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## Accuracy of Jitter and Shimmer Measurements

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### Abstract

A synthesized speech signal was used to measure the accuracy of the Jitter and Shimmer parameters calculated by a previously presented algorithm. The formant model of speech synthesis was used to produce speech signals with a controlled glottal periods and magnitudes according to previously determined Jitter and Shimmer parameters values. The Jitter parameters (jitta, jitter, rap and ppq5) and the Shimmer parameters (ShdB, Shim, apq3 and apq5) were calculated with a previously developed algorithm and compared with the analytic determined values and also with measures made with Praat software. Experiments with different type of jitter and shimmer perturbations and with different  $F_0$  values were conducted. Also the influence of  $F_0$  variations on Shimmer and Jitter measures was experimented.

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### 1. Introduction

The parameters of voice frequency (jitter) and amplitude (shimmer) perturbation are commonly used as part of a comprehensive voice examination [1]. Jitter is the measure of the cycle-to-cycle variations of the fundamental glottal period and shimmer is the cycle-to-cycle variations of the fundamental glottal period amplitudes as depicted in Fig.1. Both of these measures can be determined using absolute or relative values, originating a set of parameters related to

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each one. All of these parameters have been largely used for the description of pathological voice quality [2, 3]. Both perturbation parameters are obtained by analysis of a recorded speech of prolonged vowel phonations [4, 5, 6, 7, 8, 9].

The jitter is affected mainly by the lack of control of vibration of the cords. The voices of patients with pathologies often have higher values of jitter. The shimmer changes with the reduction of glottal resistance and mass lesions on the vocal cords and is correlated with the presence of noise emission and breathiness [4]. It is expected that patients with pathologies have higher values of shimmer.

The aims of this work is the analyses of the jitter and shimmer measures produced by a developed system. The algorithm is based on the usage of moving average over the speech signal and finding their peaks that will be the center position to search for the maximum amplitude of the speech wave form. These maximum amplitudes found under a previously determinate fundamental period variation consist in the glottal pulses [4].

The objective is to prove the reliability of the algorithm developed and which have been improved. For such a measurement of the accuracy of jitter and shimmer parameters a synthesized signal was produced with controlled values of jitter and shimmer. Then the jitter and shimmer parameters were determined using the developed system and the Praat software [10] and compared with the analytically determined values.

Two types of jitter and shimmer perturbations were simulated using a speech synthesized signal to determine the error in the measures made by the previously developed algorithm and by the Praat software.

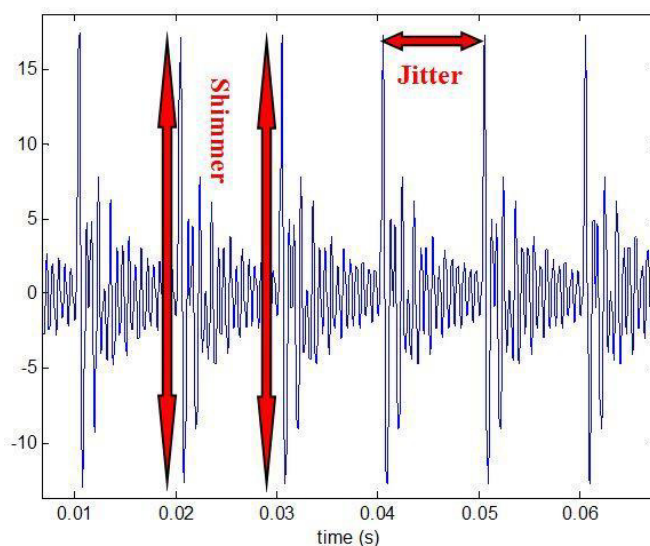


Fig.1. Jitter and Shimmer perturbation measures in speech signal.

## 2. Jitter and shimmer parameters

### 2.1 Jitter

Jitter perturbation can be given by four related parameters: the absolute jitter (jitta) is the absolute perturbation, the local or relative jitter (jitt), the relative average perturbation (rap) and the five points period perturbation (ppq5). The jitta is usually presented in  $\mu\text{s}$ , and the other three parameters in percentage of the average glottal period [2, 4, 5].

**Jitter (local):** is the average absolute difference between consecutive periods, divided by the average period, in percentage.

$$jitt = \frac{\frac{1}{N-1} \sum_{i=1}^{N-1} |T_i - T_{i-1}|}{\frac{1}{N} \sum_{i=1}^N T_i} * 100 \quad (1)$$

Where  $T_i$  is the extracted glottal period lengths and  $N$  is the number of extracted glottal periods.

**Jitter (local, absolute):** is the average absolute difference between consecutive periods, in seconds or  $\mu$ s.

$$jitta = \frac{1}{N-1} \sum_{i=1}^{N-1} |T_i - T_{i-1}| \quad (2)$$

**Jitter (RAP):** the Relative Average Perturbation is the average absolute difference between a period and the average of it and its two neighbours, divided by the average period, in percentage.

$$rap = \frac{\frac{1}{N-1} \sum_{i=1}^{N-1} |T_i - \left(\frac{1}{3} \sum_{n=i-1}^{i+1} T_n\right)|}{\frac{1}{N} \sum_{i=1}^N T_i} * 100 \quad (3)$$

**Jitter (ppq5):** the five-point Period Perturbation Quotient is the average absolute difference between a period and the average of it and its four closest neighbours, divided by the average period, in percentage.

$$ppq5 = \frac{\frac{1}{N-1} \sum_{i=2}^{N-2} |T_i - \left(\frac{1}{5} \sum_{n=i-2}^{i+2} T_n\right)|}{\frac{1}{N} \sum_{i=1}^N T_i} * 100 \quad (4)$$

## 2.2 Shimmer

Shimmer is a variation of amplitudes of consecutive periods, which also can be measured by subtracting the amplitude of the pitch period sequence to its neighbor or combinations of its neighbors. For shimmer there are also four related measures: the absolute or local shimmer that is the absolute difference in a logarithmic domain (ShdB) given in dB, the local shimmer (Shim) in percentage of the average amplitude, the three-point Amplitude Perturbation Quotient (apq3) also in percentage and the five-point Amplitude Perturbation Quotient (apq5) also in percentage.

**Shimmer (local):** is the average absolute difference between the amplitudes of consecutive periods, divided by the average amplitude.

$$Shim = \frac{\frac{1}{N-1} \sum_{i=1}^{N-1} |A_i - A_{i+1}|}{\frac{1}{N} \sum_{i=1}^N A_i} * 100 \quad (5)$$

Where  $A_i$  is the extracted amplitude and  $N$  is the number of extracted fundamental frequency periods.

**Shimmer (local, dB):** is the average absolute base-10 logarithm of the difference between the amplitudes of consecutive periods, multiplied by 20 and given in a decibel scale (dB).

$$ShdB = \frac{1}{N-1} \sum_{i=1}^{N-1} |20 * \log(A_{i+1}/A_i)| \quad (6)$$

**Shimmer (apq3):** the three-point Amplitude Perturbation Quotient is the average absolute difference between the amplitude of a period and the average of the amplitudes of its neighbours, divided by the average amplitude.

$$apq3 = \frac{\frac{1}{N-1} \sum_{i=1}^{N-1} \left| A_i - \left( \frac{1}{3} \sum_{n=i-1}^{i+1} A_n \right) \right|}{\frac{1}{N} \sum_{i=1}^N A_i} * 100 \tag{7}$$

**Shimmer (apq5):** the five-point Amplitude Perturbation Quotient is the average absolute difference between the amplitude of a period and the average of the amplitudes of it and its four closest neighbours, divided by the average amplitude.

$$apq5 = \frac{\frac{1}{N-1} \sum_{i=2}^{N-2} \left| A_i - \left( \frac{1}{5} \sum_{n=i-2}^{i+2} A_n \right) \right|}{\frac{1}{N} \sum_{i=1}^N A_i} * 100 \tag{8}$$

**3. Synthesized signal**

The acoustic module of the didactic speech synthesizer [11] was used. The synthesizer was developed as a generic system for converting text-to-speech using the Klaat formant model [12]. This formant model is very convenient because it has the source (vocal folds) and the vocal tract separated, allowing a total control of the glottal periods.

This signal was synthesized using a sampling frequency of 22050 Hz and most of the times with a fundamental frequency (F<sub>0</sub>) near to 100Hz, which corresponds to a glottal periods near to 10 ms. In the experiments with variable F<sub>0</sub>, different values for F<sub>0</sub> was naturally used and explicit in the experiments below. The signals were synthesized with the formants and bandwidths correspondent to the vowel /a/. The speech signal has synthesized with 2 seconds long.

The glottal pulses were generated by the eq. 9 with a=0.9, applied to a vector with the train of pulses spaced by the samples correspondent to the inverse of the F<sub>0</sub>. In order to produce the jitter perturbation some pulses were displaced by its original positions. The shimmer perturbation was produced with some pulses with different amplitudes.

$$G(z) = \frac{-ae \ln(a)z^{-1}}{(1-az^{-1})^2} \tag{9}$$

**4. Jitter, shimmer and F<sub>0</sub> variation experiments**

Besides the determination of jitter and shimmer within no perturbation, meaning jitter and shimmer equal to zero, different types of perturbation was produced for each parameter.

*4.1. Variation of Jitter*

Two types of perturbation were experimented. The first type consists in using a train of pulses with two different periods, successively. The second experiment consists in using a train of pulses with one different period between each 3 equal periods, successively.

For an F<sub>0</sub>=100 Hz and the sampling frequency F<sub>s</sub>=22050 Hz the glottal period corresponds to approximately 221 samples (F<sub>s</sub>/F<sub>0</sub>). The used F<sub>0</sub> will be slightly different than 100 Hz because of the shortening of one of the glottal periods.

**Jitter Perturbation of type 1**

Type 1 perturbation corresponds to a successive pairs of different glottal periods, as depicted in Fig. 2.

To produce a jitter perturbation near to 5% (jitt) the successive periods must differ in 11 samples. Therefore  $T0'=210$  and  $T0''=221$  samples. Each sample corresponds to the time of  $1/F_s$  s.

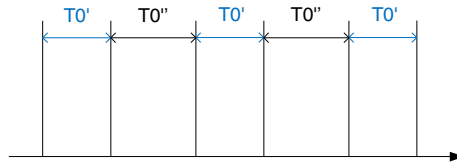


Fig. 2: Jitter perturbation type 1 with variation from one in one glottal period.

The 11 sample with a sampling frequency of 22050 Hz corresponds to a  $499 \mu s$ . This variation of glottal periods applied to the eq. 1 to 4 gives the analytic values for jitter parameters  $jitta=499 \mu s$ ,  $jitt=5.09\%$ ,  $rap=3.40\%$  and  $ppq5=2.04\%$ .

**Jitter Perturbation of type 2**

To test the behavior of jitter towards an irregular variation, we used periods of the same length, but instead of varying from one in one period the variation was of three in three samples as shown in Fig 3, using also  $T0'=210$  and  $T0''=221$  samples.

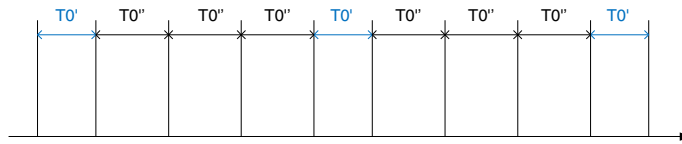


Fig.3: Jitter perturbation type 2 with variation from three in three glottal periods.

For this jitter perturbation of 11 samples it corresponds to an average variation of  $249 \mu s$ . This variation of glottal periods applied to the eq. 1 to 4 gives the analytic values for jitter parameters  $jitta=249 \mu s$ ,  $jitt=2.52\%$ ,  $rap=1.68\%$  and  $ppq5=2.02\%$ .

**4.2. Variation of Shimmer**

The shimmer variation will be produced by changing the amplitude of the pulses but with exactly the same glottal periods (no jitter perturbation).

The same two types of perturbation were used for shimmer. The glottal periods were 221 samples, corresponding to 100 Hz of  $F_0$ .

**Shimmer Perturbation of type 1**

Type 1 perturbation of shimmer was produced with an amplitude impulse variation of 25% per glottal period, as shown in Fig. 4.  $A0'=1$  and  $A0''=1.25$ .

This amplitude variation applied to eq. 5 to 8 gives the  $Shim=22.22\%$ ,  $ShdB=1.94dB$ ,  $apq3=14.82\%$  and  $apq5=8.89\%$ .

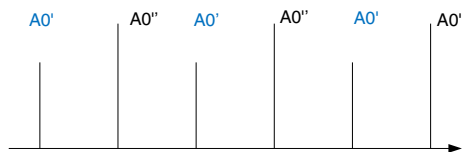


Fig.4: Shimmer perturbation of type 1 with variation from one in one sample.

**Shimmer Perturbation of type 2**

We also tested the behavior of an irregular variation for shimmer creating an algorithm which varies the amplitude from three in three samples as shown in Fig.5.  $A0'=1$  and  $A0''=1.25$ .

This amplitude variation applied to eq. 5 to 8 gives the Shim=10.53%, ShdB=0.97dB, apq3=7.02% and apq5=8.42%.

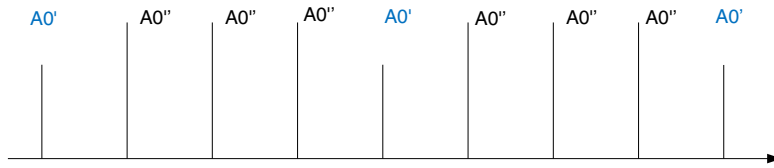


Fig.5: Shimmer perturbation type 2 with variation from three in three samples.

*4.3. Variation of the fundamental frequency*

After being tested the behavior of jitter and shimmer with some variations, it was decided to test the influence of the  $F_0$  in the shimmer and jitter parameters. For this purpose, synthesized speech signals with  $F_0$  equal to 75Hz, 100Hz and 190Hz were used.

The  $F_0$  may influence the shimmer in the synthesized speech because higher  $F_0$  signal has shorter glottal period, and because the formants model is an Infinite Impulsional Response (IIR) filter the length of the impulse response is longer than the glottal period. Therefore the influence to the amplitude of next period is higher in shorter glottal periods, or higher  $F_0$ . But after a certain value of a period this influence is not too significant.

It is not expected any change in the jitter parameter with the  $F_0$  variation.

**5. Accuracy of parameters measures**

In this section the measures of the synthesized speech signal using the developed and improved algorithm [4] and the Praat software [10] are presented and the accuracy of the measures is discussed. Praat software is used to compare the accuracy of the measures with the developed algorithm because is freely available software and largely used in research.

*5.1. Analysis of Jitter parameters*

The first experimented consists in a synthesized speech without glottal period variation or with absolute zero jitter perturbation meaning zero for jitta, jitt, rap and ppq5. Table 1 presents the measures parameters with the developed algorithm and with Praat software. As it can be seen both systems presented exactly zero for the four parameters.

Table 1: Jitter values for speech signal without glottal period variation.

| Parameter         | Praat | Algorithm |
|-------------------|-------|-----------|
| <b>Jitta (µs)</b> | 0     | 0         |
| <b>Jitt (%)</b>   | 0.00  | 0.00      |
| <b>RAP (%)</b>    | 0.00  | 0.00      |
| <b>PPQ5 (%)</b>   | 0.00  | 0.00      |

The second experiment consists in synthesized speech signal with a jitter perturbation of type 1. Table 2 presents the analytically determined values for this situation and the measures with both systems, the algorithm and Praat. As it can be seen both systems measured this jitter perturbation with very good accuracy, but the algorithm was more

accurate than Praat. The algorithm reached an error less than 0.04% for jitt, rap and ppq5, and Praat had an error less than 0.07%. For jitta Praat had an error of 9  $\mu$ s and the algorithm 0  $\mu$ s.

Table 2: Jitter values for speech signal with jitter perturbation of type 1.

| Parameter                        | Praat | Algorithm | Analytic |
|----------------------------------|-------|-----------|----------|
| <b>Jitta (<math>\mu</math>s)</b> | 490   | 499       | 499      |
| <b>Jitt (%)</b>                  | 5.02  | 5.10      | 5.09     |
| <b>RAP (%)</b>                   | 3.35  | 3.40      | 3.40     |
| <b>PPQ5 (%)</b>                  | 2.01  | 2.00      | 2.04     |

Next experiment consists in synthesized speech signal with a jitter perturbation of type 2. Table 3 presents the analytically determined values for this situation and the measures with both systems. As it can be seen both systems measured this jitter perturbation with very good accuracy, but in this case Praat was more accurate. For jitta, Praat had an error of 2  $\mu$ s and the algorithm 5  $\mu$ s. For the remaining parameters Praat had an error less than 0.03 % and the algorithm 0.05 %.

Table 3: Jitter values for speech signal with jitter perturbation of type 2.

| Parameter                        | Praat | Algorithm | Analytic |
|----------------------------------|-------|-----------|----------|
| <b>Jitta (<math>\mu</math>s)</b> | 247   | 244       | 249      |
| <b>Jitt (%)</b>                  | 2.49  | 2.47      | 2.52     |
| <b>RAP (%)</b>                   | 1.66  | 1.66      | 1.68     |
| <b>PPQ5 (%)</b>                  | 2.00  | 1.97      | 2.02     |

Now the experiments with shimmer measures are presented. First the experiment using a speech synthesized signal with no variation on the amplitude of the pulse train and  $F_0=100$  Hz, meaning a zero value for Shim, ShdB, apq3 and apq5. Table 4 presents the measures with the algorithm and with Praat. It can be seen that the algorithm measured 0.00 for all parameters and Praat measured 0.01% for Shim and zero for the other parameters.

Table 4: Shimmer values for speech signal without glottal amplitude variation.

| Parameter        | Praat | Algorithm |
|------------------|-------|-----------|
| <b>Shim (%)</b>  | 0.01  | 0.00      |
| <b>ShdB (dB)</b> | 0.00  | 0.00      |
| <b>Apq3 (%)</b>  | 0.00  | 0.00      |
| <b>Apq5 (%)</b>  | 0.00  | 0.00      |

Next experiment is the measure of shimmer parameters in a speech synthesized signal with the shimmer perturbation of type 1 and  $F_0=100$  Hz. Table 5 presents the analytically determined values and the measures with both systems. In this case the measured values by the algorithm and by the Praat are slightly higher than the ones determined analytically. This can be explained because the analytic values were determined based on the amplitude of the pulses, but the measures were made using the synthesized speech and as it was detailed in section 4.3 the length of the glottal period can change the amplitude of this periods. Anyhow the measures made by the algorithm and by Praat software are very close to each other. The ShdB only differ in 0.01 dB and the remaining parameters differ less than 0.1%. Anyhow the analytic values are very close to Praat and algorithm measures.

Table 5: Shimmer values for speech signal with shimmer perturbation of type 1.

| Parameter        | Praat | Algorithm | Analytic |
|------------------|-------|-----------|----------|
| <b>Shim (%)</b>  | 22.67 | 22.57     | 22.22    |
| <b>ShdB (dB)</b> | 1.98  | 1.97      | 1.94     |
| <b>Apq3 (%)</b>  | 15.11 | 15.05     | 14.82    |
| <b>Apq5 (%)</b>  | 9.07  | 9.03      | 8.89     |

Table 6 presents the analytically determined values and the measured values with the algorithm and with Praat using a synthesized speech signal with a shimmer perturbation of type 2 and  $F_0=100$  Hz. The same consideration as previous experiment about the analytical values has to be made. Comparing the measured values between algorithm and Praat it can be seen and error of 0.00 dB for the ShdB and less than 0.09% for the remaining parameters. Again the analytic values era very close to Praat and algorithm measures

Table 6: Shimmer values for speech signal with shimmer perturbation of type 2.

| Parameter        | Praat | Algorithm | Analytic |
|------------------|-------|-----------|----------|
| <b>Shim (%)</b>  | 10.92 | 10.99     | 10.53    |
| <b>ShdB (dB)</b> | 1.01  | 1.01      | 0.97     |
| <b>Apq3 (%)</b>  | 7.22  | 7.16      | 7.02     |
| <b>Apq5 (%)</b>  | 8.65  | 8.74      | 8.42     |

Next set of experiments consists in the measure of the shimmer parameters using only the algorithm in a synthesized speech signal with different values of  $F_0$ . Each experiment has different situations considering the amplitude of the glottal pulses.

Table 7 presents the measures of shimmer parameters with the developed algorithm in a synthesized speech signal without any variation in the amplitude of the glottal pulses. This means that the shimmer should be zero. The used values for  $F_0$  were 75, 100 and 190 Hz. It should be mentioned that the speech signal with  $F_0=100$  Hz is the same already experimented in experiment of table 4. As it can be seen the algorithm measured 0.00 almost all parameters and for the three values of  $F_0$ . Only the shim for  $F_0=190$  Hz was 0.01%.

Table 7: Shimmer values for speech signal with different  $F_0$  without amplitude variation.

| <b>F0 (Hz)</b>   | <b>75</b> | <b>100</b> | <b>190</b> |
|------------------|-----------|------------|------------|
| <b>Shim (%)</b>  | 0.00      | 0.00       | 0.01       |
| <b>ShdB (dB)</b> | 0.00      | 0.00       | 0.00       |
| <b>Apq3 (%)</b>  | 0.00      | 0.00       | 0.00       |
| <b>Apq5 (%)</b>  | 0.00      | 0.00       | 0.00       |

Table 8 presents the measured values by the algorithm along  $F_0$  values and with shimmer perturbation of type 1. The speech signal with  $F_0=100$  Hz is similar of the one presented in table 5. The four shimmer parameters are considerably higher for  $F_0=190$  Hz and vaguely higher for  $F_0=75$  Hz. The values for 75 Hz can be considered at the same level (difference less than 1%), but the higher values for 190 Hz must be justified by the consideration made in section 4.3.



Table 8: Shimmer values for speech signal with different  $F_0$  with shimmer perturbation of type 1.

| <b>F0 (Hz)</b>   | <b>75</b> | <b>100</b> | <b>190</b> |
|------------------|-----------|------------|------------|
| <b>Shim (%)</b>  | 23.54     | 22.57      | 30.67      |
| <b>ShdB (dB)</b> | 2.05      | 1.97       | 2.69       |
| <b>Apq3 (%)</b>  | 15.69     | 15.05      | 20.45      |
| <b>Apq5 (%)</b>  | 9.41      | 9.03       | 12.27      |

Table 9 presents the measured values by the algorithm along  $F_0$  values and with shimmer perturbation of type 2. The speech signal with  $F_0=100$  Hz is similar of the one presented in table 6. The same type of variations can be observed as in previous case, vaguely higher for  $F_0=75$  Hz and considerably higher for  $F_0=190$  Hz. Therefore the same conclusion can be taken.

Table 9: Shimmer values for speech signal with different  $F_0$  with shimmer perturbation of type 2.

| <b>F0 (Hz)</b>   | <b>75</b> | <b>100</b> | <b>190</b> |
|------------------|-----------|------------|------------|
| <b>Shim (%)</b>  | 11.09     | 10.99      | 14.62      |
| <b>ShdB (dB)</b> | 1.02      | 1.01       | 1.33       |
| <b>Apq3 (%)</b>  | 7.44      | 7.16       | 9.74       |
| <b>Apq5 (%)</b>  | 8.91      | 8.74       | 9.40       |

Excepting the case of the variation of fundamental frequency without the shimmer variation, the change of the fundamental frequency causes interference in the results of shimmer. This change in values can be caused by the fact that by increasing the fundamental frequency the glottal periods decrease and consequently the envelop peaks of the synthesized speech increase. Or by other words, the peaks of the synthesized speech signal can be different for different glottal periods and therefore different fundamental frequencies. But this change occurs in the synthesized speech signal and cannot be considered as an error of measure of the shimmer parameters.

Jitter values for the variation of the fundamental frequency are not shown because, as expected, the experiments did not show any variation of the jitter parameters along different values of  $F_0$ .

## 6. Conclusion

The development and improvement of an algorithm to measure the jitter and shimmer parameters required the need to know the accuracy of the measures. Therefore the acoustic module of a formant speech synthesizer was used to generate speech signal with controlled perturbation of jitter and shimmer.

Two types of perturbation were implemented for jitter and for shimmer. A speech signal without any perturbation of jitter and shimmer was also used.

The measures of the jitter and shimmer parameter made with the algorithm were compared with the analytically determined values and with the measures made by the Praat software.

Concerning the jitter parameters the algorithm and Praat produced very accurate measures in the three experiments (no jitter perturbation, jitter perturbation type 1 and jitter perturbation type 2). The algorithm produced an error less than 5  $\mu$ s for jitta parameter and less than 0.05 % for the relative parameters (jitt, rap and ppq5). The Praat software produced an error less than 9  $\mu$ s for jitta and less than 0.07% for the relative parameters.

Concerning the shimmer parameter, one last experiment showed that the synthesized speech signal can have a shimmer perturbation higher than the one produced in amplitude of the train of glottal pulses. Therefore the analytically determined values cannot be taken as too much accurate values. Anyhow the comparison of the measured shimmer parameters by the algorithm and Praat software showed a very consistency between Praat and the

developed algorithm. Namely, considering the experimented shimmer perturbation the difference is less than 0.01 dB for ShdB and less than 0.1% for the relative parameters (Shim, apq3 and apq5).

As final remark, for Jitter parameters the algorithms showed to be more accurate than Praat, and with an accuracy of 5  $\mu$ s for the jitta or 0.05% for the relative parameters. For the shimmer parameters the best reference to be compared is the Praat software and the algorithm showed results with a difference less than 0.01 for ShdB and less than 0.1% for the remaining relative parameters.

The perturbation types I and II produced with synthetic speech were used to have different types of perturbation, anyhow in further developments the perturbations of real signal will be analyzed in order to have more realistic perturbation and measured accuracy.

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