*Fractal analysis of Finch song waveforms with application to Affective Computing*

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*Abstract*—The Munia finch and a Bengalese finch song waveforms were analyzed for information complexity in terms of the percent increment fractal dimension and Shannon information entropy. The percent increment measures the change of signal as a dimensionless variable. A fighter jet sonic boom waveform encountered in mechanical engineering was performed to illustrate the fractal computation. The project found that the studied Bengalese finch song waveform segments exhibited higher fractal dimension and Shannon entropy values when comparted the studied Munia finch segments. The information complexity analysis approach in affective computing is discussed.

Keywords—component; formatting; style; styling; insert (key words)

# Introduction (*Heading 1*)

This paper addresses the question of information complexity contained in Finch song waveforms, published in Science [1]. Information complexity has been studied using fractal analysis [2, 3]. The Shannon information entropy was studied in the percent increment series generated from a waveform, in analogous to the application of volatility analysis with stock data in financial engineering [4]. The differential of log (y) in calculus notion, or delta-y divided by y in algebraic notion, is used to generate the percent increment series from a data function (y = f(x)) in an application. A military jet generated sonic boom waveform, encountered in mechanical engineering, ionosphere assisted transmission, etc., was used to illustrate the approach [5, 6]. The quantification of aesthetic values in affective computing is also discussed with applications.

# MATERIALS AND METHODS

## Materials

The Finch song waveforms were downloaded from Science News section website [7]. The NASA fighter jet waveform was downloaded from NASA website [8].

## Methods

The Higuchi fractal method of a function with equal x-axis increments can be used to extract fractal dimension value of a data series [9]. Basically a fractal length was generated by the difference of two signals at a given lag with the lag concept similar to the customarily usage in correlation analysis. Higuchi derived a simple method such that a regression fit of the fractal length versus lag would give the fractal dimension value. Higuchi showed that a Gaussian noise infinite series would have a fractal dimension of 1.5 while a uniform random white noise infinite series would carry a fractal dimension of 2.0. Note that a constant infinite series carries a fractal dimension of 1.0. A histogram carries the occurrence frequency information such that an occurrence can be treated as probability “p” in the computation of Shannon entropy using the p\* log (p) formulation.

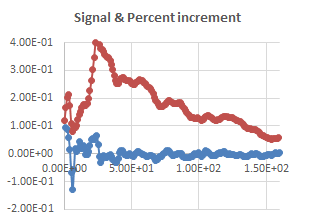
# RESULTS AND DISCUSSION

An analysis was performed on sonic boom waveform to reveal some details of the sound waveform made by a fighter jet, shown in Figure 1.



1. NASA fighter jet sonic boom wav-file shown as a waveform.

The waveform around the first peak was analyzed using the percent increment variable, which is (delta-y)/ y in algebra or d (log(x) in calculus, shown in Figure 2. The percent increment series would contain the fluctuation information in the sonic boom with some relationships to physical processes. One objective of signal processing is to unravel as much as possible the information embedded in a waveform. Even noise can be classified as Gaussian distribution noise, Levy distribution noise, etc., and it is useful to quantify the fluctuation in a sonic boom waveform that could be related to engine issues, atmospheric issues, etc.



1. Studied NASA fighter jet soic boom waveform (upper) and the corresponding percent increment data series (lower).

The percent increment histogram is shown in Figure 3. The histogram had 14 outcomes with Shannon entropy of 1.73 bits which is about 45% of the maximum 3.81 bits. In comparison, a triangular histogram with outcomes of (1, 2, 3, 4, 5, 6, 7, 6, 5, 4, 3, 2, 1, and 0.000001) would have a Shannon entropy of 3.5 bits.



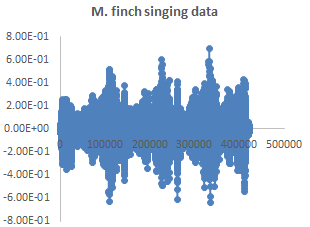
1. Percent increment histogram of the studied fighter jet sonic boom waveform.

The fractal dimension value was 1.54 using a 7-point slope in the Higuchi fractal method, shown in Figure 4. The Shannon information entropy at 45% of the maximum would be consistent with a fractal dimension value of 1.5 when the fractal dimension maximum equals to 2.0. The Shannon entropy at 45% maximum suggested that the information content is at a moderate level. The fractal dimension value of 1.5 suggested that the fluctuation complexity is Gaussian-like with a mean and a standard deviation, when complexity can be defined as the detail-change with respect to a scale-change [10]. The question of whether the origins were engine noise, aircraft vibration, atmospheric response, etc. is outside the scope of signal processing, it is still useful to unravel the information contained in the percent increment series.



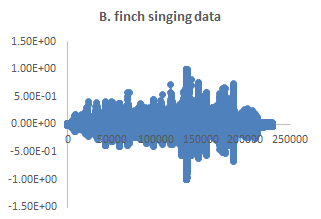
1. Higuchi fractal length (y-axis) versus lag (x-axis) shown with the 7-point slope as fractal dimension value.

The song waveforms of a Munia finch is shown in Figures 5. The Munia finch waveform had 421,947 data points for an 8-sec song.



1. Munia finch song waveform with 421,947 data points for about 8 minutes singing.

The song waveforms of a Munia finch is shown in Figures 6. The Bengalese finch waveform had 230,126 data points for a 10-sec song. The Science publication did not provide further information on how the song waveforms were captured as audio files in the wav-format, although the original songbird research paper was cited [11]. Using the same exploratory approach in the analysis of fighter jet sonic boom waveform fluctuation, the analyses of the song waveforms were conducted. Note that the Crest Factor calculation, peak signal divided by the root mean squared signal, showed that Munia finch was at 21.2 dB level and Bengalese finch at 21.8 dB level. A random data shuffling would preserve the Crest Factor value but generate new fractal dimension value and percent increment histogram.



1. Example Bengalese finch song waveform with 230,126 data points for about 10 minutes singing.

Whether a short waveform could be used to characterize the difference between the Bengalese finch and Munia finch singing was investigated The studied Bengalese finch short waveform segments are segment-1 (0 to 2,300), segment-2 (50,000 to 52,300), segment-3 (100,000 to 102,300), segment-4 (150,000 to 152,300), segment-5 (200,000 to 202,300) and segment-6 (220,000 to 222,300). The studied Munia finch short waveform segments are segment-1 (0 to 5,000), segment-2 (80,000 to 85,000), segment-3 (160,000 to 165,000), segment-4 (240,000 to 245,000), segment-5 (320,000 to 325,000) and segment-6 (400,000 to 405,000).

The corresponding fractal dimension values of the percent increment series in the studied waveform segments are shown in Figure 7 The results show that the Bengalese finch singing data have higher fractal dimension values when compared to the Munia finch singing data. The adjectives of “shorter, simpler, and full of unmelodic segments of acoustic noise” for the Muina finch would correspond to lower fractal dimension. The adjectives of “peeps, chirps, and segments that often repeat and recombine in improvisational ways” for the Bengalese finch would correspond to higher fractal dimension values with more information content. The percent increment variable would represent the vocal organ capability to support the changes in the signals as d (log (signal) in calculus notation. The fractal dimension of the percent increment series in the Bengalese finch song waveform exceeds 2.0. Our previous studies in nucleotide fluctuation showed that a fractal dimension exceeding 2.0 is associated with CG pairs [12, 13]. A genetic sequence containing A, T, C, G nucleotides can be studied in terms of information fluctuation when the A, T, C, G proton numbers (70, 66, 58, and 78 respectively) were used to convert a symbolic sequence to a numeric sequence with CG carrying the most local fluctuation among all the other 15 di-nucleotide combinations. The human specific HAR1 was discovered as the region with the most acceleration [14]. We found that the HAR1 sequence with 118 nucleotides has a fractal dimension of 2.02 while the Chimp counterpart with less CG pairs is at 1.98. The association of higher aesthetic value in affective computing with higher fractal dimension value in Finch song waveform, similar to the dynamic range analysis reported earlier in a clinical music perception study, would be an acceptable criterion [15]. A Finch song waveform would not carry words and has been proposed as the origin of language [1]. Recent results also indicated that sets of genes leaded by FOXP2 were in harmony co-expressions during song learning in young zebra finch [16]. Fractal dimension analysis would help such research.



1. Fractal dimension values (y-axis) of the studied oercent increment series for six segments (x-axis \* 1,000), Munia finch (Blue) and Bengalese finch (Red).

Digitization effect on the fractal analysis result was studied. The Bengalese finch song waveform was compressed by summing two consecutive data points as a single data point. The fractal dimension values for the studied segments are shown in Figure 8. The compressed time series show lower fractal dimension values in 5 of the 6 studied segments, consistent with the general notion that less resolution in digitization would suppress fractal dimension. Therefore the Bengalese finch waveform having 23,000 data points per second would contain even higher fractal dimension values if it was digitized at the higher resolution like the 52,000 data points per second resolution used in the Mania finch waveform.



1. Fractal dimension values (y-axis) of the studied percent increment series of the published Bengalese song waveform (Blue N = 2,300)) and compressed waveform (Red N = 1,250).

The fractal dimension cross-over feature for the percent increment data series shown in Figure 8 was computed using the waveform segment-4 could be related to a deeper mechanism in which the percent increment histogram of segment-4 shows a long-tail feature when compared to the percent increment histogram of the entire waveform, shown in Figure 9. The long-tail segment-4 histogram had a Shannon entropy at about 88% of the maximum while the entire waveform histogram had a Shannon entropy at about 85% of the maximum. For comparison, a Gaussian distribution (0, 0.06) was simulated with results showing Shannon entropy values at about 86 to 87% of the maximum.



1. Percent increment histograms of the studied Bengalese finch song waveform segment-4 (Red occurrence\* 150) and entire song waveform (Blue).

It is an interesting to address the question of the missing Shannon entropy from the maximum value in terms of aesthetic perspective. The results showed that the Bengalese finch waveform segments could support fractal dimension values beyond 2.0 with a Shannon entropy exceeding the Gaussian case. The ranking sensitive fractal dimension would serve as a realistic dynamical range indicator because a random shuffling will not change the Crest Factor values but could change the affective aspects. The apparent success of the ranking insensitive Crest Factor values could point to a hidden pre- selection process shared by Finch song waveform and human music. A recent report proposed that music expressions are for affective and not emotion communication [17]. The proposed variables of arousal and valence could be elucidated with ranking sensitive fractal dimension analysis and Shannon entropy of percent increment.

# CONCLUSIONS

The project studied the Munia and Bengalese finch song waveforms and put the Bengalese song waveform at higher fractal dimension values, consistent with the expected aesthetic values associated with the Bengalese finch songs in society. Future studies could include the surveying of perception by shuffling a waveform dataset to correlate fractal dimension values with aesthetic values while maintaining constant Shannon entropy and Crest Factor values. The development of using bio- acoustic signals collected in songbird Artic migration for climate change studies could also incorporate the fractal dimension analysis methodology [18]. Random chunk shuffling simulation studies could also reveal more details.

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