techniques are applied to deliver the best evidence in terms of sound that is authentic in nature with minimal background noise [34].

Analysis Criteria in Forensic Musicology

Publishers and artists have traditionally turned to the legal system to seek compensation from someone they accuse of profiting from the theft of one of their original works. A forensic musicologist is typically called in to evaluate the pieces and provide testimony on their parallels and differences. Because of their capacity to transform unprocessed auditory data into admissible evidence, forensic musicologists have evolved into the knowledgeable listeners who decide how jurors of fact will testify both visually and aurally about the songs presented at trial. While hearing the similarities between two songs is a significant component of forensic musicologists' expertise, a significant portion of their job is visual in nature [35]. One of their main responsibilities is to take the songs' different components such as speed, rhythm, harmony, etc. and reduce them to their melodic "fingerprints." The musicologist must next convert the melodies into visually comparable, 'eye observed' notes on a scale. The forensic musicologist creates a "knowledge structure" through which the songs may be understood, experienced, and debated in addition to making them detectable [36]. Musicology analysis as like other forensic cases is performed by the field experts. These experts have the high knowledge regarding music. Since the music is so vast therefore the expertise are limited to a certain direction. Following are the major analysis performed by a forensic expert to solve or narrow down a certain case in music [37].

Composition Analysis

When there is a claim of plagiarism in copyright issues but not involving recording media then composition analysis is performed. Musical structure analysis is performed by the licensing organization such as American society of Composers, Authors and Publishers. The case filer has to prove on the basis of the solid reasons that the defendant has access to a particular music and has similarity in rhythm, melody and structure of an already existing work. This analysis is usually referred to as comparative transcription where melodies are arranged vertically to each other with highlighting pitches, rhythms and underlying chords [38].

To reach the clue whether a defendant has already access to a particular music research moves by tracing the lines of history of radio playbacks, sales figure, or presence of a song in mainstream media. Similarity determines whether a music is truly copyrightable as unique, or something pervasive and obvious in music generally. Similarity in musical work is defined on the basis of those elements that can be notated and reproduced in performance through sheet music [39].

Famous case of George Harrison's " My sweet lord" verses Chiffon's " He is so fine" in 1976 is an example of it in which Harrison was found guilty on the basis of composition structure, despite the performance style was different. He was accused of using two melodic motifs that were structured in a particular way [40,41].

The most basic type of analysis is a comparison transcription, in which the several melodies are vertically aligned above one another and harmonious pitches, rhythms, and chords are highlighted. From the middle of the 1800s, this technique has been used in American infringement action. Comparative analysis is frequently accompanied by repertoire research, in which the musicologist looks into whether Song A's similar musical elements are unique to it or whether they have appeared in other works before. Every bogus plagiarism claim may be refuted using this expanded toolkit [43]. In USA, the copyright protection started in 1831 when sheet music was the only means for composition establishment in fixed form. Composition analysis requires approach to the notation since it conflates the underlying composition and its performance. Level of significance is analyzed in composition analysis based on the above discussed parameters [44].

Recording Analysis

In cases which involve infringement based on recording in a given context, the technique of recording analysis is performed. This is employed as the most predominant analysis in forensic musicology. Unlike composition analysis which shows similarity through reductive approach this involves identification and differentiation on the basis melody, harmony and digital signals in exact form in which they were recorded [45]. This approach requires specific programs and software which are more related to audio domain of work. They are more to the domain of engineering than to the music theory. Differences in the melody is the first to be evaluated to verify the similarity between two music works. The principles under which it works involves the vocalization of both the melody and accompaniment, whether vocal or instrumental [46]. Waveform signals or spectral analysis is followed by means of software to give very precise form of reading based on similarity. These signals are developed by the software based on voice frequency. The relative signals for frequency from both the exemplars are compared and similarity can be detected very precisely [47].

The matching of waveforms, spectral analysis, or other techniques can be used to establish instances of plagiarism that are overt in recording analysis, such as a literal "sampling" of a section of a recording. This allows for a more accurate and unbiased comparison than using musical notation by the expert [48]. The original source of the content utilized in a questioned work might be obscured or hidden to escape discovery using specialist editing or signal processing. Digital editing can make it possible to seamlessly repeat, remove, or rearrange content from an original source to create a new "variant" that calls for the expert to pinpoint how the original version "maps" to its changed counterpart [2]. Such editing may be done to extract extremely short but recognizable snippets for use as the sample materials of a later work or to adapt music to the plot of a movie or television advertisement. If access to the original multi-track recording is accessible, complete vocal instrumental

"stems" can be erased and replaced by freshly recorded material. Digital editing enables individual portions to be faded or their timbre altered [49].

Melody in software is a time ordered sequence of pitches perceived by the listeners a s single entity. Different recordings of the same composition by the same artist often include unique form of melismatic expression, which is improvised singing of a syllable at different note beside the basic and necessary aspects of the melody [50].

In popular music this melismatic technique is followed as improvisation technique. This music does not convey what is being presented on the music sheet. Compared examples in music analysis are much more subtle but the basic analysis of melodic similarity can lead to the analysis conclusion [51].

Case study of recording-based analysis: Not an experimental case study, but an example of a very high-profile case that can be found in 2012 when James Foley was murdered. James Foley was a journalist who was kidnapped by ISIS and then, later murdered. The gruesome tragedy was also released to the public via a video where a masked figure can be seen speaking. Voice analyses by experts around the globe were done in an attempt to identify the said murderer [52].

Different case studies have been done to improve the efficacy of the system and to further understand how the principles in the field work. A system with less dependence on the individual variables from the sample will prove to be ideal and without fault. At present, there are many factors that differ from case to case which might affect the objectivity of the expert leading the case.

Timing Analysis

The beat level, also known as tactus, is the most important metric level in a hierarchical metrical framework that organizes musical time. Divergences from the isochronous beat level are viewed as exceptions or unique circumstances in the majority of western music [53]. Contrarily, non-isochronous metric patterns, also known as additive, aksak, or asymmetric meters, are frequently found in the rhythms of traditional music from the Balkans and the Middle East. Such metric systems are built on asymmetries in the beat levels, which are composed of alternating long and short beat patterns [36].

Timing analysis being very precise can compare exemplars at various points throughout the recordings. It works on the principle that there is no difference of the timing, and both the exemplars are digitally recorded. The rhythmic pattern and beat are the basic aspects behind it which shows the timing evaluation between the two. Timing difference can be used to compare popular music recordings [8].

For the comparison of live classical music recordings that were otherwise differentiated in terms of spatial, dynamic and timbrel characteristics DeFrancisco found that timing and unexpected incidents can be utilized for analysis. For example, incidents in live music such as cough, breathing sound, unexpected noises wrong notes etc. can be used for analysis in respect to timing [54]. It has also been noted that fluctuations, precision at particular instant, stretches and compressions in tempo are all used for timing analysis [55].

Digital editing can be used for tampering of waveform and spectral analysis by deleting the particular note signals, re-ordering or repeating a specific pattern from the original source

to form a new variant. This make them to be undetected by recording analysis. Time compression/ expansion and pitch shifting are the popular types of signal processing techniques used for such analysis. These are based on the technique known as phase vocoding [56]. This involve the software which edit the pitch of the music without changing the timing, rhythms and tempo or vice versa. This is employed sometimes in making mash-up recordings. These two processes are linked and sometimes it requires independent manipulation of both [57].

Production Analysis

This analysis works by focusing the means of production or distribution of the recording product after it has left the studio. This is a specialized analysis which focuses on the bootlegged and pirated versions by means of computer forensic technique. Examination of digital metadata can reveal the source and the means of audio compression used in recording. For example, to determine the originality of a work not only frequency and timing is examined but audio compression, file size and metadata tags are also brought under consideration. All variations from the product's initially issued version should be noted by the expert [58].

Right management has become more complicated with the development of digital media. Many digital audio players are using digital right management system to limitize the number of devices on which the file can be played so aiming to control the unlawful music distribution. Audio watermarking is another technique for copyright protection. This involves the use of inaudible signals that are embedded with the digital audio format. These signals cannot be copied and can be used to identify the original source of recording despite copying [59]. A "fact" witness who would merely testify that reputable computer software for watermark detection showed the existence or absence of a watermark, as well as the contents of the watermark detected by the program, might also be called in if testimony based on this sort of evidence is required [49,60].

Percentage Melodic Identity (PIM) Analysis

This method is based on automated alignment and identity percentage. This method was developed in keeping the view that complex operations of similarity can be performed by the non-scientists. The automated sequence alignment and percent identity is similar as used in molecular genetics to compare DNA and protein sequences. It was first used to music to measure the cultural development of English and Japanese folk song melodies in a way that could be usefully compared to both of them and to the development of other genres of music from around the world [61]. Yet, since the alteration of copied melodies is just a further stage in the creation of music, musical copyright provides an appropriate application for this technique. The PMI approach is universal and may be used with different genres of folk and art music from throughout the world [62]. The PMI method and other melodic sequence alignment algorithms, areas similar to Judge Learned Hand's comparative method for determining musical similarity. the PMI approach like hand starts by harmonizing two melodies written in staff notation to a single tonic, erasing rhythmic information by assigning all notes the same value 1, aligning and counting corresponding notes, and finally deleting rhythmic information. Although alignments can still be performed manually, either from scratch or to correct errors in the automated alignment, as is also done in molecular genetics, the PMI method can take advantage of automated sequence alignment algorithms to

eliminate subjectivity in alignment [63]. This is an automated aligning system of notes in melody. Once the melodies under test have been aligned manually or automatically the identical notes are then divided by the average length of two melodies. Result is multiplied by 100 to obtain the percentage similarity. Efficacy rate of this method is nearly 80% and careful approach is required to save the results from false positive [64].

$$PMI= 100 (ID/L^1+L^2/2)$$

The PMI method can also be used to establish whether a given PMI value is statistically significant above and beyond what might be predicted by two melodies with comparable scales and similar stylistic characteristics. In order to accomplish this, the PMI value for a given pair of sequences is compared against the distribution of 100 random PMI values generated by randomly rearranging one of the sequences, given the same sequence lengths and compositions. As a result, a significant P value of .05. Corresponds to an observed PMI value greater than 95% of values that were randomly reshuffled [65].

Methodology of Forensic Musicology

Did there be any copying? should be the first inquiry in any music copyright issue and is also the first question in forensic musicology and probably the most crucial. So how can we tell whether there has been copying? There are extremely few instances in copyright lawsuits when the defendant admits to copying [66]. Yet, in most cases indeed, in nearly every music copyright litigation case in history defendants deny that the subjective similarity between the works is the product of plagiarism, instead contending that it is the consequence of Independent Creativity (IC). then, how might we distinguish between coincidence similarities and plagiarism using music analysis [43].

Determining the Similarity Proxy

The Similarity Proxy is based on the notion that the more similar two things are, the less likely it is that they could have developed via Independent Creation. Mathematically, this makes sense. The likelihood that a coin will fall on its tails after one toss is 0.5 (50%, or one in two). Yet, the likelihood of tossing a coin three times and getting heads, then tails, and then heads again is 0.125 (12.5%, or one in eight). However, as music is a time-based art form, there are many more options open to composers between any two successive musical occurrences. The logical conclusion is that any extremely lengthy tune that is precisely the same as any previously existing extremely long melody is probably proof of plagiarism, especially if the underlying harmony is the same. For each additional note in the melodic chain, the possibility that any resemblance across lengthy melodies may be attributed to Independent Creation falls exponentially [67]. Therefore, the study of exponential functions need not be restricted to a particular linear field, such as music Even if such elements are not themselves coverable by copyright, any musical arrangement that uses the exact same parameters as an earlier work in terms of instrumentation, musical form, musical key, or tempo, for example, provides stronger and stronger circumstantial evidence of copying as more similarities are added [39].

Any musical arrangement that uses exactly the same parameters as an earlier work in terms of instrumentation, musical form, musical key, or tempo, for example, provides stronger and stronger circumstantial evidence of copying, even if such elements are not themselves coverable by copyright [68]. The Similarity Proxy's tenets are intuitively understood by musicians and may even be taken for granted by judges and lay listeners. This is maybe the reason why a lot of composers get into the urban legend that a certain minimum number of consecutive pitches can be reproduced lawfully before the copyright police show up at your door. Similarity proxy is primary strategy used by musicologists, courts, and musicians to fight copying has always been proxy [69].

Excluding Commonplace Elements

After determining the degree of similarity, we must strip away the aspects that are common. According to conversations with other forensic musicologists, people have all likely encountered numerous approaches from hopeful potential plaintiffs who are convinced that a musical element of their Song A for instance, a

Table 1: The twenty music copyright infringement cases analyzed, ordered by increasing PMI (Percent Melodic Identity). "0"=No infringement, "1"=Infringement. *P<.01. [42].

No.	Case	Complaining work	Defending work	Defending
1	Suzane McKinley vs. Collin Raye	"I Think About You"	"I Think About You"	0
2	Ferguson vs. N.B.C.	"Jeannie Michele"	"Theme 'A Time To Love'"	0
3	Grand Upright vs. Warner	"Alone Again (Naturally)"	"Alone Again"	1
4	Jean et al. vs. Bug Music	"Hand Clapping Song"	"My Love Is Your Love"	0
5	Three Boys Music vs. Michael Bolton	"Love Is A Wonderful Thing"	"Love Is A Wonderful Thing"	1
6	Cottrill vs. Spears	"What You See is What You Get"	"What U See is What U Get"	0
7	Baxter vs. MCA	"Joy"	"Theme from 'E.T.'"	0
8	Intersong-USA vs. CBS	"Es"	"Hey"	0
9	Ellis vs. Diffie	"Lay Me Out By The Jukebox When I Die"	"Prop Me Up Beside The Jukebox (If I Die)"	0
10	Granite Music vs. United Artists	"Tiny Bubbles"	"Hiding The Wine"	0
11	Repp vs. Lloyd-Webber	"Till You"	"Phantom Song"	0
12	McDonald vs. Multimedia Entertainment	"Proposed Theme Music 'Sally Jesse Raphael Show'"	"Theme Music 'Sally Jesse Raphael Show'"	0
13	Benson vs. Coca- Cola "	"Don't Cha Know"	I'd Like To Buy The World A Coke"	0
14	Swirsky vs. Carey	"One of Those Love Songs"	"Thank God I Found You"	1
15	Bright Tunes Music vs. Harrisongs Music	"He's So Fine"	"My Sweet Lord"	1
16	Herald Square Music vs. Living Music	"Day By Day"	"Theme N.B.C.'s 'Today Show'"	1
17	Selle vs. Gibb	"Let It End"	"How Deep Is Your Love"	0
18	Fantasy vs. Fogerty	"Run Through The Jungle"	"The Old Man Down The Road"	0
19	Louis Gaste vs. Morris Kaiserman	"Pour Toi"	"Feelings"	1

chord loop, a drum part, a lyric fragment, and especially a short melodic fragment has been willfully copied by a later songwriter in the popular hit Song B [43]. In many instances, the client's viewpoint is fairly honest; they really believe as do many juries that plagiarism is the only explanation for the perceived similarities between Song B and Song A. In the majority of these situations, the investigation shows the dissatisfied client that the identical parts in issue are common to many works and that no copyright is required to protect them. Because these initiatives are frequently without value and because customers are seldom satisfied by the idea that the analysis has allowed them to avoid costly and pointless litigation, several musicologists strive to avoid taking on such projects [70].

Repertoire Research Prior Art and the IC Hypothesis

Although musicologists are skilled listeners with extensive library knowledge, we cannot simply say that we think an element is common or unique since to do so would be argumentum (the Argument From Authority fallacy [44]). We must present proof that the pertinent comparable features do, in fact, occur in other works, ideally but not necessarily works that predate Song A, in order to convince others (such as clients, judges, juries) that any similarity between Song A and Song B is accidental. the Previous Art Proxy, which holds that the existence of a musical feature in several works indicates that different composers may have independently developed it. It works best when applied to brief melodic segments, usually one to four bars of music [43]. The history of music copyright litigation in the USA has been mostly characterized by challenges involving such slender melodic similarities. Plaintiff has observed that in certain instances, a portion of their Song A's melody and a portion of the defendant's Song B's melody are comparable. These parallels are nearly never perfect, and the melodic chains are practically never longer than four bars [47].

Interviews with a number of active musicologists and an examination of more than 50 musicologist reports utilized in litigation are included in Fishman & Garcia's discussion of the evolution of prior art utilization in music copyright litigation. As they note, "Usually, it was the defendant's expert who identified the universe of previous art at issue, it is suggested that the employment of prior art research is a relatively new practice, partially motivated by the dearth of forensic musicologists in the area. Contrarily, plaintiff's side experts often avoided using particular previous art references unless they were refuting the other expert's arguments [71].

Limitations of the Field

Though forensic musicology is emerging at a high rate in modern era but like other fields it has certain limitations based on various aspects. This does not work like a CSI episode where a single knob turning by an expert leads to a noise free wanted audio. A number of different approaches are adopted and none of them is a magic. All these approaches have some limitations too. Despite it's occasionally high profile, forensic science has recently come under intense scrutiny and deep thinking. One notable report from the US National Research Council in 2009 that criticized many forensic fields, including audio forensics, for lacking scientific evaluation of reliability and error rates is one such report. Hence, it is crucial that the science behind forensic investigations be founded on undeniably objective interpretation rather than purely subjective judgements, as has occasionally been the case [72].

Lack of Experts and Contradiction in Analysis by Different Experts

Expert testimony determines many legal issues including the authentication and differentiation of musical recordings, compositions, performance rights and legal determination regarding copyright infringement cases. Music related cases date back to 19th century but no proper legal methodology is in process to be made. Expert opinion based on subjective impression or resulting from golden ear syndrome ae pseudoscientific and non-objective [73]. Since forensic musicology is an extraordinarily complex field and requires a lot of experience in the relevant field. A forensic musicologist must have vast knowledge regarding music of every kind. Therefore, the field has very limited number of experts [74].

Contradiction arises between the analysis of the single case by the two experts. Two experts of the same music field have different opinions on a single case. Since every expert has its own basis and analysis experience. It often appears that there is contradiction between the experts in the analysis by the expert technique and therefore the results are not accurate and leads to failure of the case [75].

Significant Level of Error in the Techniques Used for Analysis

As DNA profiling in forensics provides 100% match or no match between a suspected sample and the reference sample in a single run of experiment, but in forensic musicology there is a significance level of error between the done job. The techniques followed like PMI do not provide the 100% results but provide with a specific level of analysis. On the other hand, certain case is not considered done after a single analysis, an expert has to perform a lot of analysis to verify the case and go through the depth of the exemplars under test [76]. Automated speaker recognition is a new field and noise reduction through recent research can improve its working quality. The tonal quality of the speaking person is affected by this which may mitigate against the court agreeing that the person identified is actually the one talking. The general principle of the court is that every evidence submitted to court should not be modified and it is difficult to determine how far to take it when preparing samples or evidences [77]. Besides this many new computed techniques have been developed for the analysis of music but all have some limitations which make their use limited in forensic music analysis.

Acoustic fingerprinting in audio forensics involves the investigation of background noise, acoustic reflections, reverberation, and unique characteristics of the microphone and recording system that may be heard in the evidence recording [78]. It is necessary to conduct more research to determine the extent to which the acoustical environment, the characteristics of the recording microphone, and the digital audio-coding algorithms can be inferred from the stored audio recording because many common consumer recording devices include automatic gain control and perceptual audio coding/data compression algorithms intended for speech signals [79].

Modern Recording Systems and Tempering Software

With the modernity in audio recordings complexity is increasing in forensic musicology analysis. Music tampering to make pirate copies provide loss to the production companies and even music theft is also carried out to make new music by using the musical works of others [80]. Technology has influ-

enced the music in all the ways it is transmitted, preserved, heard, performed and composed [81]. Recording and broadcast of music is all under its action. In the popular and Western art music genre of electroacoustic, composers utilize technology to alter the tones of acoustic sounds, often by integrating acoustic instruments with audio signal processing like reverb or harmonization [82].

It first appeared somewhere in the middle of the 20th century, after the use of electric sound creation in composing techniques. Sampling is the use and reuse of other music. All electronic software uses these sampled pieces of music for creating new music. Think about the mid-'70s song Ring Precis by Hal Freedman. A recording of Wagner's full Ring cycle, which contains over 18 hours of music, was randomly divided into three-minute sections and played all at once by Freedman. Without a doubt, the resulting sound is unlike anything you have ever heard, but my interest in Freedman's compositional process' temporal implications is greater. In order to construct a new work out of an old one, he superimposed eighteen hours into three minutes [83]. Such tempering software are present which make it difficult for the experts to find out the match through digital forensics. Mashup is a more complex form of music type where music is collected from not a single source but from multiple sources. Mashups are a type of audio composition that start with recordings of popular music. These eclectic songs adhere to the harmonic and rhythmic rules of popular music while re-contextualizing musical and cultural preconceptions, doing away with conventional genre restrictions, and breaking copyright regulations. Mashup artists use capable and user-friendly music editing software to combine songs from the mainstream charts in very innovative ways, creating works that "...are at once familiar yet sometimes startlingly unusual". Combining it creates a mashup. Mashup analysis is more complex in such type of cases [84,85].

Poor Quality of the Sample Under Test

Like any field, there exist limitations in forensic musicology. In the case of speaker recognition, some factors like trace quality, and the time of the sample speech function as variables. The qualities that are desirable in an ideal system would be perfect calibration without dependence on the two factors mentioned above. That is the only way that can lead to the unbiased treatment of every forensic case with standard calibration [47]. Such a system will increase the reliability of voice recognition in criminal court hearings and without doubt, this will open the doors to further applications of the system in other fields [86].

The inferior quality of the trace that the experts are required to work with poses a challenge within itself. Similar sounding consonant voices are not an easy task to distinguish, especially with m and n if the band broadness provided by the phone call data is twice. Trace quality is further reduced as a result of the background noises [87].

Limited Implementation of the Field

Since being a recent field forensic musicology is being applied in developed countries with high efficiency and a number of cases have been resolved, but when it comes to the developing and underdeveloped countries there is no scope of such field. Even people of such states are not aware with the name of such field [88].

Another problem regarding this are the countries like India and Pakistan where music is on the basis of Raga system. This is the most complex type of classical music around the world where your whole composition is based on a raag pattern. Each raga has a specific pattern of notes which gives it a specific identity. This pattern is followed while making a composition in that raga. A single raga can be used by a number of musicians to make different compositions and therefore high range of similarity is present in the different compositions. In the same way similarity also exists between ragas. As different ragas have been originated from each other and they show similarity. Similar ragas are grouped into same Thats which are major divisions of ragas [89]. For example, there is quiet similarity when singing a composition in raag Asaavri and Jaunpuri because both of them follows similar pattern and there is high similarity between the compositions of such ragas. So, it often becomes difficult for the experts to identify the raga and the type of composition. So, application of forensic musicology in such areas is of no use [90].

Conclusion

Forensic musicology is a field that has gained recent popularity and is rapidly becoming the standard way to prove copyright issues and music infringement cases in court. Analysis may vary, and the approach of one forensic musicologist might differ from another forensic musicologist. Some look for the similarities between the patterns while others look for the differences.

The different applications of this field have resulted in tremendous success in criminal cases over the years. Forensic musicology has proved to be instrumental as a means of collecting evidence in cases where physical evidence is nary. Many ransom calls and kidnapping cases use these experts and their knowledge to provide the initial leads to the investigations. Though the field has its advantages, it does have its limitations and for now, experts have to work within the confines of these limitations but with advancing technology, this field will also view and experience remarkable improvements in its development.

References

1. Begault DR, Heise HD, Peltier CA. Forensic musicology: an overview. In: Audio Engineering Society Conference: 54th International Conference: Audio Forensics. Audio Engineering Society; 2014.

2. Cason RJ, Müllensiefen DJIRoL. Computers, and Technology, Singing from the same sheet: computational melodic similarity measurement and copyright law. 2012; 26: 25-36.

3. De Prisco R, Esposito A, Lettieri N, Malandrino D, Pirozzi D, et al. Music plagiarism at a glance: metrics of similarity and visualizations. In: 21st International Conference Information Visualisation. IEEE Publications. 2017; 4.

4. CHIROL J. Automatic detection of musical plagiarism.

5. Park K, Baek S, Jeon J, Jeong YS. Music plagiarism detection based on Siamese. Cable News Network. 2022; 12-38.

6. He T, Liu W, Gong C, Yan J, Zhang Nl. Music plagiarism detection via bipartite graph matching; 2021.

7. Mandasari MI, McLaren M, van Leeuwen DA. Evaluation of i-vector speaker recognition systems for forensic application; 2011.

8. Bellido JJS, L Studies. Forensic technologies in music copyright. 2016; 25: 441-59.

9. Morrison GS, Ochoa F, Thiruvaran T. Database selection for forensic voice comparison. In: Odyssey The Speaker and Language Recognition Workshop. 2012; 2012.

10. Hollien HF. Forensic voice identification. Academic Press; 2002.

11. Künzel, HJJASR. Identification and Verification, Current approaches to forensic speaker recognition; 1994.

12. Singh S, DEJIJoER Rajan, and Technology, Application of different filters in mel frequency cepstral coefficients feature extraction and fuzzy vector quantization approach in speaker recognition. 2013; 2: 419-25.

13. Motyliński M, MacDermott A, Iqbal F, Hussain M, Aleem S. Digital forensic acquisition and analysis of discord applications. In: international conference on communications, computing, cybersecurity, and informatics. Vol. ccci. IEEE Publications; 2020.

14. Mann VA, Diamond R, Carey S. Development of voice recognition: parallels with face recognition. J Exp Child Psychol. 1979; 27: 153-65.

15. Neustein A, Patil HA. Forensic speaker recognition. Springer. 2012; 1.

16. Dobre RA, Elisei-Iliescu C, Paleologu C, Negrescu C, Stanomir D. Robust audio forensic software for recovering speech signals drowned in loud music. In: 22nd International Symposium for Design and Technology in Electronic Packaging (SIITME). IEEE Publications. IEEE Publications; 2016.

17. Devlieger, DJJoPMS. Searching for similarity: confirmation bias in forensic analyses of popular music. 2022; 34: 91-111.

18. Hansen JHL, Hasan T. Speaker Recognition by Machines and Humans: A tutorial review. IEEE Signal Process Mag. 2015; 32: 74-99.

19. Morrison GSJS. Forensic voice comparison and the paradigm shift. Sci Justice. 2009; 49: 298-308.

20. Yan Q, Yang R, Huang J. Copy-move detection of audio recording with pitch similarity. In: IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP). IEEE Publications. 2015; 2015.

21. Ali Z, Imran M, Alsulaiman M. An automatic digital audio authentication/forensics system. IEEE Access. 2017; 5: 2994-3007.

22. Mopas M, Curran A. Translating the sound of music: forensic musicology and visual evidence in music Infringement Cases. Can J Law Soc / Rev Canadienne Droit Soc. 2016; 31: 25-46.

23. McLeod K, DiCola P. Creative license: the law and culture of digital sampling. Duke University Press; 2011.

24. Gully A, Harrison P, Hughes V, Rhodes R, Wormald J. How voice analysis can help solve crimes. Front Young Minds. 2022; 10.

25. Cusick SG. Music as torture/Music as weapon. In: The auditory culture reader. Routledge. 2020; 379-91.

26. Tenaille, F. Music is the weapon of the future: fifty years of African popular music. Chicago Review Press; 2002.

27. Putnam MTJPM. Society, music as a weapon: reactions and responses to RAF terrorism in the music of Ton Steine Scherben and their successors in post-9/11 music. 2009; 32: 595-606.

28. Brown, TSJGSR. Music as a weapon? Ton Steine Scherben" and the Politics of Rock in Cold War Berlin. 2009: 1-22.

29. Hadjidimitriou SK, LJJIToBE Hadjileontiadis. EEG-Based Recognit Music Liking Using Time-Freq Anal. 2012; 59: 3498-510.

30. Hadjidimitriou SK, LJJIToAC. Hadjileontiadis. EEG-based classification of music appraisal responses using time-frequency analysis and familiarity ratings. 2013; 4: 161-72.

31. Baker CJPoP. Music as a weapon of ethnopolitical violence and conflict: processes of ethnic separation during and after the break-up of Yugoslavia. Patterns of Prejudice. 2013; 47: 409-29.

32. Scardina J. What is voice recognition (speaker recognition)?-Definition from WhatIs. Com. 2020, Customer Experience. 2020.

33. Udofia SSJAJORIM, ARTS. Forensic musicology for African musicology. 2021; 9: 227-33.

34. Moorthy V, Shaw BA, Evans JT. Evaluation of tempering induced changes in the hardness profile of case-carburised EN36 steel using magnetic Barkhausen noise analysis. NDT & E International. 2003; 36: 43-9.

35. Ericson RV, Baranek PM, Chan JB. Representing order: crime, law, and justice in the news media. Milton Keynes: Open University Press; 1991.

36. Valverde MJPN. Law's dream of a common knowledge. Princeton University Press; 2003.

37. DeVlieger DL. Promoting creativity: how the use of music analysis affects value judgments in copyright litigation. University of Minnesota; 2020.

38. Begault DR, Heise HD, Peltier CA. Analysis criteria for forensic musicology. Proc Meet Acoust. 2013; 60005.

39. O'Connor SM, Bennett J. Determining the composition. 2021.

40. Skirpan R. An Argument that Independent Creation is as likely as Subconscious Copying in Music Infringement Cases. 2013.

41. DeMain BJPS. You stole my song! From George Harrison to Michael Bolton, strange tales of copyright infringement. 2007; 99: 16-20.

42. Savage PE, et al. Quantitative evaluation of music copyright infringement. In: Proceedings of the 8th international workshop on folk music analysis (FMA2018). Greece: Thessaloniki. 2018; 61-6.

43. Bennett J, WE C. Work it out: methods in forensic musicology.

44. Griffin JJLS music: a role for the principles of reverse engineering. 2010; 30: 653-73.

45. Grigoras C, CJIJoSL, Law t. Digital audio recording analysis–the electric network frequency criterion. 2005; 12: 63-76.

46. Grosche P, Müller M. Tempogram toolbox: MATLAB implementations for tempo and pulse analysis of music recordings. In: Proceedings of the 12th international conference on music information retrieval (ISMIR), Miami, USA; 2011.

47. Leo KM. Forensic musicology and the blurred lines of federal. Lexington Books; 2020.

48. Duan Z, Essid S, Liem CCS, Richard G, Sharma G. Audiovisual analysis of music performances: overview of an emerging field. IEEE Signal Process Mag. 2018; 36: 63-73.

49. Reddy Chichili VP, Kumar V, Sivaraman J. Linkers in the structural biology of protein-protein interactions. Protein Sci. 2013; 22: 153-67.

50. Conklin DJML. Melodic analysis with segment classes. Mach Learn. 2006; 65: 349-60.

51. Gómez E, Herrera P. Comparative analysis of music recordings from western and non-western traditions by automatic tonal feature extraction. Empirical Musicology Review. 2008; 3: 140-56.

52. Shane S, Hubbard BJNYT. ISIS displaying a deft command of varied media. 2014; 30.

53. Fracile NJSMASH. The aksak rhythm, a distinctive feature of the Balkan folklore. 2003; 44: 191-204.

54. Laroche J MedJIToS. Dolson, and A. processing, Improved phase vocoder time-scale modification of audio. 1999; 7: 323-32.

55. Albert S, GGJAoMR. Bell, Timing and music. 2002; 27: 574-93.

56. Pierazzo E. Digital scholarly editing: theories, models and methods. Routledge; 2016.

57. Lin Y-D, Wu T, Chen Y, Lin Y, Chen W, et al. Real-time analysis of beats in music for entertainment robots. AUSMT. 2012; 2: 319-28.

58. Cross I. Music analysis and music perception. Music Anal. 1998; 17: 3-20.

59. Moffat D, Sandler MB. Approaches in intelligent music production. In: Arts. MDPI; 2019.

60. Renza D, Lemus CJEswa, Lemus C. Authenticity verification of audio signals based on fragile watermarking for audio forensics. Expert Systems with Applications. 2018; 91: 211-22.

61. Savage PE, Atkinson QD. Automatic tune family identification by musical sequence alignment. In: Proceedings of the 16th ISMIR conference; 2015.

62. Bella SD, Peretz I, Aronoff N. Time course of melody recognition: A gating paradigm study. Percept Psychophys. 2003; 65: 1019-28.

63. Cronin CJHL. I hear America Suing: music Infringement int he Era of Electronic Sound. 2014; 66: 1187.

64. Yuan Y, et al. Perceptual and automated estimates of infringement in 40 music copyright cases; 2022.

65. Miyazaki Ki, AJP Rakowski. Recognition of notated melodies by possessors and nonpossessors of absolute pitch. Percept Psychophys. 2002; 64: 1337-45.

66. Rodriguez AJAaS. Towards a methodology for voice quality analysis and character coherence in dubbing. SSRN Journal.

67. Schwartz SJibCdG. Wicked's musical themes; 2004.

68. Selfridge-Field EJCTL. Substantial musical similarity in sound and notation: perspectives from digital musicology. 2017; 16: 249.

69. Walton D. Informal logic: A pragmatic approach. Cambridge University Press; 2008.

70. Lund JJVS, E LJ. An empirical examination of the lay listener test in music composition copyright infringement. 2011; 11: 137.

71. Maher RCJAT. Lending an ear in the courtroom: forensic acoustics. 2015; 11: 22-9.

72. Krasilovsky MW, Schemel S, This business of music: The definitive guide to the business and legal issues of the music industry. Billboard Books; 2007.

73. Broucek V, Turner P. Computer incident investigations: e-forensic insights on evidence acquisition. In: EICAR Conference Best Paper proceedings. Luxembourg, Grand Duchy and Luxembourg: EICAR; 2004.

74. Guarnera LA, DC Murrie, MTJTIiPS. Boccaccini, Why do forensic experts disagree? Sources of unreliability and bias in forensic psychology evaluations. Translational Issues in Psychological Science. 2017; 3: 143-152.

75. Crawford T, Gibson L. Modern methods for musicology: prospects, proposals, and realities. Routledge; 2016.

76. Rumsey FJJotAES. Audio forensics: not an episode from CSI. 2016; 64: 440-4.

77. Zhou Z, Diao W, Liu X, Zhang K. Acoustic fingerprinting revisited: generate stable device id stealthily with inaudible sound. In: Proceedings of the 2014 ACM SIGSAC conference on computer and communications security. 2014; 429-40.

78. Love SCJUJ, Circuit Split: de Minimis Sampling from Copyrighted Recordings after VMG Salsoul, LLC v. Ciccone. 2018; 22: 2018.

79. Maher RC. Audio forensic examination. IEEE Signal Process Mag. 2009; 26: 84-94.

80. Peitz M, PJIJoIO. Waelbroeck, Why the music industry may gain from free downloading—the role of sampling. 2006; 24: 907-13.

81. Rodgers TJOS. On the process and aesthetics of sampling in electronic music production. Org Sound. 2003; 8: 313-20.

82. Miller PD. Sound unbound: sampling digital music and culture. Mit Press; 2008.

83. Braun SKJIJoCS. Forensic evidence of copyright infringement by digital audio sampling analysis-identification–marking. International Journal of Cyber-Security and Digital Forensics. 2014; 3: 170-82.

84. MACCHIUSI I. 'CUT AND PASTE IMAGINATION': MASHUPS, technology and the aesthetics of collage. TORONTO: YORK UNIVERSITY; 2010.

85. Niitsuma M, Tomita Y, Yan WQ, Bell D. Towards musicologist-driven mining of handwritten scores. IEEE Intell Syst. 2018; 33: 24-34.

86. Roeck, DFFFFFR. Cause the Samplers Gonna Sample: should Courts Allow de Minimis Copying of Sound Recordings, or Should They Shake It off? 2022; 127: 205.

87. Verde S, Pretto N, Milani S, Canazza S. Stay true to the sound of history: philology, phylogenetics and information engineering in musicology. 2018; 8: 226.

88. Sarkar R, Naskar SK, Saha SK. Raga identification from Hindustani classical music signal using compositional properties. Comput Visual Sci. 2019; 22: 15-26.

89. Kaimal V, SJIJoCS. Barde. introduction to identification of raga in Carnatic music and its corresponding Hindustani music. International Journal of Computer Sciences and Engineering. 2018; 6: 955-8.