Malay Rebab: Sound Analysis of the Kelantan Traditional Musical Instrument

Aaliyawani E. Sinin,[a,]* Sinin Hamdan,[b] Khairul A. Mohamad Said,[b] Marini Sawawi,[b] Khairil A. D. Kamarudin,[c] and Ahmad F. Musib [d]

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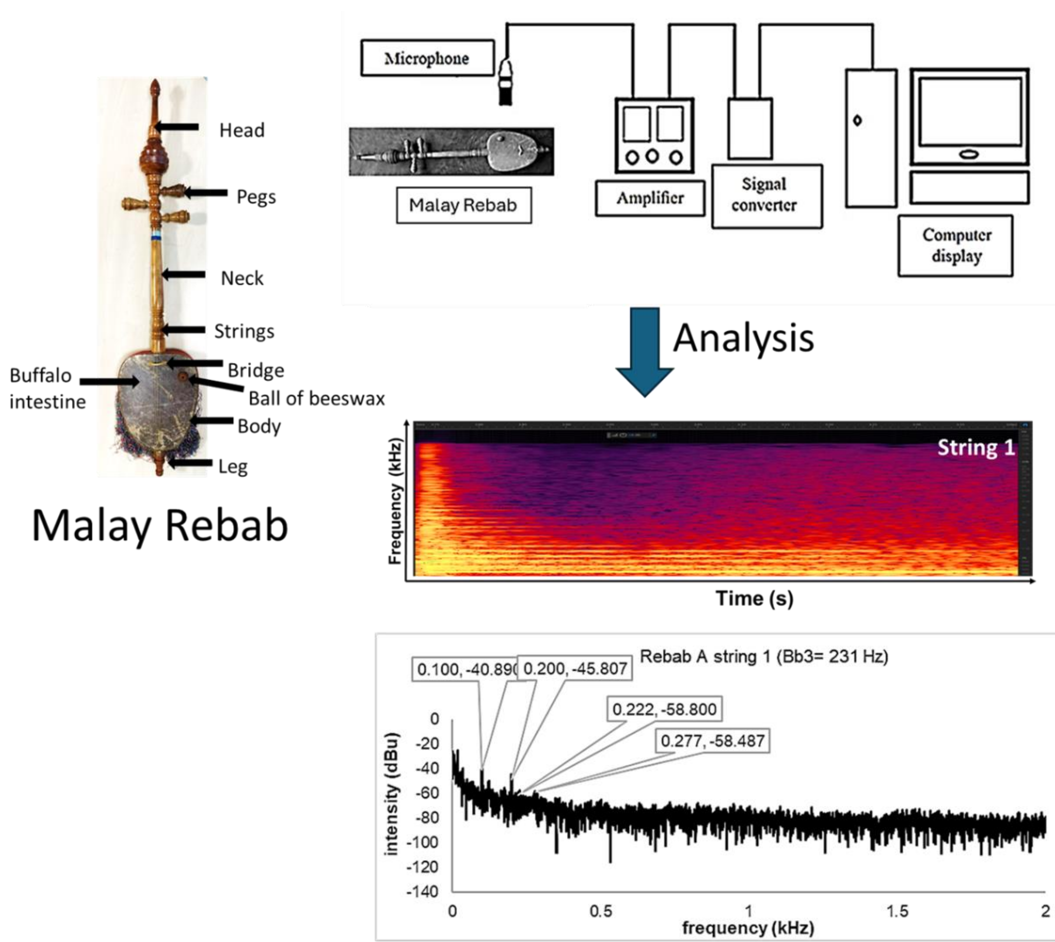
GRAPHICAL ABSTRACT



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The ‘Malay’ rebab is a vertical, strung chordophone played similarly to a cello. The rebab strings sit on a bridge. The bridge is placed on a buffalo intestine on the front face. The buffalo intestine surface is pressed by the bridge in such a way that the string tension is not in a fully stable position. A ball of beeswax attached near the bridge mutes the sound reverberations. This investigation was undertaken by analyzing the rebab sound utilizing Fast Fourier Transform (FFT) for spectrum analysis *via* a PicoScope. The highest note is Bb (Bb3 = 0.231 kHz), played on the 1st string. The intermediate note is F (F3 = 0.172 kHz) played on the 2nd string. The lowest note is C (C3 = 0.135 kHz), played on the 3rd string. For string 1, the fundamental pitches (f0) were 0.222 kHz, 0.237 kHz and 0.224 kHz for rebab A, B, and C, respectively. For string 2, the f0 were 0.174 kHz, 0.177 kHz and 0.168 kHz for rebab A, B and C respectively. For string 3, the f0 were 0.125 kHz, 0.149 kHz and 0.126 kHz for rebab A, B and C respectively. All the strings show non-harmonicity.

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Keywords: ‘Malay’ rebab; Fast Fourier Transform; FFT; ‘Makyung’

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INTRODUCTION

With the advent of Islam in Sumatra, Java, and Malaysia, the rebab spread to Southeast Asia. It has significant resemblances to the historical Persian form. Being devoid of both a fingerboard and fret, and with a bow that is loosely strung as opposed to the tight bow of the violin, this instrument is exceptionally challenging to play. Furthermore, its range is narrow, and it spans over just one octave. Within a gamelan orchestra, the ‘Malay’ rebab serves as an embellishment to the fundamental melody, while also playing a significant role as the primary accompaniment in traditional music of the East coast Peninsular Malaysia. The healing ritual rite known as 'Main Puteri', the traditional ‘Malay’ spiritual dance theatre called ‘Makyung’, and the solo theatre performance called 'Tarik Selampit' are especially noteworthy here. New musical creative strategies have been employed by music composers to incorporate the ‘Malay’ rebab instrument into Western orchestra or musical ensemble settings. The advent of electrically amplified ‘Malay’ rebab instruments utilized equal tempered tunings prevalent in modern music contexts. Therefore, the auditory genuineness of the traditional ‘Malay’ rebab instrument has become uncertain, which has prompted this investigation to determine the genuine acoustic characteristics of the instrument. This study utilizes the acoustics techniques using Fast Fourier Transform (FFT) and Adobe Audition to obtain precise frequency analyses. Several previous studies on the acoustic characteristics of traditional instruments, especially using FFT analysis, were done by the authors. (Hamdan *et al.* 2023, 2024, Sinin *et al.* 2023, 2025). The acoustic characteristics of the instrument offer clearly measurable sound benchmarks. The outcomes of this study will empower music practitioners and culture policy makers to protect and maintain the fundamental aspects of this intangible 'Malay' cultural legacy, while also acknowledging and appreciating the evolution of modern art music.

Upon reaching the archipelago, namely in the state of 'Kelantan', Malaysia, traditional music underwent improvisation in terms of performance, composition, and presentation in accordance with the local culture (Mat Zain 2015). However, the utilization of it in certain regions of the Peninsular Malaysia, such as Kedah, Malaysia, has become obsolete with time. Nevertheless, the rebab continues to be performed at the 'Makyung' theatre, which was officially acknowledged by UNESCO as a 'Masterpiece of the Oral and Intangible legacy of Humanity' and was included in the world's artistic legacy (UNESCO 2003). Culture is a comprehensive array of spiritual, material, intellectual, and emotional attributes that define the identity of a community or social group. Currently, the global cultural legacy holds significant value, as it serves as a reflection of a nation's identity (Mohd 2018). The Southeast Asian rebab may have been influenced by the Chinese 'erhu', a two-stringed spiky violin of archaic provenance, which has a similar resonance. 'Main Puteri' was a time-honored therapeutic method in 'Kelantan', Malaysia, performed by a shaman, which included inducing trances and other ceremonial processes accompanied by the rebab drum. Previously, it was even conducted at hospitals located on the East coast to guarantee secure recuperation. In 'Kelantan', Malaysia, the traditional storytelling style known as 'Tarik Selampit' was also accompanied by the rebab. 'Makyung' is a prominent Kelantanese ritual closely associated with the rebab. An archaic kind of dance and theatrical performance executed in the regions of 'Kelantan' Malaysia and Pattani in Southern Thailand. The peak period of 'Makyung' occurred between the 19th and early 20th centuries, although its origins likely date back to a far earlier period. The narratives presented in 'Makyung' theatre embody prehistoric myths and traditions, many originating from the Hindu-Buddhist heritage. Indeed, there are others who argue that 'Makyung' may have originally symbolized the rice deity 'Dewi Sri'. During a performance, the rebab serves as the primary instrument that complements the dancers, vocalists, and spoken narration, while the orchestra also incorporates drums and percussion. Today, the performance of 'Makyung' has ceased in 'Kelantan', Malaysia but occasional performances are organized at 'Akademi Seni Budaya dan Warisan Kebangsaan' (The National Academy of Arts, Culture and Heritage, Malaysia) and 'Istana Budaya' (The National Theatre, Malaysia).

This research is the initial step in determining the distinct features of rebab sound using FFT and spectrogram methods. The project utilized the PicoScope oscilloscope to perform FFT for precise analysis of sound frequencies. The frequency spectrum offers measurable acoustic benchmarks. The rebab is highly regarded for its timbre, like that of a human voice, yet it possesses a quite restricted range, spanning only a little over one octave. The rebab is utilized in a diverse range of musical groupings and genres, in accordance with its extensive dissemination, construction, and playing techniques varying across different regions. Wallaschek (1893) asserts that the bowed rebab instrument originated within the context of Muslim culture. It spread to several locations, particularly Southeast Asia, *via* Islamic commercial channels (Taichi 2020). Rebab is a crucial embellishing instrument in the Indonesian gamelan, adding ornamentation to the fundamental melody. It is composed of a wooden body, often (but not common today) made from a single coconut shell. The front face is covered with a meticulously stretched buffalo intestine. The instrument consists of three brass strings that are tuned to a fifth interval. Unlike current Western stringed instruments, the horsehair bow is knotted loosely, and the right tension is managed by the player's bow hand. This unique setup contributes to the challenging technique required to play the instrument. The rebab is not required to strictly adhere to the scale of the other gamelan instruments and can be played with a certain degree of flexibility, concluding its phrases after the beat of the gong ‘ageng’, which serves as the governing element of the ensemble.

The rebab is a musical instrument with three strings. The origin of this instrument is traced back to the Middle East region (Hardy Shafii and Awang Osman, 2020). It was initially referenced in the 10th century and gained popularity in mediaeval and subsequent Arabic music. During the mediaeval period, the name rebab was commonly used to refer to any instrument that had a bent shape (Britannica 2018). These rebab forms are prevalent in the Middle East, Africa, Central Asia, Northern India, and Southeast Asia. The rebab is a significant musical instrument used to enhance and embellish fundamental melodies in Indonesian gamelan music, often known as 'karawitan' (Becker and Feinstein 2020). The rebab is commonly featured in a traditional performance known as ‘Makyung’ in the southern regions of Thailand and the northern regions of Malaysia. The intensity of this ceremony increases with the sound of the rebab, followed by pipes and gongs. The opening ceremony of the ‘Makyung’ performances pays tribute to these musical instruments. The rebab is the sole musical instrument in the ‘Makyung’ performance that possesses exceptional strength in terms of both intensity and sound quality. The rebab possesses remarkable autonomy as a standalone musical instrument, devoid of any reliance on other instruments. It is a traditional musical instrument that is part of a tiny group of chordophone instruments that are not commonly seen in Southeast Asian music ensembles (Matusky and Tan 1997; Abdul Latif *et al*. 2010).

Rebab is categorized into two distinct categories, each possessing unique qualities based on its playing technique. The 2-string rebab is utilized in gamelan performances in Indonesia. Malaysia has their own cultural legacy and unique identity (Ishak and Nassuruddin 2014). The traditional ‘Malay’ art form known as ‘Wayang Melayu’ is extinct. It used a 2-string rebab instrument. In contrast, ‘Makyung’, ‘Main Puteri’, and ‘Tarik Selampit’ utilize the 3-string rebab instrument (Mat Zain 2015). Rebab holds significant cultural importance in Malaysia, particularly in the regions of ‘Kelantan’ and northern Terengganu. The rebab from this region exhibits a markedly distinct look compared to rebabs from other locations. The instrument consists of three strings, three tuning pegs, a removable headstock with ornamental elements, and a buffalo intestine. The tuning is contingent upon the vocal characteristics of the vocalist. Currently, it is set in place specifically for the goal of education and acquiring knowledge. The highest note is Bb (Bb3 = 0.231 kHz), played on the 1st string (referred to as ‘Cin’ string). The intermediate note is F (F3 = 0.172 kHz) played on the 2nd string. The lowest note is C (C3 = 0.135 kHz), which is played on the 3rd string (known as the ‘Bor’ string).

The rebab is categorized into 10 components, namely head, pegs, neck, strings, a ball of beeswax, body, bridge, buffalo intestine, leg, and fabric used to cover the back (see Fig. 1a). All rebab samples used buffalo intestine on top body. The leg, body, next, pegs holder and head are 6.5, 24, 32.5, 13, and 25 cm, respectively. The total length is 101 cm. The body often used is made of jackfruit wood. The body is hidden beneath a decorative fringing. The bridge and tuning pegs are made from jackfruit wood. The movable bridge is fixed in position during sound collection. The copper strings are from acoustic guitar strings (Ziko). Ziko is a brand of guitar strings and accessories that are known for their quality, durability, and affordability. Ziko guitar strings are made with pure copper wire and are coated with an ultra-thin membrane. They are designed to produce a rich, full-bodied tone with sparkling high-end clarity. Figures 1b, 1c, 1d, and 1e show the front view, back view, side view, and the bow (76 cm) respectively.

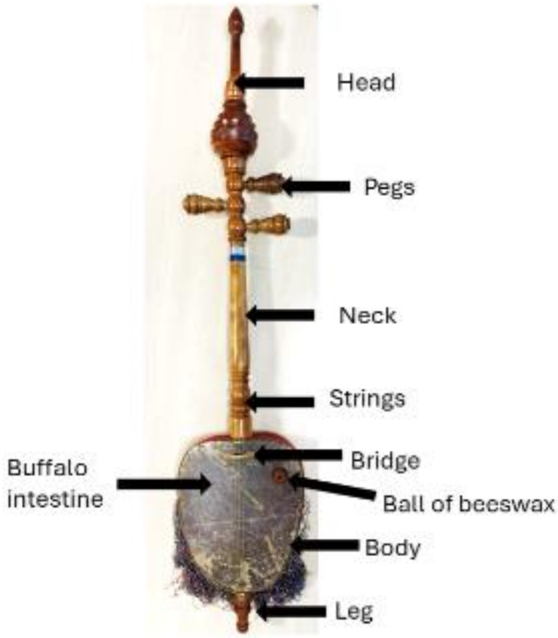


Fig. 1a. The different parts of rebab

Fig. 1b: Front view **Fig. 1c:** Back view **Fig. 1d:** Side view **Fig. 1e:** bow

Concealed behind an ornamental fringe, the body was initially constructed from a coconut shell (and subsequently wood), with a buffalo intestine or bladder firmly wrapped across the front side. Upholstery is employed to envelop the rear. There is a compact movable bridge located on the body. An affixed ball of beeswax near the bridge attenuates the sound reverberations. An elongated wooden foot extends from the base. The rebab is played in an upright position, like a cello. Initially, the bow was suspended using coconut fibers; however, presently it is adorned with horsehair.

The jackfruit (*Artocarpus heterophyllus*) is a species of tree in the Moraceae family (see Fig. 2). It is well-suited to tropical lowlands and is widely cultivated in Philippines, India, Bangladesh, Sri Lanka, Indonesia, Malaysia, and Australia. Botanist Ralph Randles Stewart suggested it was named after William Jack (1795 to 1822), a Scottish botanist who worked for the East India Company in Bengal, Sumatra, and Malaya. 'Nangka' is another name used borrowing from Tagalog related to 'nangkà' in Cebuano and in 'Malay', both from the same Austronesian language family. 'Nangka' has a relatively short trunk and dense treetop. It easily reaches heights of 9 m to 21 m and trunk diameters of 30 cm to 80 cm. The leathery leaf blade is 20 cm to 40 cm long, and 7.5 cm to 18 cm wide. Figure 2 shows the jackfruit tree. The wood of the tree is used for the production of musical instruments. In Indonesia, hardwood from the trunk is carved out to form the barrels of drums used in the 'gamelan', and in the Philippines, its soft wood is made into the body of the 'kutiyapi', a type of boat lute. It is also used to make the body of the Indian string instrument 'veena' and the drums 'mridangam', 'thimila', and 'kanjira' (Chauhan *et al.* 2021). The static coefficient of friction on wood, stainless steel, plywood, and glass is 0.25, 0.20, 0.20, and 0.21, respectively. Jackfruit can experience impact energies of over 8.5 kJ when falling, which is about 50 times greater than a durian.

Fig. 2. Jackfruit tree

EXPERIMENTAL

The time signals obtained from PicoScope oscilloscopes and data recorders for real-time signal acquisition were viewed and analyzed using the PicoScope computer software (Pico Technology, 3000 series, Eaton Socon, Cambridgeshire, England). The PicoScope program facilitates analysis through the utilization of Fast Fourier Transform (FFT), a spectrum analyzer (Pico Technology, 3000 series, Eaton Socon, Cambridgeshire, England), voltage-based triggers, and the capability to save and retrieve waveforms. The schematic diagram of the experimental setup is depicted in Fig. 3a. The 3 rebabs used in this work are shown in Fig. 3b. The sound capture was sufficiently loud to be detected by the signal converter, facilitated by the amplifier (Behringer Powerplay Pro XL, Behringer, Zhongshan, Guangdong, China). The sound spectra were acquired by measurements conducted using a PicoScope. Following the capture and recording of the sound data, the FFT was analyzed using Adobe Audition 2023 (Adobe Inc., version 23.3, San Jose, CA, USA) to determine the dominant frequency for each tone at a certain moment. Fourier transformation is a mathematical technique used to identify fundamentals, harmonics, and subharmonics.

The study was conducted in an anechoic chamber in Universiti Malaysia Sarawak (UNIMAS). The microphone was held above the top surface along the axis of symmetry at 20 cm. In this study, the audio signal derived from the plucking by an expert player was recorded. The audio signal is recorded in mono, at 24-bit resolution and 48 kHz sampling rate. The audio signal was recorded with the aid of a digital audio interface in a .wav format. To ensure the recorded audio signal was at the optimum level, audio signal calibration of the recording system was carried out. A test tone of 1 kHz sine wave was used in calibrating the recording system. Here the “unity” calibration level was at +4 dBu or −10 dBV and was read by the recording device at 0 VU. In this regard, the European Broadcasting Union (EBU) recommended the digital equivalent of 0 VU for the test tone generated to the recording device of the experimentation. This was recorded at −18 dBFS (digital) or +4 dBu (analogue), which is equivalent to 0 VU. In this thorough procedure of calibration, no devices were unknowingly boosting or attenuating their amplitude in the signal chain at the time that the recording was carried out. The recording apparatus was the Steinberg UR22mkII audio interface, Audio-Technica AT4050 microphone, XLR cable (balance), with microphone position on axis, and microphone setting with low cut (flat) 0 dB. The PicoScope computer software was used to view and analyze the time signals from PicoScope oscilloscopes and data loggers for real time signal acquisition. PicoScope software enables analysis using FFT, a spectrum analyzer, voltage-based triggers, and the ability to save/load waveforms to a disc. A typical sound signal (ms *vs* mV) was obtained from the PicoScope oscilloscope, where mV-millivolt is a measure of potential electrical produce by the sound. A typical frequency spectrum (kHz *vs* dBu) was obtained from the PicoScope oscilloscope where dBu-decibel units specifically for measuring voltage. The dBu is dB relative to 0.775 volts such that 0 dBu=0.775 volts. The frequency spectrum displays all the high notes present in the entire sound sample. Peaks indicate dominant harmonic or secondary frequencies in each sound signal waveform. Differences in shape and distribution for each spectrum explain the distinct characteristics of each string.

In this work, the experiment was done by plucking the strings by a professional player to ensure the same plucking parameters were applied for all rebabs. With every attempt, the player employed the same method, applying the same amount of force and angle to the pluck. To minimize variances, the player thoroughly rehearsed the precise plucking motions before the recordings. This methodological rigor reduces the impact of human variability, enhancing the reproducibility and reliability of the experimental outcomes. The placement of the rebab was strategically chosen to optimize sound collection while minimizing interference. To provide a fair comparison, the rebab was all played in the customary sitting position. This position promotes natural sound output and resonance and is most indicative of normal playing circumstances. To capture the authentic acoustic qualities of each rebab, a microphone was positioned in front the rebab at a constant distance and angle during the recording process. This arrangement makes sure that the recordings accurately capture the tonal qualities of all rebabs without adding distortion or bias from different microphone positions.

To ensure durability and dependability, sound data for all rebabs were gathered in numerous rounds. Each rebab was played and recorded under identical settings to minimize any abnormalities or deviations. The rebabs were played in their customary sitting position, and microphones were positioned at the same height and angle in front the player to guarantee that the recordings accurately captured the acoustic qualities of each instrument without adding any bias. Following this, the recordings from these several iterations were averaged to smooth out irregularities and produce a more trustworthy comparison that gave a thorough and accurate depiction of the acoustic characteristics of all rebabs. By utilizing multiple rounds of data collection and averaging the results, the comparison is robust and reliable. This detailed methodology strengthens the validity of the present findings and provides a clear and accurate comparison between all the rebabs.

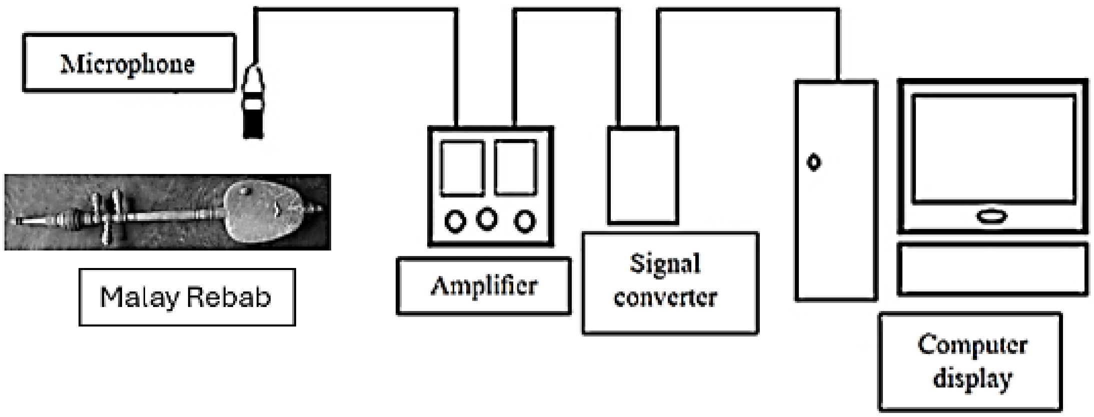


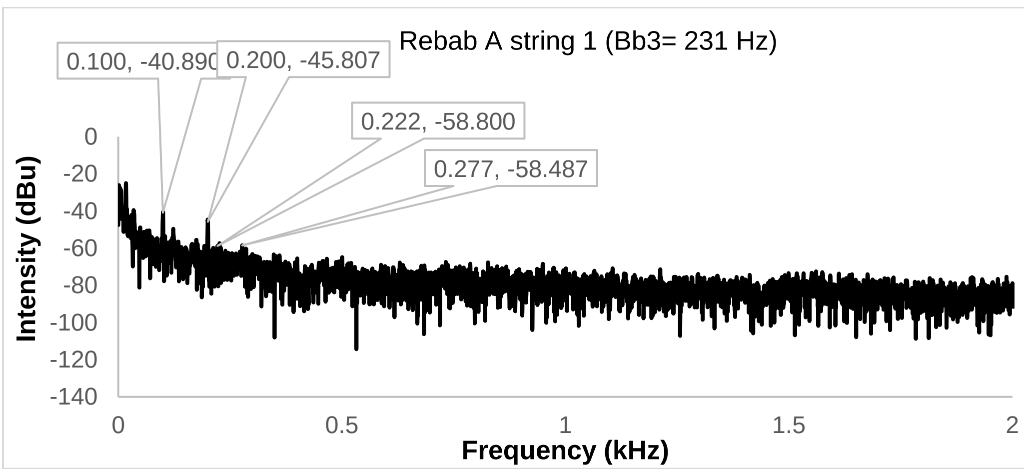
Fig. 3a. Schematic diagram of the experimental setup

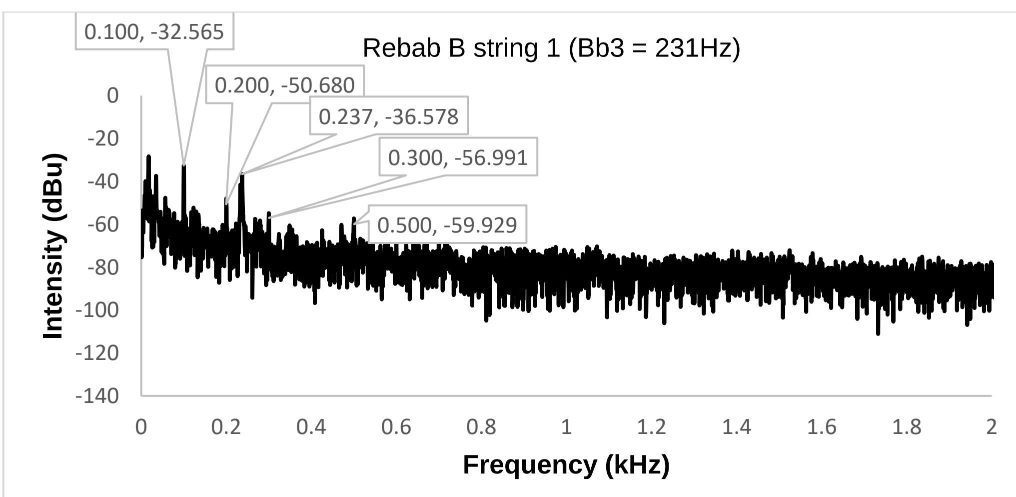
Rebab A Rebab B Rebab C

Fig. 3b. Rebab A, B and C

RESULTS AND DISCUSSION

Figures 4a, 4b, and 4c show the frequency *vs*. intensity of strings 1, 2, and 3, for rebabs A, B, and C. Strings 1, 2, and 3 were tuned to Bb3, F3, and C3, respectively. For string 1, the intended pitch was Bb3 (0.231 kHz), but the fundamental pitch (f0) from the PicoScope measurement were 0.222, 0.237, and 0.224 kHz for rebabs A, B, and C, respectively. Several non-harmonic partials occurred for all rebabs. For string 2, the intended pitch was F3 (0.172 kHz), but the f0 was 0.174, 0.177, and 0.168 kHz for rebabs A, B, and C respectively. The f0 were not reflected as the highest fundamental intensity. Instead, the partials at 0.200, 0.242, and 0.350 kHz appeared to have a higher intensity than the f0. Several non-harmonic partials occurred for all rebabs. For string 3, the intended pitch was C3 (0.135 kHz), but the f0 was 0.125, 0.149, and 0.126 kHz for rebabs A, B, and C, respectively. The f0 also did not reflect the highest fundamental intensity. However, the 1st overtone 0.261 kHz and 0.266 kHz appeared to have a higher intensity than the f0 (0.132 kHz) in rebabs B and C. Several non-harmonic partials occurred for all rebabs. Although the strings were tuned to the intended pitch, the f0 did not show the highest fundamental intensity as shown in all rebabs.





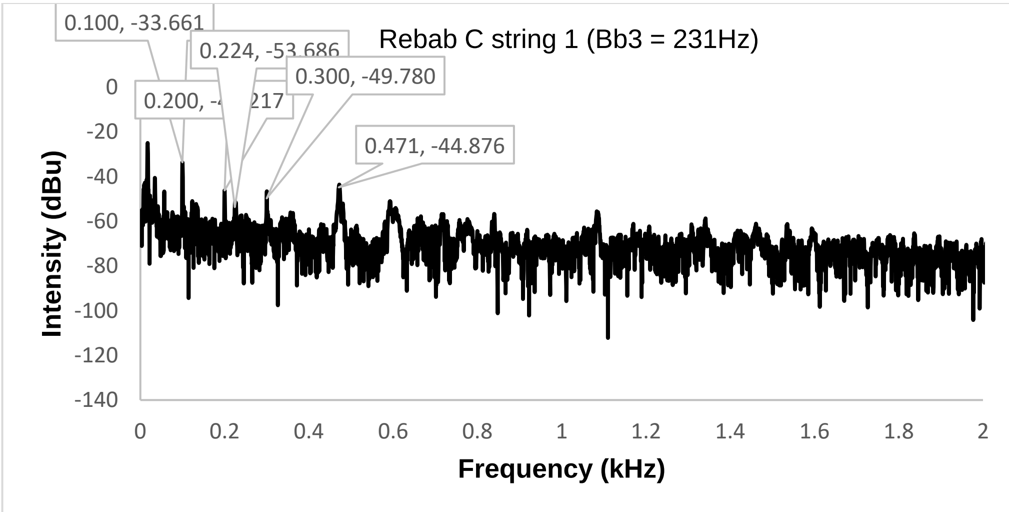
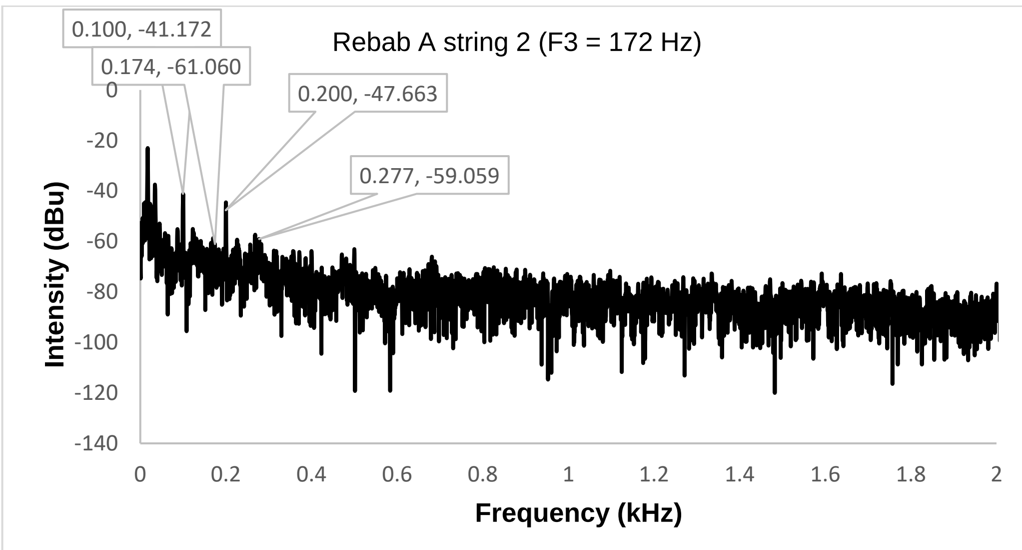
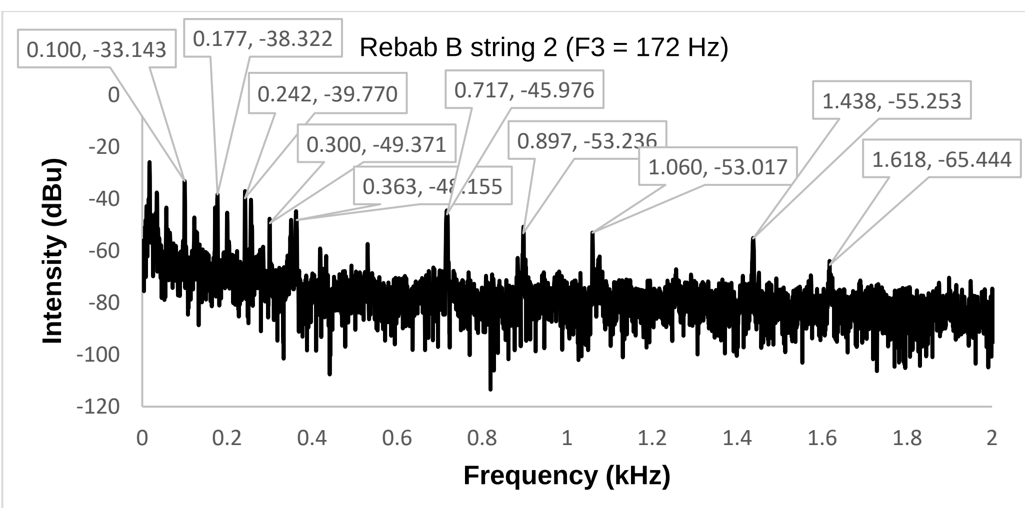


Fig. 4a. The frequency *vs*. intensity of string 1 (Bb3 = 231 Hz) from rebab A, B and C





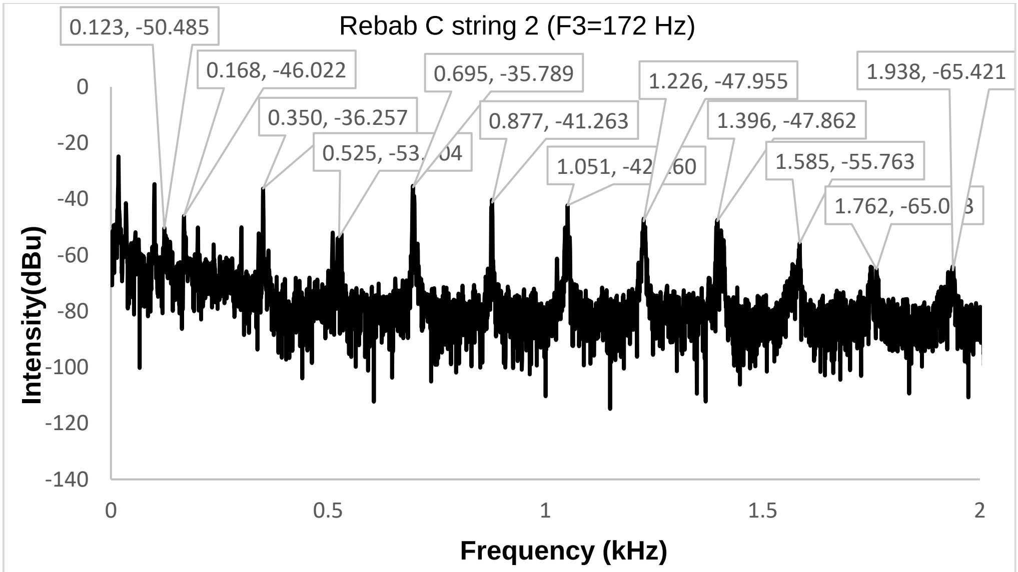
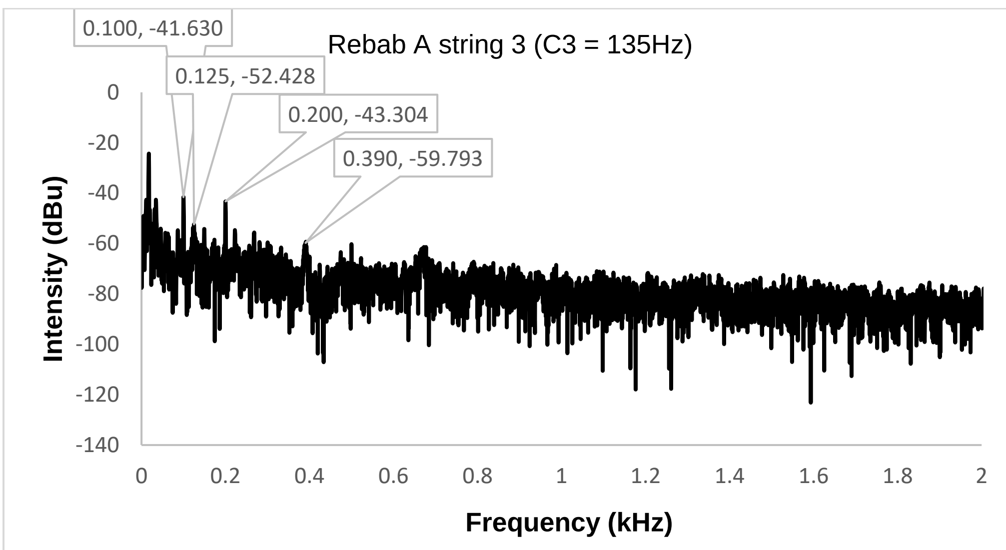
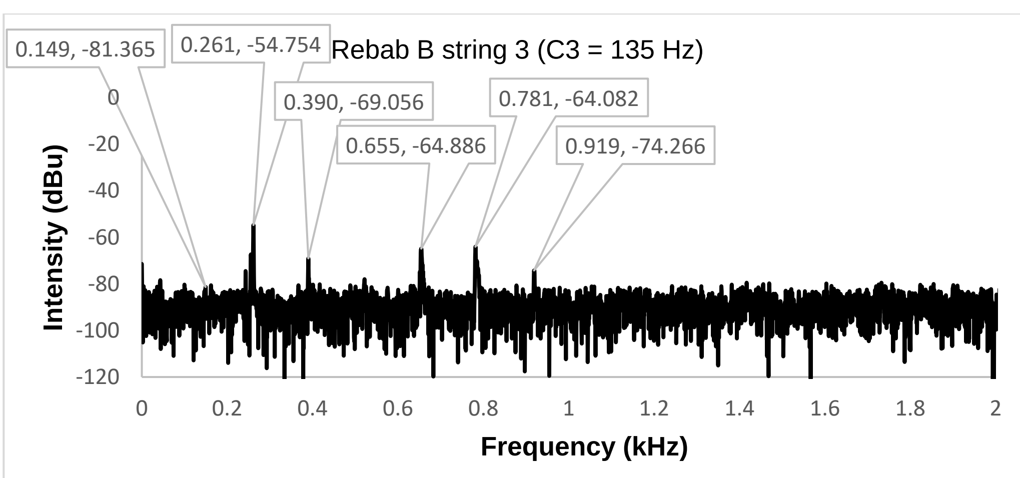


Fig. 4b. The frequency *vs*. intensity of string 2 (F3 = 172 Hz) from rebab A, B and C





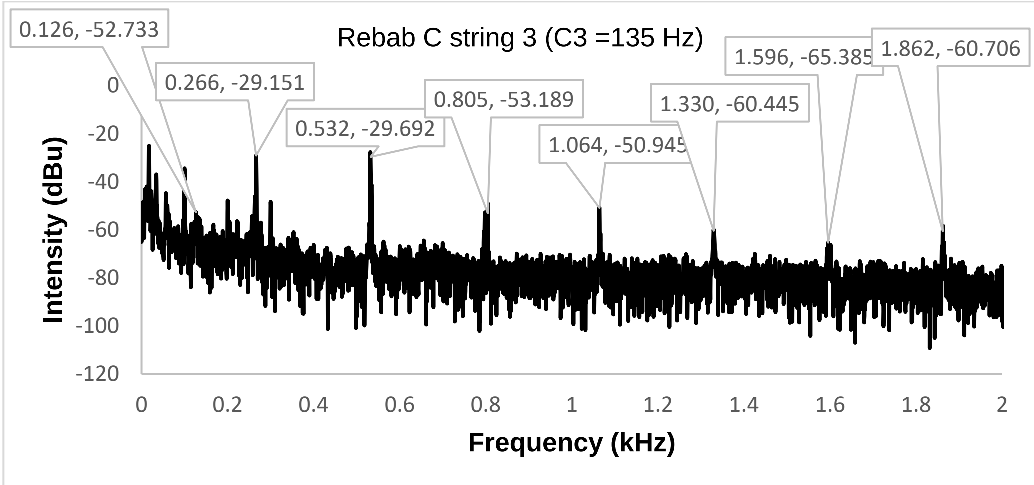


Fig. 4c. The frequency *vs*. intensity of string 3 (C3 = 135 Hz) from rebab A, B and C

Table 1 shows the frequencies for strings 1, 2, and 3 from rebabs A, B, and C. All the strings did not show harmonicity. A harmonic is a sound wave that has a frequency that is an integer multiple of a fundamental tone. The lowest frequency sound that can be produced is the fundamental tone frequency. A non-harmonic partial is any partial that does not match an ideal harmonic. Non-harmonicity is a measure of the deviation of a partial from the closest ideal harmonic, which typically is measured in cents for each partial. Many pitched acoustic instruments are designed to have partials that are close to being whole-number ratios with very low non-harmonicity; therefore, in music theory, and in instrument design, it is convenient, although not strictly accurate, to speak of the partials in those instruments' sounds as harmonics, even though they may have some degree of non-harmonicity. The rebab strings sit on a bridge that is placed on a stretched buffalo intestine. The stretched buffalo intestine is pressed by the bridge in such a way that the strings tension is not fully stable.

Table 1. Frequency (kHz) for string 1, 2 and 3 from rebab A, B, and C

String 1 (Bb3)			String 2 (F3)			String 3 (C3)		
Rebab A	Rebab B	Rebab C	Rebab A	Rebab B	Rebab C	Rebab A	Rebab B	Rebab C
0.100	0.100	0.100	0.100	0.100	0.123	0.100	0.261	0.126
0.200	0.200	0.200	0.174	0.177	0.168	0.125	0.390	0.266
0.222	0.237	0.224	0.200	0.242	0.350	0.200	0.655	0.532
0.277	0.300	0.300	0.277	0.300	0.525	0.390	0.781	0.805
	0.500	0.471		0.363	0.695		0.919	1.064
				0.717	0.877			1.330
				0.897	1.051			1.596
				1.060	1.226			1.862
				1.438	1.398			
				1.618	1.585			
					1.762			
					1.938			

When the string is plucked, the vibration by the strings is not fully stable. The stretched buffalo intestine experiences a small vibration that vibrates the bridge and eventually the string experience vibration, which is not necessarily in harmonics with the f0. This is not significant for the thinner string (as in string 1) with less non-harmonic partials compared with thicker strings (in string 2 and string 3). The frequency range showed that a thinner string vibrates less than a thicker string.

Figures 5a, 5b, and 5c show the spectrograms from Adobe Audition for strings 1, 2, and 3, respectively from rebab A.

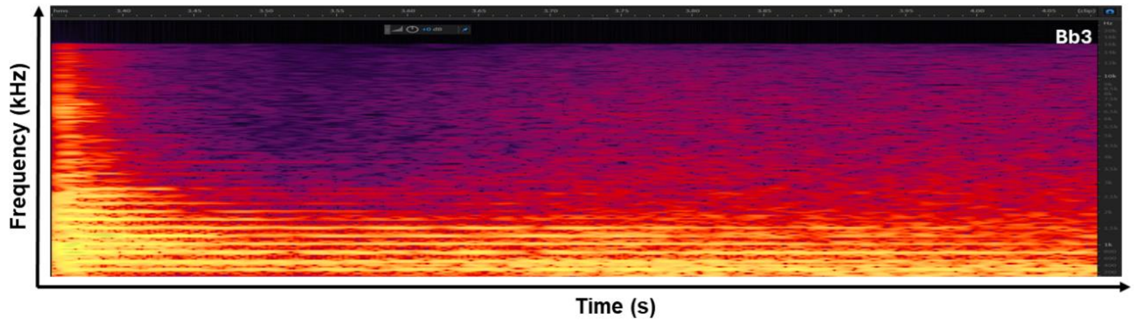


Fig. 5a. The spectrogram from Adobe Audition for string 1 (Bb3) from rebab A

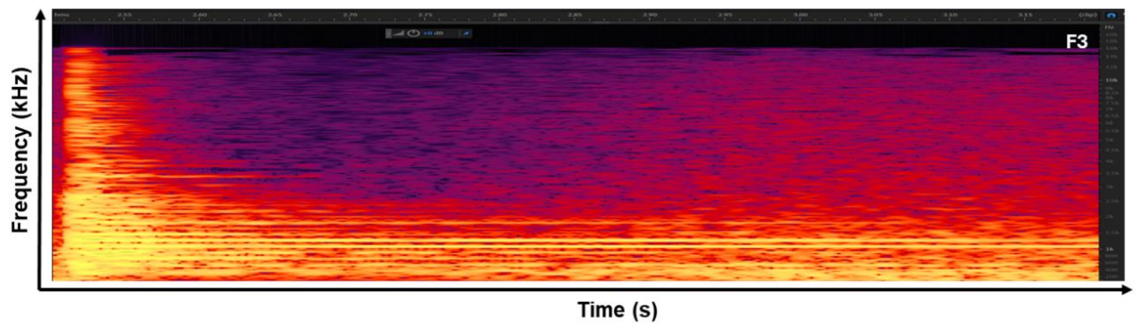


Fig. 5b. The spectrogram from Adobe Audition for string 2 (F3) from rebab A

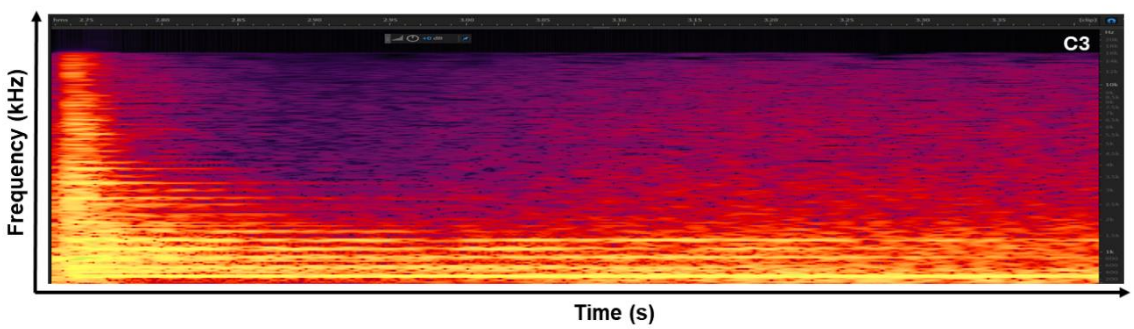


Fig. 5c. The spectrogram from Adobe Audition for string 3 (C3) from rebab A

The results of this study provide a scientific foundation for preserving and understanding the traditional music practices of the Malay rebab. By utilizing Adobe Audition and Fast Fourier Transform (FFT) to document its acoustic characteristics, the study offers a reliable resource for musicians and instrument makers aiming to uphold the instrument's historical sound integrity. These standardized benchmarks also facilitate the revival of diminishing traditions including ‘Main Puteri’ and ‘Tarik Selampit’, ensuring the rebab's original sound quality remains intact during cultural revitalization. Sound preservation is critical to safeguarding the rebab's distinctive timbre and tonal qualities from modern alterations. With shifts in musical preferences and technological advancements, the rebab faces the risk of neglect or distortion. This research enables ethnomusicologists, audio preservationists, and cultural heritage organizations to create high-quality digital recordings that ensure the rebab's legacy endures, even if live performances become rare. Additionally, the study highlights the importance of preserving regional sound variations, such as those from 'Kelantan', Malaysia, to showcase the diversity of this ancient art form.

The study has provided valuable insights for integrating the rebab into modern music ensembles in contemporary contexts. The acoustic profiles are a foundation for adapting the rebab to Western tuning systems and orchestration without compromising its authenticity. Electrically amplified rebabs, for instance, can be designed to emulate traditional tonalities, enabling their inclusion in global music festivals, fusion genres, and even film soundtracks. These adaptations preserve the rebab's cultural identity and enhance its appeal to younger audiences. This research also carries significant implications for education and cultural policy. Music academies can use it to teach students about the rebab's construction, performance techniques, and acoustic qualities. Cultural policymakers can leverage the findings to support initiatives balancing preservation and modernization, such as funding rebab performances, promoting their role in cultural events, and assisting artisans in crafting traditional instruments. By addressing these practical aspects, the study ensures the Malay rebab remains a vibrant and evolving tradition, bridging the gap between historical reverence and modern relevance.

By providing multiple perspectives to comprehending the rebab's acoustic and physical characteristics, the signal collection and analysis serve as an essential resource for furthering the digital preservation of the rebab. This study generates a thorough dataset by looking at the components used in its creation, including the kind of wood, skin membrane, and strings. This dataset is crucial for both recording the current state of the rebab and supporting cutting-edge machine learning (ML) and artificial intelligence (AI) applications. By modeling the rebab's physical and acoustic properties using this data, these tools enable users to experiment with new instrument design and virtual performance possibilities. Recent studies in ethnomusicology have emphasized the need for digitizing traditional musical instruments to ensure their longevity and accessibility. For example, projects that combine high-resolution imaging, acoustic measurements, and ML have successfully reconstructed the sounds of lost instruments like ancient lyres or early pianos. Incorporating references to such efforts would highlight how this study aligns with global trends in preserving and modernizing intangible cultural heritage. By sitting this work within the broader narrative of digital preservation, the study not only underscores its ethnomusicological relevance but also positions the rebab as a pioneering example in bridging tradition and technology. Taking the rebab to the next step-through AI, immersive design, and virtual interaction-ensures its continued resonance in both historical and contemporary music-making contexts.

CONCLUSIONS

1. For string 1, the intended pitch was Bb3 (0.231 kHz), but the fundamental pitches (f0) from the PicoScope measurement were 0.222, 0.237, and 0.224 kHz for rebab A, B, and C, respectively.
2. For string 2, the intended pitch was F3 (0.172 kHz), but the f0 was 0.174, 0.177, and 0.168 kHz for rebabs A, B, and C, respectively.
3. For string 3, the intended pitch was C3 (0.135 kHz), but the f0 was 0.125, 0.149, and 0.126 kHz for rebabs A, B, and C respectively.
4. All the strings did not show harmonicity.
5. This dataset is crucial for both recording the current state of the rebab and supporting cutting-edge machine learning (ML) and artificial intelligence (AI) applications. By modeling the rebab's physical and acoustic properties using this data, these tools enable users to experiment with new instrument design and virtual performance possibilities. Within the broader narrative of digital preservation, the study not only underscores its ethnomusicological relevance but also positions the rebab as a pioneering example in bridging tradition and technology. Taking the rebab to the next step-through AI, immersive design, and virtual interaction-ensures its continued resonance in both historical and contemporary music-making contexts.

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REFERENCE CITED

Abdul, L. A., Kechot, A. S., and Baharuddin, S. A. (2010). "Identiti rebab di alam Melayu [The identity of the fiddle in the 'Malay' world]," (https://www.scribd.com/doc/39638983/IdentitiRebab-Di-Dalam-Melayu), Accessed on 01 Sept 2024.

Becker, J., and Feinstein, A. H. (2020). *Karawitan: Source Readings in Javanese Gamelan and Vocal Music*, University of Michigan Press, Ann Arbor, MI, USA.

Britannica, E. (2018). "Rebab," (https://www.britannica.com/art/rebab), Accessed on 01 Sept 2024.

Chauhan, C., Singru, P. M., and Vathsan, R. (2021). "The effect of the extended bridge on the Timbre of the Sarasvati Veena: A numerical and experimental study," *J. Meas. Eng*. 9(1), 23-35. DOI: 10.21595/jme.2020.21712. ISSN 2335-2124.

Hamdan, S., Said, K. A. M., Musib, A. F., Rahman, M. R., Sawawi, M., and Sinin, A. E. (2024). "Pratuokng: The Borneo bamboo zither of Bidayuh Sarawak," *BioResources* 19(1), 1305-1315. DOI: 10.15376/biores.19.1.1305-1315.

Hamdan, S., Said, K. A. M., Rahman, M. R., Sawari, M., and Sinin, A. E. (2023). "Borneo lute 'sape': The frequency spectrum and time frequency analysis (TFA)," *BioResources* 18(4), 6761-6771, DOI: 10.15376/biores.18.4.6761-6771.Mat, Z. Z. (2015). *Pengenalan Asas Rebab 'Kelantan' [Basic Introduction for*

Rebab 'Kelantan'], Doctoral Thesis, Universiti Pendidikan Sultan Idris, Tanjung Malim, Malaysia.

Hardy Shafii A. S., Awang Osman J. (2020). *Structure Dialectics of Makyung in Yala, Heritage*, New Straits Times, Kuala Lumpur, Malaysia.

Ishak, S., and Nassuruddin, M. G. (2014). "Traditional 'Malay' healing practices: Expressions of cultural and local knowledge," *Procedia Soc. Behav. Sci.* 140, 291-294. DOI: 10.1016/j.sbspro.2014.04.422

Mat Zain, Z. (2015). *Pengenalan Asas Rebab Kelantan (Basic Introduction to Rebab Kelantan)*, Master's Thesis, Universiti Pendidikan Sultan Idris, Malaysia.

Matusky, P., and Tan, S. B. (1997*). Muzik Malaysia: Tradisi klasik rakyat dan sinkretik [The Music of Malaysia: The Classical, Folk and Syncretic]*, UM Press, Kuala Lumpur, Malaysia.

Mohd, Y. (2018). "Pemuliharaan warisan budaya melalui perundangan warisan dan agensi pelaksana di Malaysia [Conservation of cultural heritage through inheritance law and implementing agency in Malaysia]," *Jurnal Melayu* 17(2), 143-159. ISSN 1675-7513

Sinin, A. E., Hamdan, S., Said, K. A. M., Abdul Aziz, D. S., and Musib, A. F. (2023). "Acoustics of the forgotten 'tapi' two-strings lute of Lun Bawang," *BioResources* 18(4), 7905-7914. DOI: 10.15376/biores.18.4.7905-7914.

Sinin, A. E., Hamdan, S., Said, K. A. M., Muzib, A. F., Kamarudin, K. A. D., and Hasnan, H. H. (2025). "Acoustic characteristics of bamboo-based guitar-A case study," *BioResources* 20(1), 140-154. DOI: 10.15376/biores.20.1.140-154.

Taichi, A. (2020). *Applying Flow Theory to Strings Education in P-12 and Community Schools: Emerging Research and Opportunities: Emerging Research and Opportunities*, IGI Global, Okayama, Japan.

UNESCO (2003). "Convention for the safeguarding of the intangible cultural heritage," UNESCO, (https://www.unesco.org/en/legal-affairs/convention-safeguarding-intangible-cultural-heritage), Accessed on 01 Sept 2024.

Wallaschek, R. (1893). "Primitive music: An inquiry into the origin and development of music, songs, instruments, dances, and pantomimes of savage races," *Nature* 48, 290-291. DOI: 10.1038/048290a0

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