**Indonesian Journal of Electrical Engineering and Computer Science**
Vol. 39, No. 3, September 2025, pp. 1865~1876
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v39.i3.pp1865-1876


# An innovative approach to Raga pattern identification

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**Article Info**

***Article history:***

Received Sep 27, 2024
Revised Apr 8, 2025
Accepted Jul 2, 2025

***Keywords:***

Fast Fourier transform
Fundamental frequency
Indian classical music
Music therapy
Pattern matching
Raga

**ABSTRACT**

Raga is a fundamental element of Indian classical music (ICM), crucial for identifying the unique characteristics of a given song. Recognizing the embedded Raga allows for various applications, including music therapy, and leveraging the therapeutic effects of different Ragas. The use of mathematical techniques such as fast Fourier transform (FFT) and fundamental frequency measurement (FFM) in calculating note values has proven effective for Raga pattern recognition. Both methods yield nearly identical results, facilitating accurate identification of Ragas. Once identified, these Ragas can be used for specific therapeutic purposes, harnessing their healing potential.



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## 1. INTRODUCTION

Music is a universal language, serving as a powerful medium of communication that can be both enjoyable and therapeutic for listeners. The intersection of music and computational science is remarkably close, particularly in the realm of recommendation systems. These computer-based tools utilize advanced algorithms to suggest relevant items to users based on their preferences. A music recommendation system (MRS) predicts a user's musical taste by analyzing a localized music collection and then curating a personalized set of songs from a broader database. MRS can be broadly categorized into two types: Content-Based MRS and collaborative filtering-based MRS. Content-based MRS examines the attributes of songs—such as tempo, instrumentation, and genre—to classify and recommend music that aligns with a user's listening history. On the other hand, collaborative filtering-based MRS employs a multi-user utility approach, leveraging shared preferences and listening behaviors across users to generate recommendations.

Music is a powerful element in the entertainment world, possessing healing capabilities that make it a significant focus in the emerging research area of music information retrieval (MIR) within computational musicology. MRS creates personalized music playlists from large databases based on user preferences, and they can also be applied in music therapy, significantly impacting societal well-being. MIR is a modern computational research field focused on extracting musical data from diverse sources. It integrates techniques from signal processing, machine intelligence, human-computer interaction, pattern recognition, audio mining, and computational musicology, often combining these approaches for enhanced analysis. MRS considers various factors, such as star ratings, seasons, cultures, human moods, locations, behaviours, preferences, and different times of the day.

Indian classical music (ICM) remains relatively unexplored from a computational musicology perspective, though some research has emerged in the last decade. The fundamental unit of ICM is the Raga. Once a Raga is identified computationally, it can serve various purposes, including music therapy. In the modern context, music therapy is a noble and harmless treatment procedure globally accepted for addressing various health issues. Unlike chemical drugs, music therapy is free from side effects and is particularly beneficial and safe for pediatric healthcare applications, helping to alleviate symptoms and improve children's quality of life [1]. ICM is also effective for mental health issues such as depression, stress, and anxiety [2]. Mental health problems are unfortunately common across all age groups today. Managing these issues, especially depression, is a significant concern in society. Fortunately, music therapy and interventions offer efficient solutions for mental health management [3], [4].

A Raga is a musical pattern, and in computational musicology, identifying a Raga is essentially a pattern recognition problem. Once the Raga of a song is identified, it can be used for healing purposes if the Raga possesses specific therapeutic properties. Therefore, recognizing the Raga of a given song is an important computational task. This work addresses the problem of automatic Raga recognition in ICM, motivated by the needs and potential of music therapy. A model for Raga recognition is proposed, which is object-oriented. Using this model, one can identify the Raga of a given song. The entire work is based on ICM, and a procedure has been designed to identify the Raga patterns of a song. This procedure employs mathematical concepts such as the discrete fourier transform (DFT) and fundamental frequency measure (FFM).

Results were obtained by applying the proposed model and procedure to various songs based on ICM. These results were computed through experiments using WaveSurfer software, as well as through computations based on FFM. The process demonstrates how the computed values can be mapped to identify a Raga from the available Raga database.

The rest of the paper is organized as follows: section 2 discusses the relevant literature. Section 3 highlights the associated background of this work. The proposed model for identifying Ragas in ICM is presented in section 4 and section 5, followed by a discussion of the results in section 6. The paper concludes in section 7.

## 2. RELATED WORK

Mental illness is prevalent in today's society, defined by the American Psychiatric Association as significant changes in behavior, emotions, or both, leading to difficulties in social and functional aspects of life [5]. According to PINEREST Christian Mental Health Services, 19% of adults, 46% of teenagers, and 13% of children experience mental health issues [6]. Music, known for its pleasantness and therapeutic capabilities [7], is integral to ICM through its fundamental component known as 'Raga'. A Raga is a scale formed by combining the seven basic notes: Sa, Re, Ga, Ma, Pa, Da, and Ni [7]. Music therapy, a field within paramedicine, applies music for therapeutic purposes, addressing psychological and physiological conditions such as mesothelioma, asthma, depression, and even asbestos cancer [8]. Ragas play a crucial role in music therapy; for instance, Raga Ahirbhairav and Todi are used for hypertension, Raga Punnagavarali for anger and violence control, Raga Todi for relief from cold and headaches, Raga Shivaranjani for memory-related issues, Raga Bhairavi for sinus and toothache relief, Raga Chandrakauns for heart problems and diabetes, and Raga Darbari for tension reduction and relaxation [8].

There is a distinct relationship between Raga and rasa in ICM, where Raga denotes the musical origin and rasa signifies the emotional essence of music. This direct connection between music and emotions has been well-established. Koduri and Indurkhya [9], an author developed a content-based, culture-specific music recommendation system. Erkkila *et al.* [10] describe a research project focused on developing a music analysis system for clinical music therapy. Music therapy based on ICM is a highly effective treatment for mental illnesses and contributes significantly to mental health management [11]. Paper [12] provides detailed insights into various Ragas and their corresponding therapeutic benefits. Su *et al.* [13] introduce the concept of music recommendation using content and context information mining. Additionally, [14] introduces a context-aware mobile MRS tailored for daily activities.

Adriano *et al.* [15] propose a modeling technique and a practical tool that formalize music composition rules. Additionally, [15] discusses music analysis using music Petri nets and incorporates Schoenberg's rules. Chakrabarty *et al.* [16], a method for determining the similarity between two songs involves comparing the notes and fundamental frequencies, employing Pearson's Correlation Coefficient. Furthermore, [17] introduces a web-based application for generating and downloading song lists tailored to users' age groups. This application recommends songs from an online music library based on user preferences and categorizes unfamiliar songs based on user reviews.

Research in musical automation and social network analysis has flourished in recent years, contributing significantly to the automation of music creation processes and their analysis. Chordia [18], a novel rag classification method based on spectrally derived tones, is introduced, achieving 100% accuracy through tone profiles, which are histograms of note values weighted by their durations. Tonal modulation is explored through graph theory in [19], leveraging concepts like graph connectivity, group structures, graph coloring, metrics, Hamiltonian paths, and Euler tours to address musical challenges such as modulation sequences and chord progressions. Shetty and Acharya [20] propose an automated system for determining the Raga name in ICM from audio files, employing note transcription and artificial neural networks to analyze ascending and descending note patterns. Pandey *et al.* [21], "TANSEN," an automated system based on Hidden Markov Models, effectively identifies Ragas from audio samples. Additionally, [22] presents a system using support vector machines (SVM), maximum a posteriori (MAP) methods, multivariate likelihood models (MVN), and Random Forests for direct Raga recognition from audio signals. These advancements underscore the intersection of music theory with computational techniques, enhancing understanding and application across musical domains.

A novel method leveraging object-oriented modeling is introduced in [23] to classify various melodious audio streams into specific featured classes. These classes are distinguished by unique musical properties, enabling the classification of pieces into different subclasses, addressing the complex categorization challenges posed by the breadth of ICM. Furthermore, [24] describes an efficient system capable of automatically extracting the main music from polyphonic recordings. This approach focuses on creating and classifying pitch contour files, minimizing errors in voice detection within the recordings.

The intersection of mathematics and music has been a subject of study for centuries, with scholars such as Pythagoras and Helmholtz laying foundational theories that describe the mathematical principles underlying musical harmony and acoustics. Pythagoras' discovery of numerical relationships between the lengths of strings and the pitch they produce initiated a mathematical approach to understanding music, which has since evolved through various disciplines [25]. The system of equal temperament, where an octave is divided into 12 equal semitones, has been the standard in Western music since the 18th century. This system allows for the easy transposition of music and consistent tuning across different keys, but it is not without its critics [26].

## 3. BASIC TERMINOLOGIES

Here is a table listing some common terminologies related to Ragas in ICM in Table 1. These terminologies provide a foundational understanding of the key concepts and components that form the structure and performance of Ragas in ICM.

Table 1. Experimental values of seven notes

| Terminology | Description |
|---|---|
| Raga | A melodic framework in ICM that uses a specific set of notes to create a particular mood or emotion. |
| Thaat or Raga Origin | A parent scale or mode from which Ragas are derived. There are ten primary Thaats in Hindustani music. |
| Swaras or Notes | The seven basic notes in Indian music: Sa (Shadja), Re (Rishabh), Ga (Gandhar), Ma (Madhyam), Pa (Pancham), Dha (Dhaivat), Ni (Nishad). |
| Arohana or Ascending Notes | The ascending scale of a Raga. |
| Avarohana or Descending Notes | The descending scale of a Raga. |
| Vadi or Most Important Note | The most important or prominent note in a Raga. |
| Samvadi or 2nd Most Important Note | The second most important note in a Raga, often a perfect fourth or fifth from the Vadi. |
| Shruti or Scale | Microtonal pitches that lie between the main notes, used to enhance the subtle nuances of a Raga. |
| Fast fourier transform (FFT) | The FFT is an algorithm designed to efficiently calculate the DFT and its inverse. The DFT is a mathematical method that converts a series of complex numbers from the time domain into a corresponding sequence in the frequency domain. When applied to music note identification, FFT analyzes the frequencies within an audio signal to determine the specific musical notes being played. |
| Fundamental frequency measurement (FFM) | FFM is a crucial concept in various fields like acoustics, music, speech processing, and signal processing. FFM is crucial for determining the pitch of musical notes. |

## 4. PROPOSED METHOD

The origin of a Raga can be identified by recognizing the group of notes that comprise it. Each Raga is derived from a specific Raga origin, or thaat. Multiple Ragas can share the same Raga origin, similar to how objects in object-oriented programming share properties of their class. In this analogy, the thaat is represented as a class. Different thaats like Bilawal, Asavari, Bhairavi, and Bhairav are objects of the thaat class, sharing common properties. However, identifying a thaat requires extracting its constituent notes, necessitating the classification of note groups as a class. Specific sequences of notes then become objects of this note class. In this system, identifying a particular Raga pattern within a song is crucial. The following procedure outlines the steps involved in recognizing Raga patterns:

a) Note extraction: extract the notes from the given audio file.
b) Sequence identification: identify sequences of notes that correspond to known Raga patterns. The process of sequence identification involves recognizing and pinpointing specific sequences of musical notes that match established Raga patterns. This is achieved through the measurement and analysis of the fundamental frequency of each note, a method known as FFM.
c) That classification: by employing FFM, one can accurately determine the pitch of each note, allowing for a detailed comparison with the characteristic sequence patterns of various Ragas. Classify these sequences to determine the underlying thaat.
d) Pattern recognition: match the identified note sequences with existing Raga patterns to recognize the specific Raga.
e) Validation: to ensure the accuracy of the identified Raga name for a given song, one can utilize the FFT o its constituent frequencies. This analysis can be conducted directly through Wavesurfer, an open-source software designed for audio analysis. Wavesurfer provides a user-friendly interface and a pomethod for validation. This process involves analyzing the audio file by transforming its time-domain signal into the frequency domain using FFT, a mathematical technique that decomposes the audio signal intwerful tools for visualizing and examining the frequency spectra of audio files. By leveraging Wavesurfer's capabilities, one can meticulously compare the identified Raga patterns against the spectral data obtained from the FFT, ensuring that the identified Raga accurately matches the musical characteristics present in the audio file.

This structured approach ensures accurate identification of Ragas by methodically analyzing the musical components.

## 5. ALGORITHM 1: RAGA PATTERN MATCHING

The algorithm identifies the Raga of a given song by extracting its seven fundamental frequencies using the frequency filtering method (FFM) and performing an FFT-based analysis. It begins by initializing an array (S1Fi[]) containing the extracted frequencies and determining their occurrence count. The Vaadi (most frequent) and Samvaadi (second most frequent) notes are identified, while the remaining five notes are derived using a mathematical pitch ratio formula. The FFT is then applied to refine note identification, and a Note-error percentage is calculated. If the error is $\leq$ 5%, the algorithm confirms a Raga pattern match; otherwise, it declares no match, ensuring a structured computational approach to Raga recognition. The computational steps of Algorithm 1 are given:

Algorithm 1. Raga pattern matching

```
input: a song
OUTPUT: Raga name of the song
Function: Returns the seven fundamental frequencies using FFM
    1.  START
    2.  INITIALIZE S1Fi[] = {S1Fi[0], S1Fi[1], S1Fi[2], ..., S1Fi[n-1]}
    3.  SET length = sizeof(S1Fi) / sizeof(S1Fi[0])
    4.  DEFINE OR[length] // OR is the array for counting occurrences
    5.  SET visited = -1
    6.  SET i = 0
    7.  WHILE i < length DO
            1.  SET count = 1
            2.  SET j = 0
            3.  WHILE j < length DO
                    1.  IF S1Fi[i] == S1Fi[j] THEN
                            1.  count++
                            2.  OR[j] = visited
                    2.  END IF
                    3.  j = j + 1
            4.  END WHILE
            5.  IF OR[i] != visited THEN OR[i] = count
            6.  i = i + 1
    8.  END WHILE
    9.  SET i = 0
    10. WHILE i < length DO
            1.  IF OR[i] != visited THEN
```

```
                1.  PRINT S1Fi[i]
                2.  PRINT OR[i]
        2.  END IF
        3.  i = i + 1
11. END WHILE
12. SET VAADI_Note to the maximum occurring element of S1Fi[]
13. SET SAMVAADI_Note to the second maximum occurring element of S1Fi[]
14. FIND the other 5 notes using the formula: NPV = (PPV * NR) / PR
    Where:
    NPV = Next Pitch Value
    PPV = Previous Pitch Value
    NR = Next Ratio
    PR = Previous Ratio
15. FIND notes using FFT
16. CALCULATE Note-error %
17. IF Note-error % ≤ 5 THEN PRINT "Raga pattern matched"
    ELSE PRINT "Raga pattern not matched"
18. END
```

## 6. RESULTS AND DISCUSSION

While in earlier studies, all musical notes or chords are recorded in digital format, and their Fourier spectra vary but this current study is used to compute these spectra which is called FFT. Each note's frequency ratio, as listed in Table 2 of the twelve-note system, is used in the analysis. Using the WavePad Sound Editor software, FFT analysis was performed. The results from this analysis were compared with calculated values to determine their accuracy, which is discussed in the following section. Figure 1 shows the waveforms of wavelengths w1 and w2, respectively. These diagrams clearly illustrate that, with a constant velocity, wavelength is inversely proportional to frequency. Additionally, they demonstrate that frequency can change even when amplitude remains constant.

Table 2. Experimental values of seven notes

| Note | Sa | re | Ga | Ma | Pa | dha | Ni |
|---|---|---|---|---|---|---|---|
| Frequency | 193 | 203 | 229 | 257 | 290 | 305 | 343 |

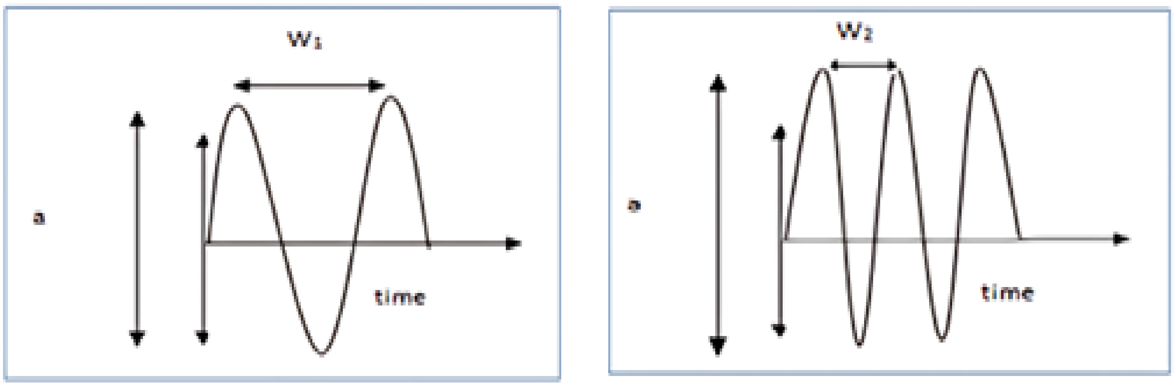


Figure 1. Waveform of the wavelength w1 (a is amplitude) and Waveform of the wavelength w2 (a is amplitude)

The relationship between velocity (V), wavelength (W), and frequency (F) is given by the formula:

$$V = W \, X \, F \quad (1)$$

where V = velocity, W = wavelength, and F = frequency (cycles per second).

Figure 2 shows the maximum amplitude of a waveform, indicating the highest peak amplitude. Figure 3 illustrates the highest frequency of the maximum amplitude. In this graph, the X-axis represents amplitudes ranging from -128 dB to 0 dB, while the Y-axis represents time. The notes used in the ascent and descent of Raag Bhairavi are Sa, re, Ga, Ma, Pa, dha, Ni.

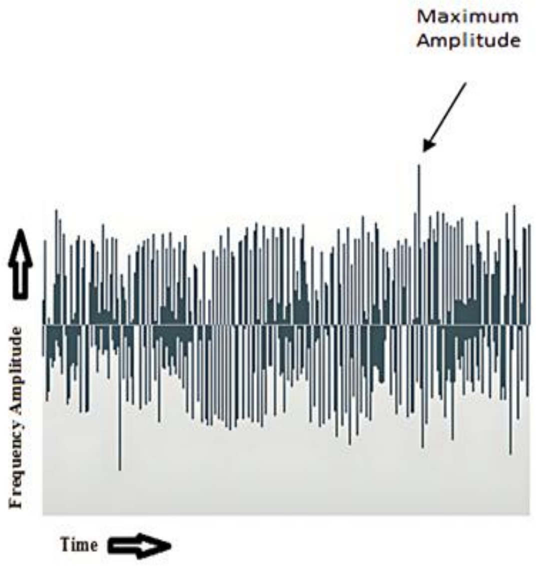


Figure 2. The maximum amplitude of a waveform

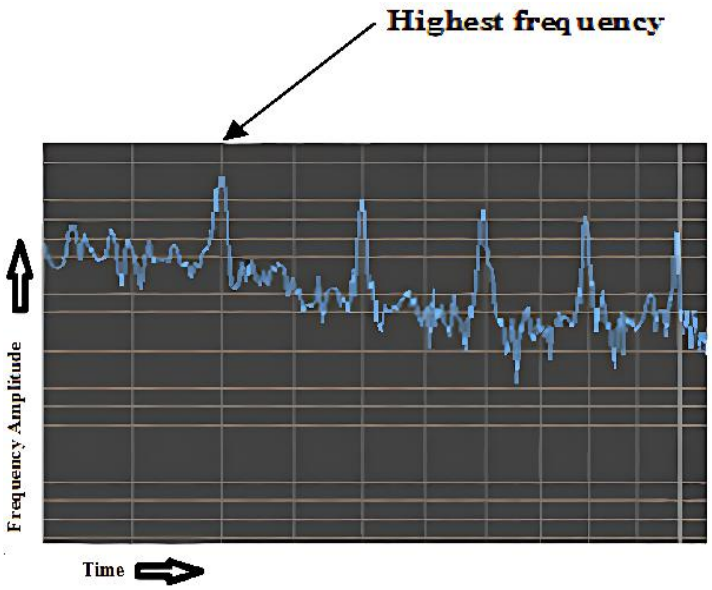


Figure 3. Highest frequency of the maximum amplitude

From Figure 4, the segments corresponding to all eight notes are identified. Figure 5 display the presence of each note within the waveform. The segments of each note in the waveform are determined by listening to the song. As illustrated in Figure 5, the highest amplitude of each note's segment determines the maximum intensity. The highest frequency value among the various frequencies contributing to the largest amplitude of each segment is considered the frequency value of that note. Consequently, the frequency value of the note ‘Sa’ is determined to be 193 Hz, as depicted in Figure 6.

In Figure 6, the highest frequency value among all the frequencies contributing to the largest amplitude of a given segment is considered the frequency value of that note. Similarly, for the note ‘re,’ the frequency value is determined to be 203 Hz, as shown in Figure 7. Once again, the highest frequency amplitude is taken as 229 Hz, despite the region containing another high peak amplitude frequency level, as this value exceeds the vocal range. Consequently, the frequency of the next note, ‘Ga,’ is 229 Hz, as shown in Figure 8. The remaining four notes—'Ma,' 'Pa,' 'dha,' and 'Ni'—are analyzed in the same manner using FFT. The experimental values of all the notes are provided in Table 3.

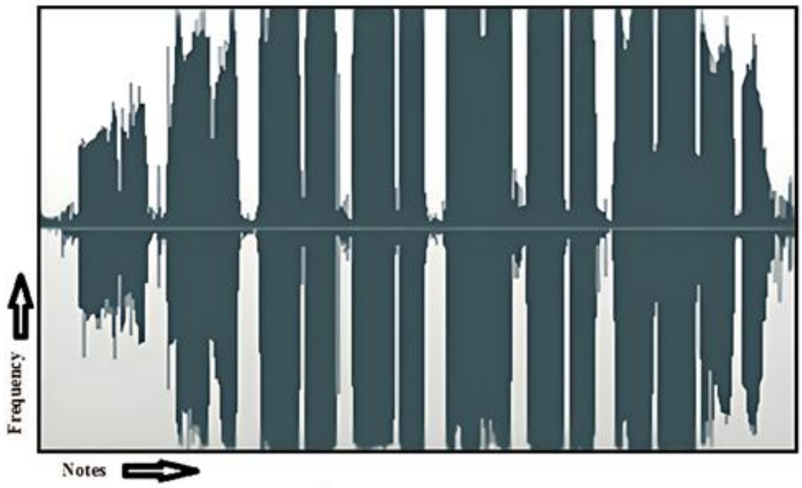


Figure 4. Waveform of ascent and descent of raag Bhairavi

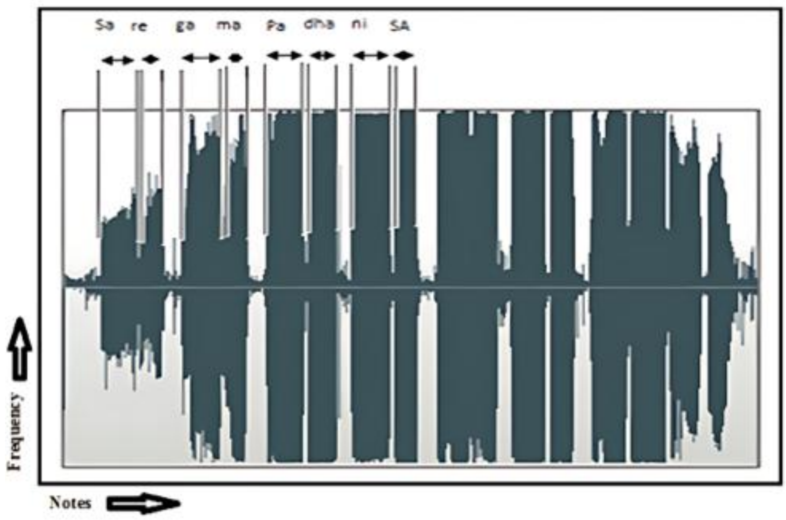


Figure 5. Region of each note in the waveform

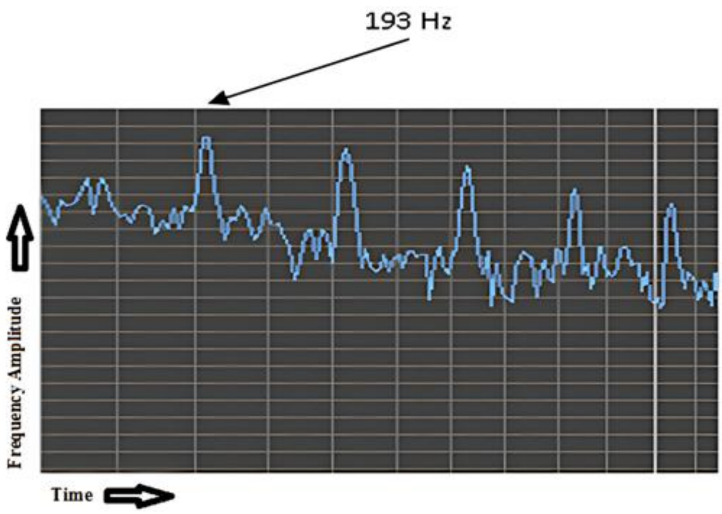


Figure 6. The experimental frequency value of 'Sa'

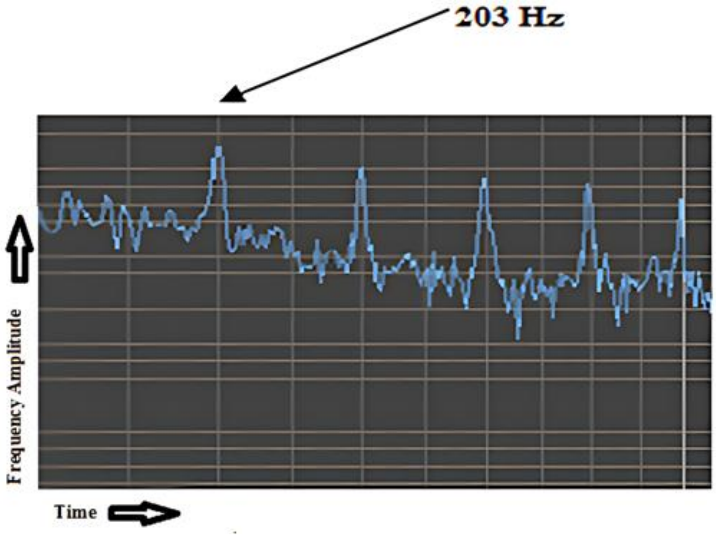


Figure 7. The experimental frequency value of note ‘re’

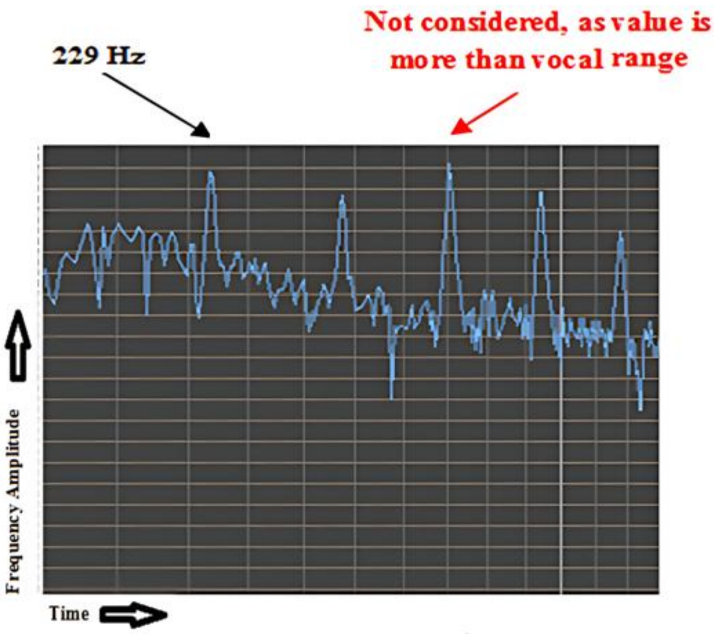


Figure 8. Showing the experimental frequency value of note ‘Ga’

Table 3. Experimental frequency values of all notes using FFT

| Indian music notes | Frequency |
|---|---|
| Sa | 193 |
| re | 203 |
| Ga | 229 |
| Ma | 257 |
| Pa | 290 |
| dha | 305 |
| Ni | 343 |

The fundamental frequency range is 100–500 Hz for males and 130–800 Hz for females. Therefore, a singer's fundamental frequency cannot be lower than 100 Hz. Identifying the tonic 'Sa' or 'Do' is crucial, as these serve as the fundamental frequencies upon which all other notes are based. Using this fundamental frequency, the accuracy of the singer's pitch can be assessed. Once the tonic 'Sa' is identified, the other notes can be determined using the frequency ratios of the twelve notes, as detailed in Table 2. This study explores a comprehensive fact that the notes of a song with the highest amplitude are analyzed by the system. When a user inputs a song into the software, the system interacts with various features present in the sample song, such as the most important note (Vaadi Swar), the second most important note (Samvaadi Swar), and the other ten note structures, using FFT and the Note-Frequency Ratios. The fundamental frequency of the tonic 'Sa' is found to be 195 Hz. Using this value and the note-frequency ratio table, the other six notes are identified. The obtained values of these notes are presented in Table 4.

Table 4. Experimental frequency values of all notes using FFM

| All notes | Note value | Notes present/absent |
|---|---|---|
| Sa | 195 | Present |
| re | (195 × 1.054) ÷ 1 = 205 | Present |
| Re | (205 × 1.125) ÷ 1.054 = 218 | Absent |
| ga | (218 × 1.186) ÷ 1.125 = 229 | Absent |
| Ga | (229 × 1.253) ÷ 1.186 = 241 | Present |
| ma | (241 × 1.333) ÷ 1.253 = 256 | Absent |
| Ma | (256 × 1.415) ÷ 1.333 = 271 | Present |
| Pa | (271 × 1.500) ÷ 1.415 = 287 | Present |
| dha | (287 × 1.580) ÷ 1.500 = 302 | Present |
| Dha | (302 × 1.691) ÷ 1.580 = 323 | Absent |
| ni | (323 × 1.777) ÷ 1.690 = 339 | Absent |
| Ni | (339 × 1.893) ÷ 1.777 = 360 | Present |

Table 5 displays the calculated values of all seven notes present in Table 4 of the given Raga using the FFM method. The experimental values in Table 3 closely match the calculated values in Table 5, indicating that the analysis can effectively verify the accuracy of the work. If the frequency value of a note from the experiment deviates from the calculated value, the system will identify the error using Table 6, allowing the user to understand the deviation. The results indicate that the values of the seven notes obtained through FFT/DFT experiments are very similar to those calculated using FFM. The acceptable percentage (%) error for each note is also specified. Figure 9 illustrates the comparative results of note values obtained using FFT/DFT and FFM for a given input song.

Table 5. Present seven notes and their frequency using FFM

| Indian music notes | Frequency |
|---|---|
| Sa | 195 |
| re | 205 |
| Ga | 241 |
| ma | 271 |
| Pa | 287 |
| dha | 302 |
| Ni | 360 |

Table 6. Error difference in computation (using FFT and FFM)

| Indian music notes | Experimental note values using FFT/DFT | Calculated note value using FFM | Error % |
|---|---|---|---|
| Sa | 193 | 195 | 1.036 |
| re | 203 | 205 | 0.9852 |
| Ga | 229 | 241 | 5.24 |
| Ma | 257 | 271 | 5.447 |
| Pa | 290 | 287 | 1.045 |
| dha | 305 | 302 | 0.9933 |
| Ni | 343 | 360 | 4.956 |

After all the notes are identified, their structures are compared with the Raga knowledge base to determine the Raga or song origin. Once the Raga of a song is identified, the song can be classified for use in addressing various health and mental disorders. This mapping process utilizes the knowledge of music therapy to inform its application.

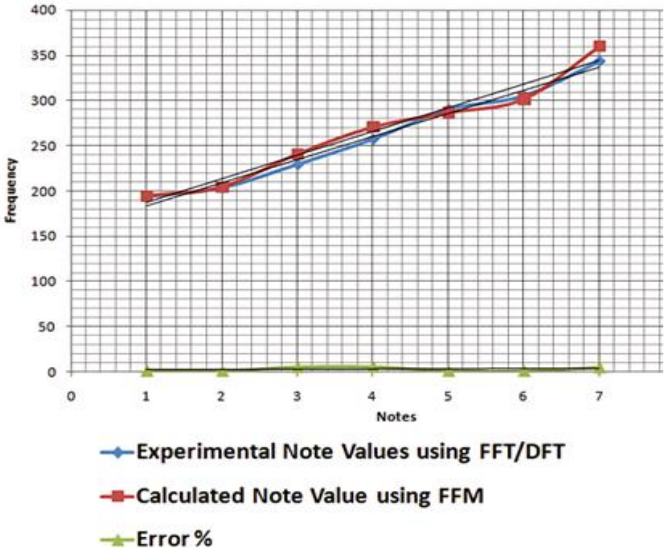


Figure 9. Comparative results (Note values using FFT/DFT & FFM of the input song with error %)

## 7. CONCLUSION

Raga stands as the cornerstone of ICM, representing its essence and character. Recognizing the specific Raga embedded within a song is crucial not only for appreciating its musical depth but also for harnessing its potential applications, including in music therapy. This recognition process translates computationally into a pattern recognition challenge within the realm of ICM. Our findings provide conclusive evidence that the note structure and Raga-origin or Thaat name of any song can be extracted efficiently. So, we delve into the intricate task of Raga pattern recognition. We propose a computational model grounded in an object-oriented approach to effectively identify Ragas. Central to our approach is a procedure designed to compute diverse note values, essential for discerning Ragas within musical compositions. Leveraging mathematical tools such as the DFT and FFM, we calculate these note values, comparing results obtained through experimental methods using Wave Surfer software with those derived from FFM computations. Remarkably, both methodologies yield closely aligned note values critical for accurate Raga pattern recognition.

These computed note values play a pivotal role in linking a song to its corresponding Raga in a knowledge base. Once identified, the Raga can be utilized in various applications, particularly in music therapy, harnessing the therapeutic potential associated with each Raga's unique characteristics. The proposed solution may be beneficial in automating the process of Raga pattern recognition which emerges not only as a computational challenge but also as a pivotal step towards enhancing the efficacy and scope of automated music therapy interventions.

## ACKNOWLEDGEMENTS

We would like to express our gratitude to all those who supported us throughout the course of this research. Special thanks go to Techno Main Salt Lake for providing the necessary facilities and resources. We are also grateful to our colleagues from the Department of CSE (AI & ML) who provided valuable insights and expertise that greatly assisted the research.

## FUNDING INFORMATION

Authors state no funding involved.

## AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

## CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

## DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created in this study.

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