Acoustic analysis on the voice of choir singers using Spectroid

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Abstract. This study was conducted based on interdisciplinary approach, physics, and vocal music science, it could be used as an alternative activity to support student learning about a sound wave. The aim of this study was to analyze the voices of the school choir singers using Android App namely Spectroid... The result showed that 16 of 18 singers had been in the right position based on their type of voice. There are two singers had not been in the right position because they positioned in a bass group which their voice could not reach the minimum limit of Bass frequency. The Soprano group which had the frequency range 148.6 Hz-1045.6 Hz, 6 of 8 singers could be in mezzo-soprano and 4 of them could be in Alto. The Tenor group (96.4 Hz-697.0 Hz), 1 of 2 singers could be in Baritone but both of them could not be in Bass. The Bass group (81.4 Hz – 493.8 Hz), 2 of 4 singers are true Bass but all of them could be in Baritone and 1 of them could be in tenor. All of 4 singers in Alto group (171.2 Hz-702.0 Hz), only positioned in Alto.

1. Introduction
School choir is one of extra-curricular activities that has been favoured by students, although they sing in a group, each of them has own sounds characteristic. The sounds are produced by the physical system, the vocal human track [1], which modulates the pitch of the voice [2], so that every people, include the choir singers, have different characteristic of the sounds.

There are several studies related both to acoustic analysis of human voice and musical instruments, such as the Acoustical characteristics study that conducted on the voice of school teachers in Iran [3], also there are studies to compare the experimental results of Bonang Barung waves superposition simultaneously and mixing using Audacity and MATLAB [4] and to measure the sound intensity produced angklung using a sound level meter [5].

The study of acoustic has both physical and vocal science side. Acoustic is a part of physics science that related to sound study. The acoustic waves, also known as sound waves, are longitudinal waves since the elements of their medium move in a direction that parallel to the direction of the wave propagation [6]. The propagation of the sounds is affected by the laws of mechanics and the properties of the medium [7]. Harmonic sound waves occur when air molecules oscillate with simple harmonic motion around their equilibrium due to the vibrational sound source such as a person’s vocal folds in the larynx [8] and have a sinusoidal pattern of displacement [9]. The sinusoidal waves are characterized by their amplitude, frequency, and phase as shown by the harmonic sound wave function (1) [10].
\[ s(x,t) = s_{\text{max}} \sin \left( \frac{2\pi}{\lambda} x - 2\pi ft \right) = s_{\text{max}} \sin(kx - \omega t) \]  

where \( s(x,t) \) is the displacement of the molecules from equilibrium that cause the change of density and pressure of the air (\( m \)), \( \lambda \) is the wavelength (\( m \)), \( f \) is the wave frequency (Hz) that corresponds to the pitch of sound and this is the main parameter to classify the voice, \( s_{\text{max}} \) is amplitude (\( m \)) that affects to the loudness of the sound as described in equation (2) [11].

\[ I = \frac{E}{A} = \frac{1}{2} \rho v (\omega s_{\text{max}})^2 \]  

where \( I \) is the intensity of the sound (\( W/m^2 \)) that corresponds to the sound level in decibel (dB), \( E \) is the energy of the wave, \( A \) is unit the area that passed by the energy, \( \rho \) is the density of the medium and \( v \) is the speed of the sound in the air. Thus, the intensity of the sound wave is proportional to the amplitude and the energy, also inverse to the wide of an area. The greater the amplitude, the bigger the intensity of the sound wave, so that the sound is louder.

In the vocal science side, the voice of choir singers is classified into the vocal types based on the vocal range frequencies [12], as shown in table 1. Like other studies on acoustic analysis, this study compared those required pitch range with a maximum frequency range that can be reached by participants, respect to the fundamental frequency (F0) [13][14].

| Types of Sound | Gender (M/F) | Range Vocal | Frequency (Hz) |
|----------------|--------------|-------------|----------------|
| Soprano        | F            | C4-C6       | 261.626 – 1046.50 |
| Mezzo-Soprano  | F            | A3-A5       | 220.000 – 880.000 |
| Alto           | F            | F3-F5       | 174.614 – 698.456 |
| Tenor          | M            | C3-C5       | 130.813 – 523.251 |
| Baritone       | M            | F2-F4       | 87.3071 – 349.228 |
| Bass           | M            | E2-E4       | 82.4069 – 329.628 |

The very now students are part of the digital generation and very open to technology such as smartphone although most of them just use it for both communication tools and social-network media purposes [15], therefore, using a smartphone as learning media is an interesting thing to do [16]. Current smartphones have offered many utilities such as GPS, light sensor, and sound measurement application that draw attention from people such as educators, acoustic and environmental researchers [17]. Some educators even developed their own apps that help the student engagement with a sound wave in the physics classroom [18]. Spectroid is one of the Android apps and a real-time audio spectrum analyzer with reasonable frequency resolution across the entire frequency spectrum. It is able to capture the frequency of sound with the greatest intensity. The aim of this study is to analyze and classify the voice types of the school choir singers. The procedure also has the potential to be developed as a physics student activity.

2. Method

This study used repeated data retrieval method. The participants consisted of 18 singers of the senior high school choir in Mojoagung, Jombang. The research participants were asked to sound vowels within the lower threshold of the type of their voice (such as soprano, etc) assisted with MIDI piano-keyboard app to find the intended sound. For example, if the participant was a soprano singer, she was asked to sound vowel /a/ for five times within the lower threshold frequency of soprano type which is around
261 Hz (C4 tone frequency), then they sounded it within frequencies that are lower and higher than the threshold to get the lowest and highest frequencies they could reach. This data was taken from the vowels only because they are produced due to vibrations in the vocal cords without the constriction of the vocal tract and sounded with the open mouth [19]. The vowels sounds have a longer duration pronunciation than consonant and clearer so that they are easier to recognize and analyze [20].

The sounds frequencies generated by the participants were monitored by Spectroid to ensure the participants were at the right tone frequency and captured. The distance between smartphone speaker and the mouth of the participant should have been constant and not been too far (± 8 cm) because Spectroid displayed the frequency of the loudest sound automatically. The procedure was repeated on other vowels /a/, /u/, /e/, /o/. From the data, the mean of frequency $\bar{f}$ is given as the sum of frequency $f_i$ divided by the number of repetitions $N$ as shown at equation (3) [21].

$$\bar{f} = \frac{1}{N} \sum_{i=1}^{N} f_i \quad (3)$$

### 3. Results and Discussions

The coach classified the choir members into 4 groups of voice types, namely soprano, alto, tenor and bass. To test whether Spectroid is feasible to be used as a frequency measurement instrument, it had been compared to the Audacity software (installed on the laptop) since it is well-known as a sound measurement tool. The result showed that Spectroid can read the sound frequencies as good as the Audacity software.

#### 3.1. Group of Soprano (consisting of eight participants)

Soprano is a type of female voice with a high tone frequency (261.626 – 1046.50 Hz). The results of the measurement of the sound frequency of the soprano group are delivered in table 2.

| Participant | Vowel /a/ | Vowel /u/ | Vowel /ø/ | Vowel /e/ | Vowel /o/ |
|-------------|-----------|-----------|-----------|-----------|-----------|
| S1          | 246.4     | 260.0     | 697       | 264.4     | 270.6     |
| S2          | 175.2     | 256.6     | 1034      | 175.8     | 1045      |
| S3          | 222.8     | 260.4     | 781.4     | 219.2     | 257.6     |
| S4          | 148.6     | 262       | 986.2     | 150.4     | 263.8     |
| S5          | 177.8     | 266       | 870.6     | 175.8     | 269       |
| S6          | 194.4     | 261       | 787.2     | 194.6     | 261       |
| S7          | 218       | 263       | 700.8     | 220.4     | 262.4     |
| S8          | 263.6     | 263.6     | 696.4     | 263.4     | 263.4     |

The data explains the frequency distribution of the participants namely S1-S8. There are three frequencies measured, the lowest (L) frequency, a threshold (T) and highest (H). The lowest data (L) shows the lowest frequency that can be achieved by a soprano. The threshold data (T) is the frequency that had been sounded by the participants around the lower threshold of a soprano. When a soprano singer can reach the sound at this frequency, it shows that she has met the criteria for the type of soprano voice.

The highest data (H) shows the highest sound frequency that can be achieved by a singer. The lowest and highest frequency is different among the soprano singers because this occurs due to various
factors such as the amount of training and talent [22]. Comparing the frequency data in table of each vowels, it is known that the soprano singers have a stable frequency on the measured frequency, for example, the lowest frequency of participant 1 (S1) on /a/, /i/, /al/, /e/, and /o/ are 246.4 Hz, 246.4 Hz, 247.8 Hz, 244.4 Hz and 247.0 Hz. From table 2, we can analyze that S1 had the shortest vowel range, so she would not comfortably sing songs on very high notes. Otherwise, S2 had the greatest tone range. The lowest frequency that could be reached by her was on the lower threshold of the alto so she was also able to sing well as a mezzo-soprano and alto singer. Judging from the criteria for the frequency threshold of each type of sound, the result of the soprano group analysis is simply described in table 3.

**Table 3. Results of the analysis of soprano singers**

| Participant | Soprano | Mezzo Soprano | Alto |
|-------------|---------|---------------|------|
| S1          | ✓       |               | ✓    |
| S2          | ✓       | ✓             | ✓    |
| S3          | ✓       | ✓             | ✓    |
| S4          | ✓       | ✓             | ✓    |
| S5          | ✓       | ✓             | ✓    |
| S6          | ✓       | ✓             | ✓    |
| S7          | ✓       | ✓             | ✓    |
| S8          | ✓       |               | ✓    |

3.2. **Group of Tenor (consisting of two participants)**
Tenor is a type of male voice with a high tone frequency (130.813 – 523.251 Hz). Data from the measurements of vowel tenor singers are shown in table 4.

| Participant | Vowel /a/ | Vowel /i/ | Vowel /u/ | Vowel /e/ | Vowel /o/ |
|-------------|-----------|-----------|-----------|-----------|-----------|
| T1          | 107.6     | 128.2     | 693       | 108.2     | 129.2     |
| T2          | 96.8      | 131.8     | 440.4     | 96.4      | 131.6     |

All participants could meet the lowest threshold tenor. We can see that T1 has the longest vowel range. For a tenor, the highest frequency is important, because he sings all kinds of high pitch song. T1 could not sing comfortably as a baritone singer because he only reached a few frequencies below the tenor threshold. That was different from T2, although the highest frequency that could be achieved was not as high as participant 1, he had a minimum frequency that was lower than T1. T2 could be a baritone singer if needed and sang more comfortably than T1 within the note. Judging from the criteria for the frequency threshold of each type of sound, the results of the analysis of the tenor group can be seen simply in table 5.

**Table 5. Results of the analysis of Tenor singers**

| Participant | Tenor | Baritone | Bass |
|-------------|-------|----------|------|
| T1          | ✓     |          | ✓    |
| T2          | ✓     | ✓        | ✓    |
3.3. *Group of Bass (consisting of four participants)*

Bass is a type of male voice with a low tone frequency (82.4069 – 329.628 Hz). Data from the measurement of the voices of bass singers are shown in table 6. Thus, we see that only two of the four bass singers, B1 and B2, were able to reach the lower bass threshold. The measurement of the sound frequency in the bass group was only repeated by two times because the lower bass threshold was also the lowest tone that could be reached by the participants. The highest frequency of B2 reached the tenor zone, he could be a fine tenor singer. B3 and B4 were actually baritone singers because their lowest voice frequency was at the threshold of baritone instead of bass.

**Table 6. Frequencies of voices of Bass singers (Hz)**

| Participant | Vowel /a/ | Vowel /i/ | Vowel /u/ | Vowel /e/ | Vowel /o/ |
|-------------|-----------|-----------|-----------|-----------|-----------|
|             | L         | T         | H         | L         | T         | H         | L         | T         | H         | L         | T         | H         |
| B1          | 81.6      | 81.6      | 217       | 81.4      | 81.4      | 218.6     | 82        | 82        | 215.6     | 81.6      | 215.6     | 82.2      | 82.2      | 217.6     |
| B2          | 82.6      | 82.6      | 191.4     | 82.8      | 82.8      | 197.2     | 83.6      | 83.6      | 193.2     | 83        | 83        | 192.8     | 83.4      | 193.2     |
| B3          | 87.8      | 87.8      | 491.2     | 89.2      | 89.2      | 490.6     | 88.2      | 88.2      | 492.8     | 89.8      | 89.8      | 492.2     | 87.4      | 492.8     |
| B4          | 94.4      | 94.4      | 176       | 96.2      | 96.2      | 176.6     | 97        | 97        | 175.2     | 95.6      | 177.4     | 97        | 97        | 174.6     |

The school choir was only divided into 4 groups namely soprano, alto, tenor and bass, therefore those two baritone singers were included in the bass group. B3 has a very large voice range so he can sing as a tenor very well. B4 was a true baritone because his voice was not able to reach the lowest bass threshold. Judging from the threshold criteria for the frequency of each type of voice, the results of the bass group analysis is delivered in table 7.

**Table 7. Results of the analysis on Bass singers**

| Participant | Position on the choir group |
|-------------|----------------------------|
|             | Tenor | Baritone | Bass   |
| B1          | -     | √        | √      |
| B2          | √     | √        | -      |
| B3          | -     | √        | -      |
| B4          | -     | √        | -      |

3.4. *Group of Alto (consisting of four participants)*

Alto is a voice type of female singer which has a frequency range from 174.614 – 698.456 Hz. The Data of frequency measurement results of alto’s voice is displayed in table 8. All of the participants had the lowest sound frequency at the lower threshold so that the two measurements were taken. A1, A2, and A4 had sound frequency ranges that were exactly the same as the frequency range of alto voice. Those participants were alto singers with a consistent low tone. A3 had a wider range than others and she could sing above the maximum frequency but all of the alto singers remained alto.

**Table 8. Frequencies of voices of Alto singers (Hz)**

| Participant | Vowel /a/ | Vowel /i/ | Vowel /u/ | Vowel /e/ | Vowel /o/ |
|-------------|-----------|-----------|-----------|-----------|-----------|
|             | L         | T         | H         | L         | T         | H         | L         | T         | H         | L         | T         | H         |
| A1          | 178       | 178       | 700.8     | 178       | 178       | 695.2     | 176.8     | 176.8     | 697.6     | 176.6     | 176.6     | 702      | 176.2     | 176.2     | 698.6     |
| A2          | 171.4     | 171.4     | 702       | 173.6     | 173.6     | 697.6     | 173.4     | 173.4     | 699.6     | 171.2     | 171.2     | 701      | 174.2     | 174.2     | 698.4     |
| A3          | 175.8     | 175.8     | 787       | 173.2     | 173.2     | 786       | 174.2     | 174.2     | 787       | 175.2     | 175.2     | 784      | 174.8     | 174.8     | 783       |
4. Conclusion
Based on the analysis, it confirms that 16 of the 18 research participants had been in the correct type of voice group based on the threshold frequency limit rule. However, two participants from the bass group whose sound frequency could not reach the lower threshold of the bass because there was no baritone group in school. The two participants were then included in the group of bass. From eight participants in the soprano group, there were six participants who could be in mezzo-soprano position and four people in alto position. One of the participants in the tenor group could be in both bass and baritone. Two of four participants in the bass group, only two singers were actually in the bass position, one in the tenor position but all of them could be in baritone position. All of the alto singers can only sing as alto singers.

References
[1] C. Bickley and S. Hunnicutt, “Acoustic Analysis of Laughter,” in Proceedings of the International Conference on Spoken Language Process (Volume 2), 1992.
[2] R. J. Zatorre and S. R. Baum, “Musical melody and speech intonation: Singing a different tune,” PLoS Biol., vol. 10, no. 7, p. 5, 2012.
[3] A. Dehghan and R. C. Scherer, “Acoustic analysis of voice: Iranian teachers,” J. Voice, vol. 27, no. 5, p. 655.e17-655.e21, 2013.
[4] L. Widayanti and Y. Pramudya, “Perbandingan hasil eksperimen superposisi gelombang bunyi Bonang Barung secara simultan dan mixing berbantuan Audacity dan MATLAB,” Spektra J. Fis. dan Apl., vol. 2, no. April, pp. 61–66, 2017.
[5] R. S. Hartanti and B. Astuti, “Analysis of Angklung Sound Intensity as a Acoustic Instrument,” Nat. Sci. Math. Res., vol. 2, no. 1, pp. 122–126, 2016.
[6] R. A. Serway, J. S. Faughn, C. Vuille, and C. A. Bennet, College Physics, Seventh ed. Thomson, 2006.
[7] R. Feynman, R. Leighton, and M. Sands, Feynman Lectures on Physics Volumes 1, 2, 3, Third ed. California Institute of Technology, 2013.
[8] D. Ross, J. Choi, and D. Purves, “Musical intervals in speech,” Proc. Natl. Acad. Sci., vol. 104, no. 23, pp. 9852–9857, 2007.
[9] J. M. Hillenbrand, “The Physics of Sound.” Western Michigan University, pp. 1–44, 2016.
[10] A. P. Tipler and G. Mosca, Physics for scientist and engineers, Fifth ed. 2004.
[11] R. A. Serway and J. W. Jewett, Physics for scientist and engineers, Sixth ed. 2004.
[12] I. Wijayanto and R. Dwifebrianti, “Jenis Tipe Jangkauan Suara Pada Pria Dan Wanita Menggunakan Metoda Mel-Frequency Cepstral Coefficient,” in Konfrensi Nasional Sistem dan Informatika, 2013, no. October 2013, p. 9.
[13] J. P. Teixeira, C. Oliveira, and C. Lopes, “Vocal Acoustic Analysis – Jitter, Shimmer and HNR Parameters,” Procedia Technol., vol. 9, pp. 1112–1122, 2013.
[14] C. T. Herbst, E. Duus, H. Jers, and J. G. Svec, “Quantitative Voice Class Assessment of Amateur Choir Singers: A Pilot Investigation,” Jircs, vol. 4, no. 1, pp. 47–59, 2012.
[15] K. Anwar, D. Rusdiana, I. Kaniawati, and I. T. B. Viridi, Sparisoma (Nuclear Physics and Biophysics Research Division, “Pemanfaatan Applikasi Smartphone Android sebagai Media Belajar Fisika,” in Seminar Nasional Quantum, 2016, no. 229, pp. 71–82.
[16] M. Á. González et al., “Mobile phones for teaching physics,” Proc. Second Int. Conf. Technol. Ecosyst. Enhancing Multicult. - TEEM ’14, pp. 349–355, 2014.
[17] C. A. Kardous and P. B. Shaw, “Evaluation of smartphone sound measurement applications ( apps ) using external microphones—A follow-up study,” J. Acoust. Soc. Am., vol. 140, no. 4, p. EL327-EL333, 2016.
[18] S. H. Hawley and R. E. McClain Jr., “Visualizing Sound Directivity via Smartphone Sensors,” Phys. Teach., vol. 56, no. 2, pp. 72–74, 2018.
[19] A. E. Fahrudin, N. R. Diyanti, and T. N. Manik, “Identifikasi Suara Vokal Suku Banjar Berdasarkan Frekuensi Formant,” *J. Fis. FLUX*, vol. 8, no. 2, pp. 175–181, 2011.

[20] N. Rezaei and A. Salehi, “An Introduction to Speech Sciences (Acoustic Analysis of Speech),” *Iran. Rehabil. J.*, vol. 4, no. 4, pp. 5–14, 2006.

[21] D. K. R. Bevington, Philip R., *Data reduction and error analysis for the physical sciences*, Third ed. New York: McGraw-Hill, 2003.

[22] M. L. D. Deroche, C. J. Limb, M. Chatterjee, and V. L. Gracco, “Similar abilities of musicians and non-musicians to segregate voices by fundamental frequency,” *J. Acoust. Soc. Am.*, vol. 142, no. 4, pp. 1739–1755, 2017.