ΕΛΛΗΝΙΚΗ ΔΗΜΟΚΡΑΤΙΑ
ΠΑΝΕΠΙΣΤΗΜΙΟ ΚΡΗΤΗΣ

Ψηφιακή Επεξεργασία Φωνής

Διάλεξη: Μοντελοποίηση Σήματος Πηγής με Χρήση Γλωττιδικών Μοντέλων

Παρουσίαση: Gilles Degottex

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Voice source modeling using a glottal model

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Introduction

Motivations and Applications

Applications:

- Voice tranformation
- Speech synthesis
- Identity conversion
- Expressive synthesis

Motivations and Applications

Applications:

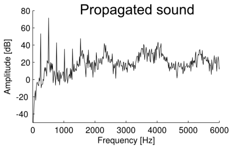
- Voice tranformation
- Speech synthesis
- Identity conversion
- Expressive synthesis

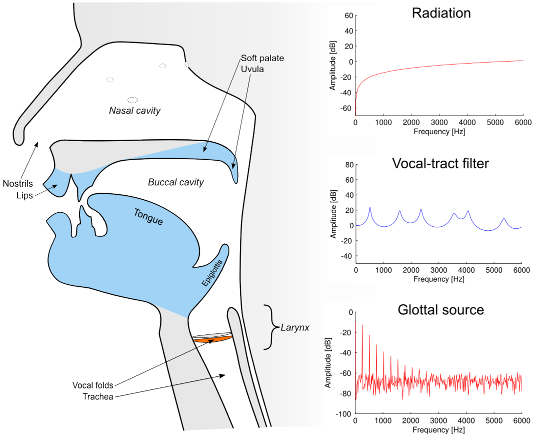
For ...

- Contemporary musique, sound installations
- Music and Cinema
- Video games
- Comunication technologies

Approach based on signal processing

Voice production





Approach based on signal processing

Source-filter model:

$$S(\omega) = G^{\theta_g}(\omega) \cdot C^{\theta_c}(\omega) \cdot L^{\theta_l}(\omega)$$

Waveform = Glottal-Source · Vocal-Tract-Filter · Radiation
with the parameters $\theta_g, \theta_c, \theta_l$ of each element

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Model inversion:
E.G. General expression of the glottal source:

$$G(\omega) = \frac{S(\omega)}{C^{\theta_c}(\omega) \cdot L^{\theta_l}(\omega)}$$

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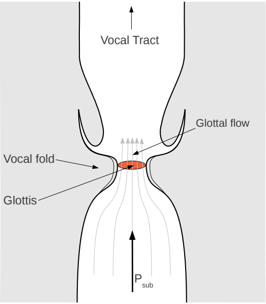
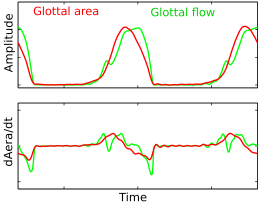
\+ Simplicity of inversion
− Strong approximation
hyp: Sufficient for voice manipulation with respect to **perception**

Glottal source modeling & Voice production model

The glottal source $G(\omega)$ - Vocal folds, Glottal area and Flow

©Erkki Bianco & Ircam property [1]



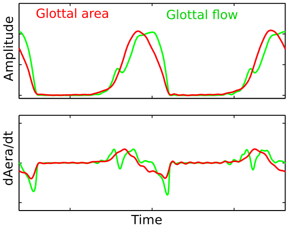


Glottal flow Air flow going through the glottis.

Glottal source in the source-filter model is an approximation of the glottal flow which should be suffisant for perceptual manipulation of the voice.

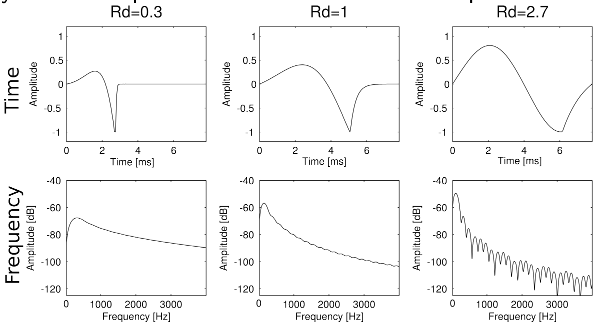
1 http://gillesdegottex.eu/IrcamUSC

The glottal source $G(\omega)$ - The Transformed Liljencrants-Fant model (LF)



Glottal model = analytical description of the deterministic component

- $1/f_0$ Time duration
- E Amplitude
- ϕ Time position
- Rd Shape



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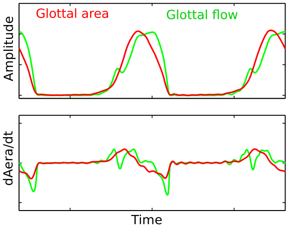

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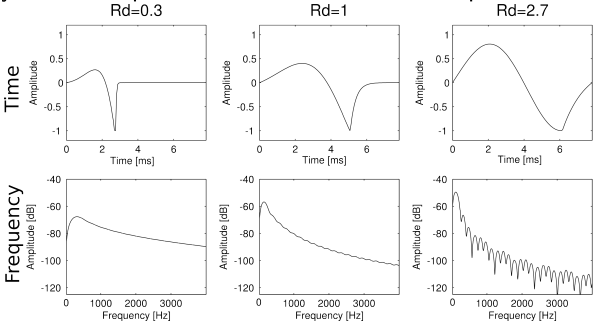


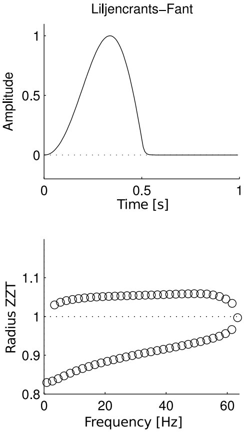
The glottal source $G(\omega)$ - Its use

Given a glottal model:

* How to estimate its parameters ?
* Comment estimer le filtre du conduit-vocal ?
* Comment transformer et synthétiser un signal vocal ?

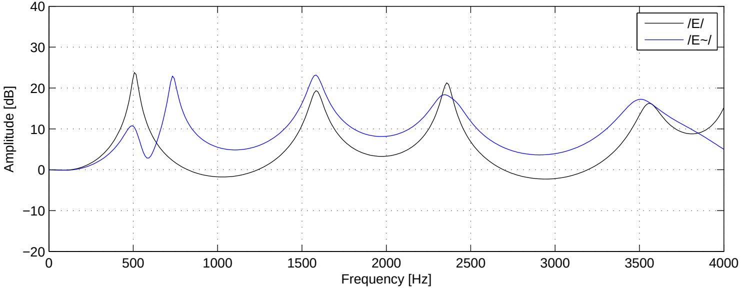
The glottal source $G(\omega)$ - Mixed-phase property of the glottal pulse

The glottal pulse is a **mixed-phase signal**.



The Vocal Tract Filter $C(\omega)$

It represents the resonnances and anti-resonnances of the vocal tract.



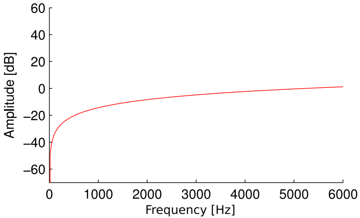
Passivity: The poles are inside the UC.
Postulate: The zeros are also inside the UC.
$\Rightarrow C(\omega)$ is minimum-phase.

This difference of phase property is the basis for parameter estimation.

The radiation $L(\omega)$

Constant model, without parameters [1]:

$$L(\omega) = j \cdot \omega$$



1 J.L. Flanagan, *Speech Analysis Synthesis and Perception*, Springer Verlag, 1972.

Complete model of the voice production

hyp: Split by a Voiced/Unvoiced Frequency (VUF):

$$S(\omega) = \begin{cases} e^{j\omega\phi} \cdot H^{f_0}(\omega) \cdot G^{(Rd,f_0)}(\omega) \cdot C_{-}(\omega) \cdot j\omega & \text{pour } \omega < \text{VUF} \\ N^{\sigma_g}(\omega) \cdot C_{-}(\omega) \cdot j\omega & \text{pour } \omega > \text{VUF} \end{cases}$$

$G^{(Rd,f_0)}(\omega)$ Shape of the glottal model

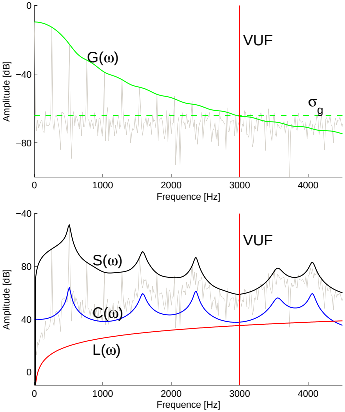
$e^{j\omega\phi}$ Time position of the shape

$H^{f_0}(\omega)$ Harmonicity

$N^{\sigma_g}(\omega)$ Turbulance noise

$C_{-}(\omega)$ Vocal Tract Filter (VTF)

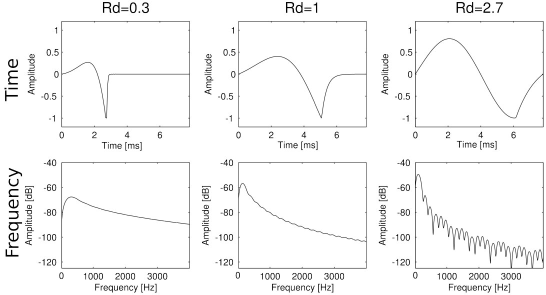
$j\omega$ Radiation



Estimation of the glottal parameters

Harmonic model for the Rd estimation

Estimation of the shape parameter *Rd* of the LF glottal model



hyp: f_0 is known $\Rightarrow$ **harmonic model:**

$$\begin{array}{ccccccccc} S(\omega_h) & = & e^{j\omega_h\phi} & \cdot & G^{(Rd,f_0)}(\omega_h) & \cdot & C_{-}(\omega_h) & \cdot & j\omega_h \\ S_h & = & e^{jh\phi} & \cdot & G_h^{Rd} & \cdot & C_{h-} & \cdot & jh \end{array}$$

Indexed notation ! $X_h \equiv X(\omega_h)$

Vocal Tract Filter general expression

The general expression of the glottal source and the vocal tract filter are:

$$e^{jh\phi} \cdot G_h^{Rd} = \frac{S_h}{C_{h-} \cdot jh} \qquad C_{h-} = \frac{S_h}{e^{jh\phi} \cdot G_h^{Rd} \cdot jh}$$

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For the VTF, we force it to be minimum-phase using $\mathcal{E}_-(.)$

$$C_{h-} = \mathcal{E}_- \left(\frac{S_h}{G_h^{Rd} \cdot jh} \right)$$

Phase Minimization Criterion [1]

The convolutive residual:

$$R_h = \frac{S_h}{M_h^{(Rd,\phi)}}$$

$$M_h^{(Rd,\phi)} = S_h \quad \Leftrightarrow \quad R_h^{(Rd,\phi)} = 1 \; \forall h$$

$\Rightarrow$

$$|R_h^{(Rd,\phi)}| = 1 \quad \text{and} \quad \angle R_h^{(Rd,\phi)} = 0 \quad \forall h$$

Idea

- Ensure an unitary amplitude spectrum
- Minimize the phase spectrum

1 R. Smits and B. Yegnanarayana, *Determination of Instants of Significant Excitation in Speech Using Group Delay Function*, IEEE Trans. Speech and Audio Processing, vol. 3, pp. 325–333, 1995.

Mean Squared Phase (MSP)

In the context of the used voice production model

$$R_h^{(Rd,\phi)} = \frac{S_h}{e^{jh\phi} \cdot G_h^{Rd} \cdot C_{h-} \cdot jh} = \frac{S_h}{e^{jh\phi} \cdot G_h^{Rd} \cdot \mathcal{E}_{-}(S_h / G_h^{Rd} \cdot jh) \cdot jh}$$

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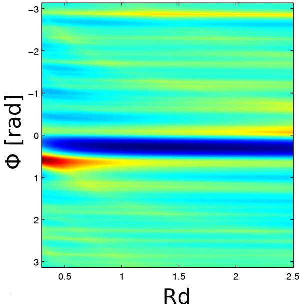
Minimize the quadratic mean of the residual phase

$$\mathrm{MSP}(Rd, \phi, N) = \frac{1}{N} \sum_{h=1}^{N} \left(\angle R_h^{(Rd,\phi)} \right)^2$$

Method MSP



Functions of Phase Distorsion

Functions of Phase Distorsion (FPD)

Functions of Phase Distorsion of X_h:

$$\Phi_k(X_h) = \Delta^{-1}\Delta^2\angle\left(\frac{X_h}{\mathcal{E}_-(X_h)}\right)$$

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$\mathcal{E}_-(.)$ Minimum phase realization of X_h
$\Rightarrow$ remove the VTF C_{h-}

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Δ^2 2^{nd} order difference operator
$\Rightarrow$ remove the linear-phase component $e^{jh\phi}$

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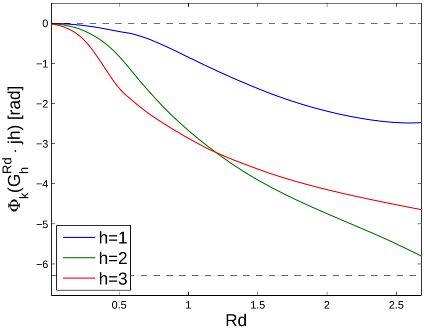
Δ^2 2^{nd} order difference operator
$\Rightarrow$ remove the linear-phase component $e^{jh\phi}$

Δ^{-1} anti-difference operator
$\Rightarrow$ obtain a representation similar to the group-delay

FPD - Example

For the Liljencrants-Fant (LF) model:

$$\Phi_k(G_h^{Rd} \cdot jh) = \Delta^{-1}\Delta^2 \angle \left(\frac{G_h^{Rd} \cdot jh}{\mathcal{E}_-(G_h^{Rd} \cdot jh)} \right)$$



FPD - Properties

FPD

$$\Phi_k(X_h) = \Delta^{-1}\Delta^2\angle\left(\frac{X_h}{\mathcal{E}_-(X_h)}\right)$$

Property of $\Phi_k(G_h^{Rd})$ for a glottal model:

1. Independent of the glottal pulse duration (period length)
2. Independent of the minimum-phase component
3. Independent of the time position of the glottal pulse
4. Independent of its amplitude E

$\Rightarrow$ Only related to the shape of the glottal pulse

FPD and phase minimization

The convolutive residual can be expressed as:

$$R_h^{Rd} = \frac{S_h}{e^{jh\phi} \cdot G_h^{Rd} \cdot \mathcal{E}_-(S_h/G_h^{Rd} \cdot jh) \cdot jh} = e^{-jh\phi} \frac{S_h/G_h^{Rd} \cdot jh}{\mathcal{E}_-(S_h/G_h^{Rd} \cdot jh)}$$

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To get ride fo the linear-phase term we can use the differance operators:

$$\Delta^{-1}\Delta^2\angle\left(R_h^{Rd}\right) = \Delta^{-1}\Delta^2\angle\left(\frac{S_h/G_h^{Rd} \cdot jh}{\mathcal{E}_-(S_h/G_h^{Rd} \cdot jh)}\right)$$

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Which is equal to the FPD:

$$\Phi_k(X_h) = \Delta^{-1}\Delta^2\angle\left(\frac{X_h}{\mathcal{E}_-(X_h)}\right) \quad \text{with} \quad X_h = S_h/G_h^{Rd} \cdot jh$$

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We therefore minimize the error:

$$\mathrm{MSPD}^2(Rd, N) = \frac{1}{N}\sum_{k=1}^{N}\left(\Phi_k(S_h/G_h^{Rd} \cdot jh)\right)^2$$

Method MSPD^2

MSPD^2: *Mean Squared Phase using the 2^{nd} order phase Difference*

Method based on $MSPD^2$

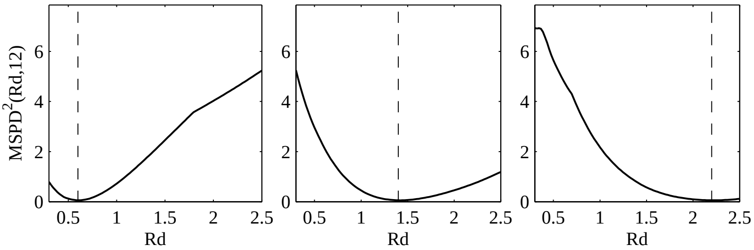

Figure: $MSPD^2(Rd, 12)$ with 3 different synthetic signals with different Rd values.

Quasi-closed form expression of the *Rd* parameter

FPD - Quasi-closed form expression of the *Rd* parameter

Goal: Find an explicit expression of Rd from S_h (e.g. $Rd = f(S_h)$)

$$S_h = e^{jh\phi} \cdot G_h^{Rd} \cdot \mathcal{E}_{-}\left(\frac{S_h}{G_h^{Rd} \cdot jh}\right) \cdot jh$$

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And we put observations and models on each side of the equation:

$$\frac{S_h}{\mathcal{E}_-(S_h)} = e^{jh\phi} \cdot \frac{G_h^{Rd} \cdot jh}{\mathcal{E}_-(G_h^{Rd} \cdot jh)}$$

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$$\frac{S_h}{\mathcal{E}_-(S_h)} = e^{jh\phi} \cdot \frac{G_h^{Rd} \cdot jh}{\mathcal{E}_-(G_h^{Rd} \cdot jh)}$$

$\Rightarrow$

$$\Phi_k(S_h) = \Phi_k(G_h^{Rd} \cdot jh)$$

FPD - Expression quasi explicite de Rd - Méthode

$$\Phi_k(S_h) = \Phi_k(G_h^{Rd} \cdot jh)$$

$$\text{for } \sigma_k = \Phi_k(S_h) \text{ find } Rd : \Phi_k(G_h^{Rd} \cdot jh) = \sigma_k$$

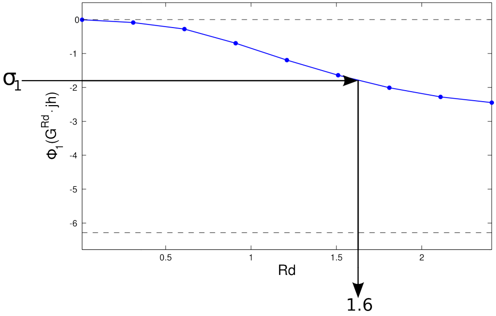
Method FPD^{-1}

FPD - Expression quasi explicite de *Rd* - Méthode

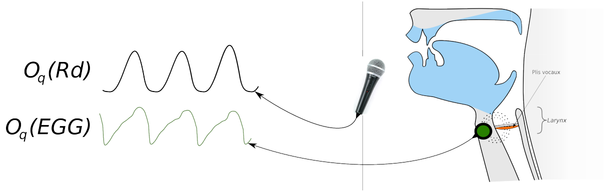
$$\Phi_k(S_h) = \Phi_k(G_h^{Rd} \cdot jh)$$

for $\sigma_k = \Phi_k(S_h)$ find Rd : $\Phi_k(G_h^{Rd} \cdot jh) = \sigma_k$ Method FPD^{-1}

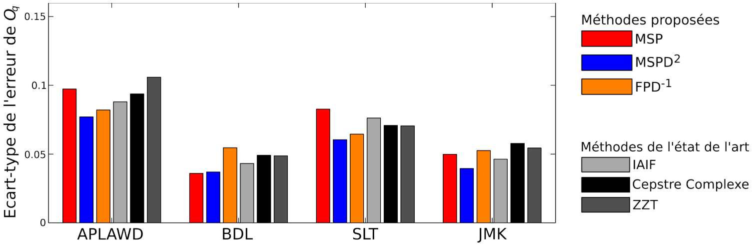
Numerical approximation using a lookup table:



Evaluation



We compare $O_q(Rd)$ vs. $O_q(EGG)$



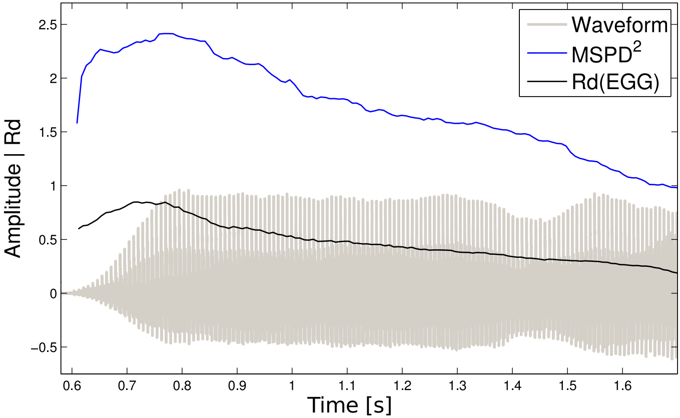
IAIF P. Alku, and H. Tiitinen and R. Naatanen, *A method for generating natural-sounding speech stimuli for cognitive brain research*.

CC T. Drugman, B. Bozkurt and T. Dutoit, *Complex Cepstrum-based Decomposition of Speech for Glottal Source Estimation*.

ZZT B. Bozkurt, B. Doval, C. d'Alessandro and T. Dutoit, *ZZT representation with application to source-filter separation in speech*.

Example of estimation

Son



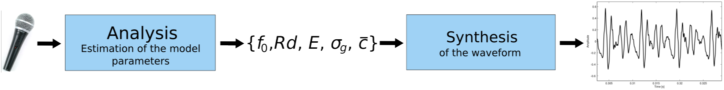
Application
Voice transformation

Analysis/Synthesis - SVLN

Model of the voice production used in SVLN

$$S(\omega) = \left[H^{f_0}(\omega) \cdot G^{Rd}(\omega) + N^{\sigma_g}(\omega)\right] \cdot C^{\bar{c}}_{-}(\omega) \cdot j\omega$$

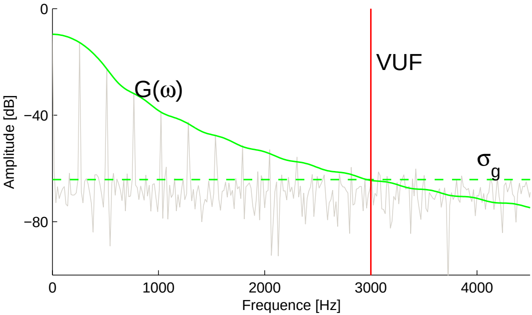
Analysis/Synthesis procedure



SVLN: *Separation of the Vocal-tract with the Liljencrants-Fant model plus Noise*

Analysis - Estimation of the glottal source parameters

- f_0 Known *a priori*
- Rd Method based on MSPD[2]
- E Log energy of the window
- σ_g Crossing point between $G(\omega)$ and VUF

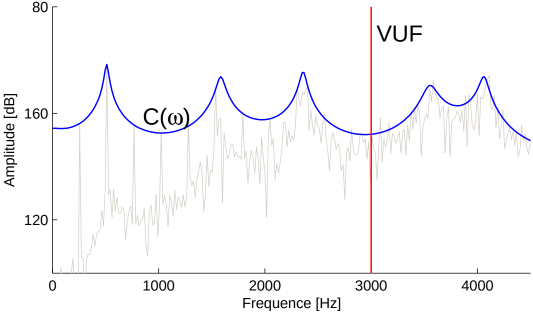


VUF known *a priori* by classification of the spectral peaks.

Analysis - Estimation of the VTF

$$C(\omega) = \begin{cases} \mathcal{T}\left(\frac{S(\omega)}{G^{Rd}(\omega)\cdot j\omega}\right)\cdot\gamma^{-1} & \text{if } \omega < \text{VUF} \\ \mathcal{P}\left(\frac{S(\omega)}{G^{Rd}(\text{VUF})\cdot j\omega}\right)\cdot\frac{\sqrt{\pi/2}}{\gamma\cdot e^{0.058}} & \text{if } \omega \geq \text{VUF} \end{cases}$$

$\mathcal{T}(.)$ The *True-envelope*
$\mathcal{P}(.)$ Real cepstrum
$\gamma = \sum_t \text{win}[t]/(f_s/f_0)$ number of periods in the window.



C. Yeh, *Multiple fundamental frequency estimation of polyphonic recordings*, Ph.D. thesis, UPMC, 2008.

Synthesis

- A sound chunk: Pulses $G(\omega)$ · VTF $C(\omega)$ · Radiation synthesis $L(\omega)$

Synthesis

- A sound chunk: Pulses $G(\omega) \cdot$ VTF $C(\omega) \cdot$ Radiation synthesis $L(\omega)$
- *Overlap-add* of the sound chunks

Synthesis

- A sound chunk: Pulses $G(\omega)$ · VTF $C(\omega)$ · Radiation synthesis $L(\omega)$
- *Overlap-add* of the sound chunks

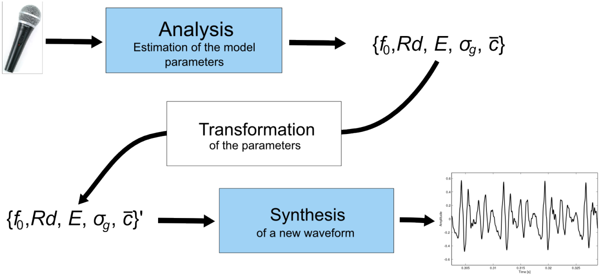
For any observed speech spectrum $S(\omega)$:

$|S(\omega)|$ always reproduced

$\angle S(\omega)$ imposed by the glottal model, the Gaussian noise and the phase of the VTF ($\angle C_{-}(\omega)$)

Voice transformation

Transformation process



Sound examples

http://gillesdegottex.eu/SVLN

Σας ευχαριστώ για την προσοχή σας

Τέλος Ενότητας

Χρηματοδότηση

- Το παρόν εκπαιδευτικό υλικό έχει αναπτυχθεί στα πλαίσια του εκπαιδευτικού έργου του διδάσκοντα.
- Το έργο «**Ανοικτά Ακαδημαϊκά Μαθήματα στο Πανεπιστήμιο Κρήτης**» έχει χρηματοδοτήσει μόνο τη αναδιαμόρφωση του εκπαιδευτικού υλικού.
- Το έργο υλοποιείται στο πλαίσιο του Επιχειρησιακού Προγράμματος «Εκπαίδευση και Δια Βίου Μάθηση» και συγχρηματοδοτείται από την Ευρωπαϊκή Ένωση (Ευρωπαϊκό Κοινωνικό Ταμείο) και από εθνικούς πόρους.

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Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

Σημειώματα

Σημείωμα αδειοδότησης

.

Σημείωμα Αναφοράς

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