Formant Estimation from Noisy Voiced Speech

Ashok Krishnamurthy
Jian Li
Randy Moses
Department of Electrical Engr.
The Ohio State University

Closed phase speech signal model

- Speech signal in the closed phase is the free response of a linear system.
- Let $s(n)$, $n = 0, \ldots, N-1$ be speech signal in closed phase. Then

$$s(n) = \sum_{i=1}^{K} A_i e^{-\alpha_i n} \cos(\omega_i n + \phi_i) + e(n).$$

- The formant frequencies are

$$\frac{\omega_i F_s}{2\pi} \text{Hz}, i = 1, \ldots, K.$$

  F_s is the sampling frequency in Hz.

- The formant bandwidths are

$$\frac{\alpha_i F_s}{\pi} \text{Hz}, i = 1, \ldots, K.$$

- The energy of each formant mode in the closed phase is

$$\frac{(1 - |z_i|^{2(N-1)})|c_i^2|}{1 - |z_i|^2}, \; i = 1, \ldots, K.$$

  where $z_i = e^{-\alpha_i + j\omega_i}$ and $c_i = A_i e^{j\phi_i}$.

Solution Procedure

- Two step solution procedure. (Parthasarathy and Tufts, IEEE ASSP–35, Sep. 1987).

- First step:
  Solve backward linear prediction equations:

$$\underbrace{\begin{bmatrix} s(1) & s(2) & \cdots & s(L) \\ s(2) & s(3) & \cdots & s(L+1) \\ \vdots & \vdots & \vdots & \vdots \\ s(N-L) & s(N-L+1) & \cdots & s(N-1) \end{bmatrix}}_{Y} \underbrace{\begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_L \end{bmatrix}}_{\underline{b}}$$

$$= -\underbrace{\begin{bmatrix} s(0) \\ s(1) \\ \vdots \\ s(N-L-1) \end{bmatrix}}_{\underline{y}}$$

Solution Procedure (contd.)

- Second step:

  Find roots of $B(z) = z^L + b_1 z^{L-1} + \cdots + b_L$. The formants are a subset of these roots, and this gives the formant frequencies and bandwidths.

  Use the roots to obtain the amplitudes, phases and energies of the formants.

- Retain K highest energy modes as the formants.

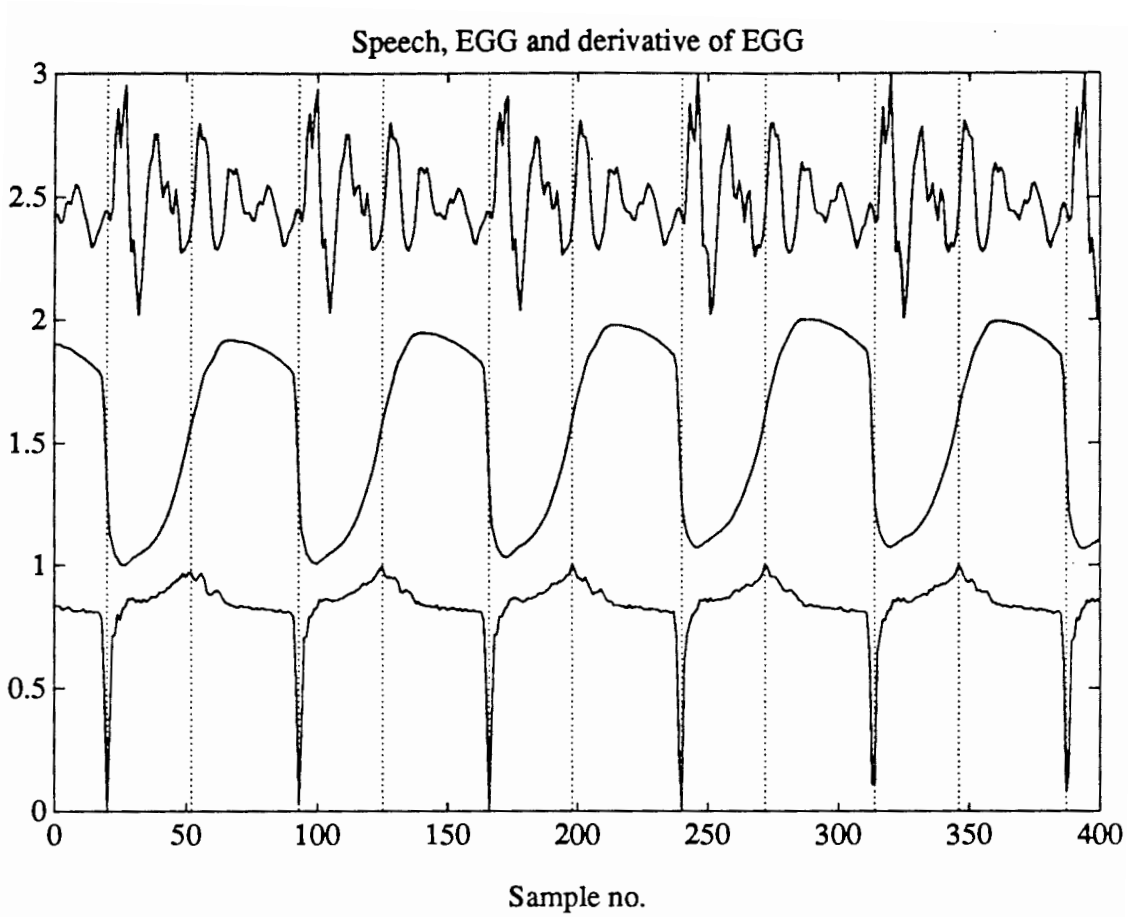
Modifications to Parthasarathy & Tufts procedure

- Use the electroglottograph signal to locate the closed glottal phase.
- Use total least squares in solving $Y\underline{b} = -\underline{y}$.
- Use data from multiple consecutive closed phases (typically 3). $Y_1\underline{b} = -\underline{y_1}$, $Y_2\underline{b} = -\underline{y_2}$ and $Y_3\underline{b} = -\underline{y_3}$ are combined to yield

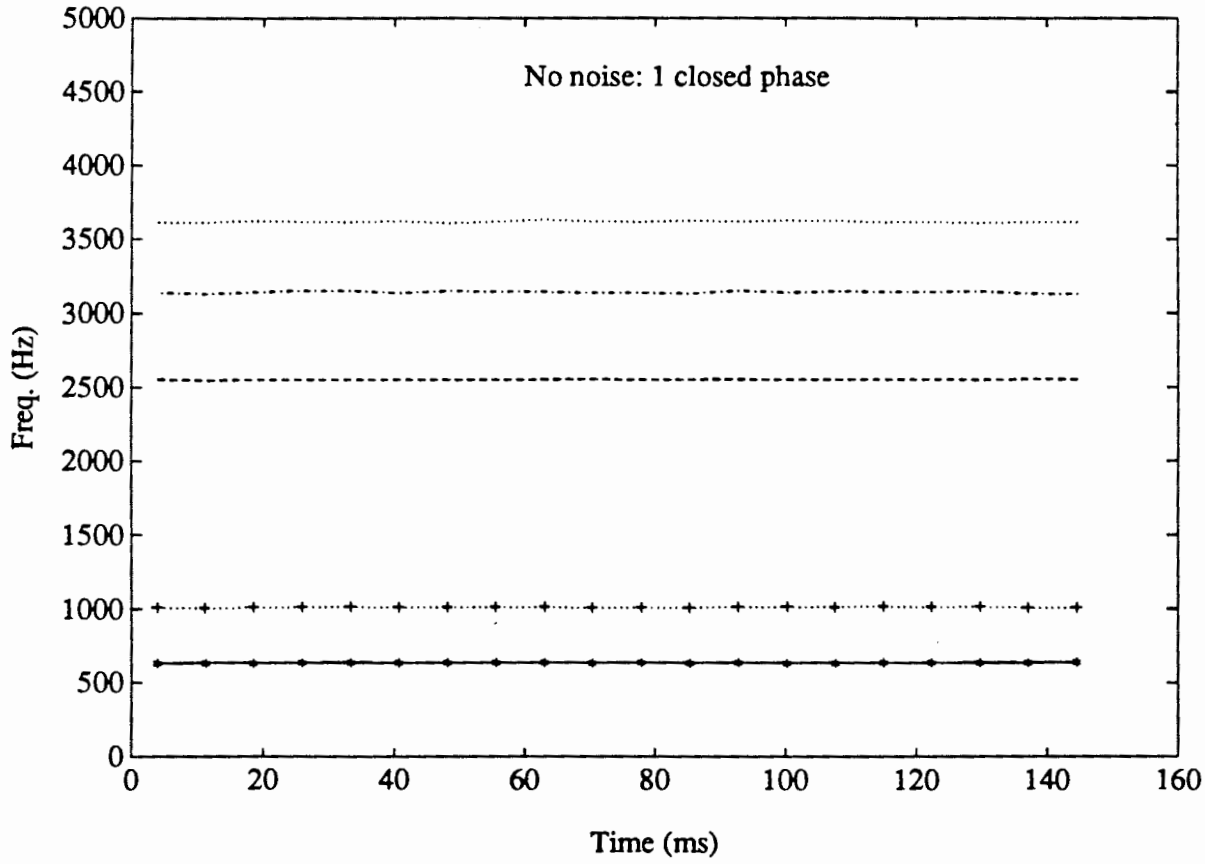
$$\begin{bmatrix} Y_1 \\ Y_2 \\ Y_3 \end{bmatrix} \underline{b} = - \begin{bmatrix} \underline{y_1} \\ \underline{y_2} \\ \underline{y_3} \end{bmatrix}.$$

Example Results

- Normal, male speaker.
- Analyzed steady vowel portion from "bach".
- 16 bit A/D, sampling frequency 10 KHz.
- Simultaneously recorded speech and electroglottograph signals.

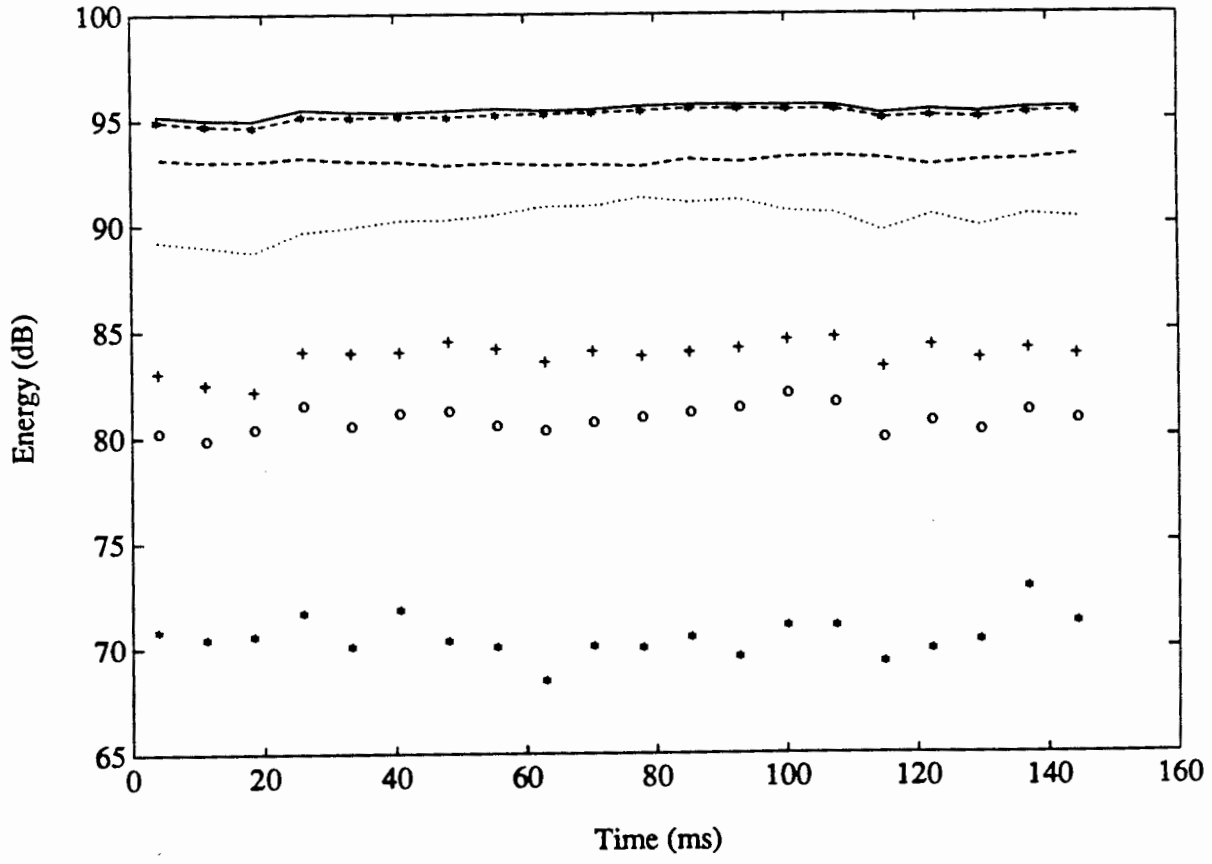

Speech, EGG and derivative of EGG
3
2.5
2
1.5
1
0.5
0
0
50
100
150
200
250
300
350
400
Sample no.

Formant contour, no noise



Energy of different formant modes

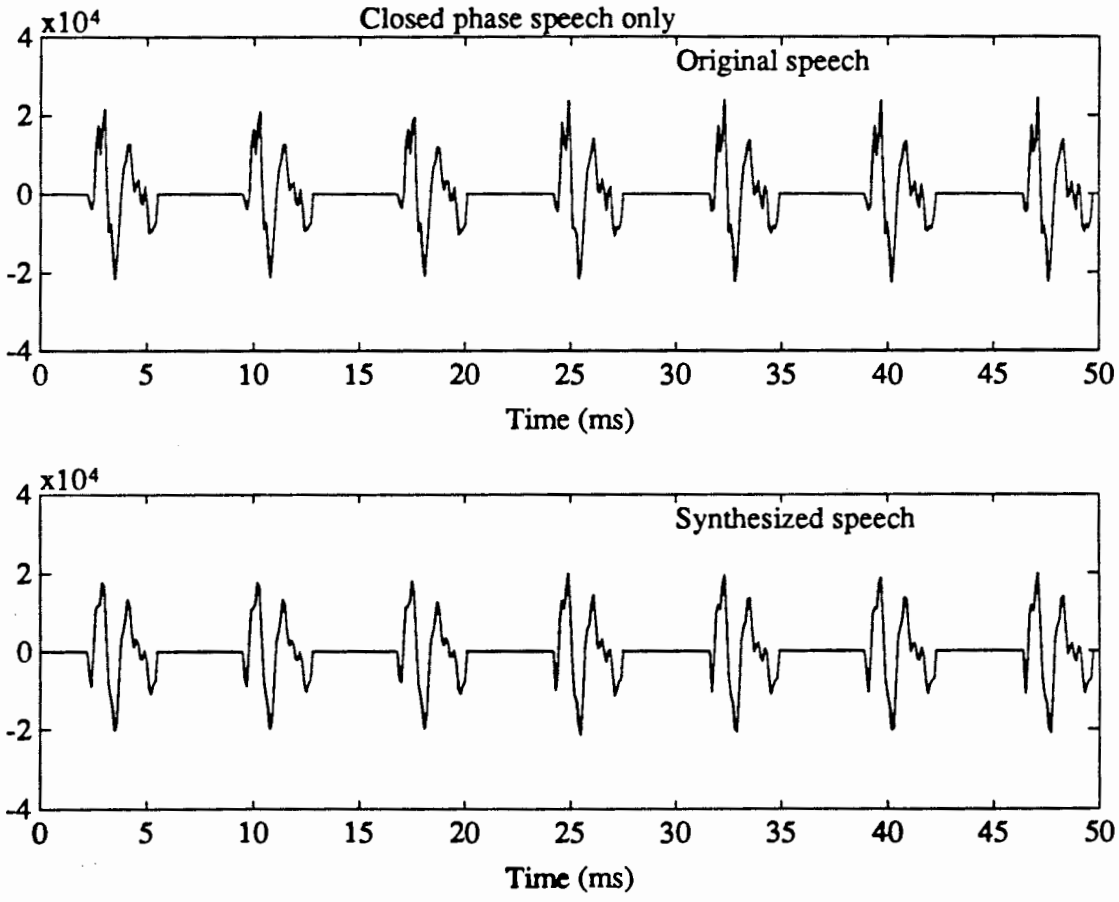
- speech signal ——
- first formant ----------
- second formant .....
- third formant + +
- three highest energy formants -•-•-



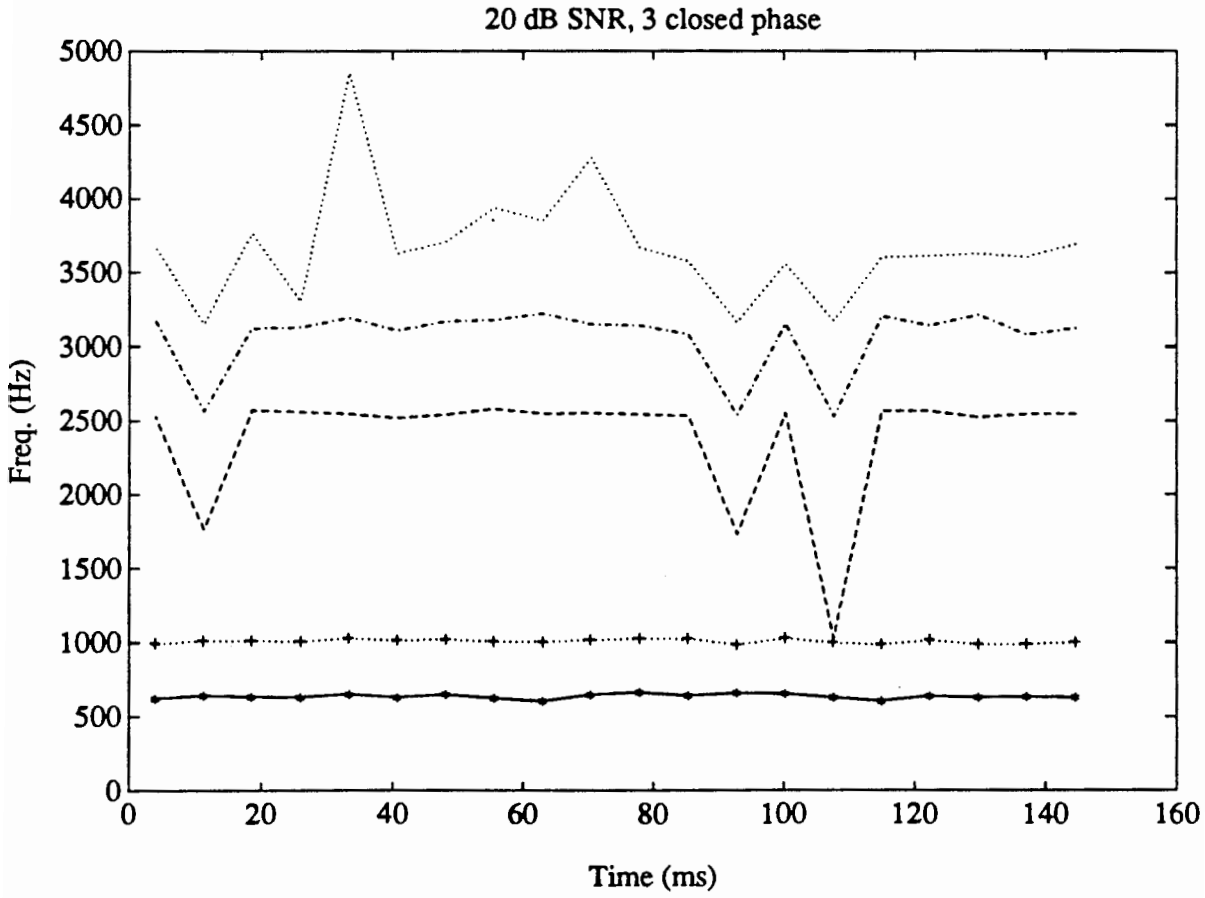
Comparison of original and synthesized speech

No noise.

Only 3 highest energy formants used in synthesis.



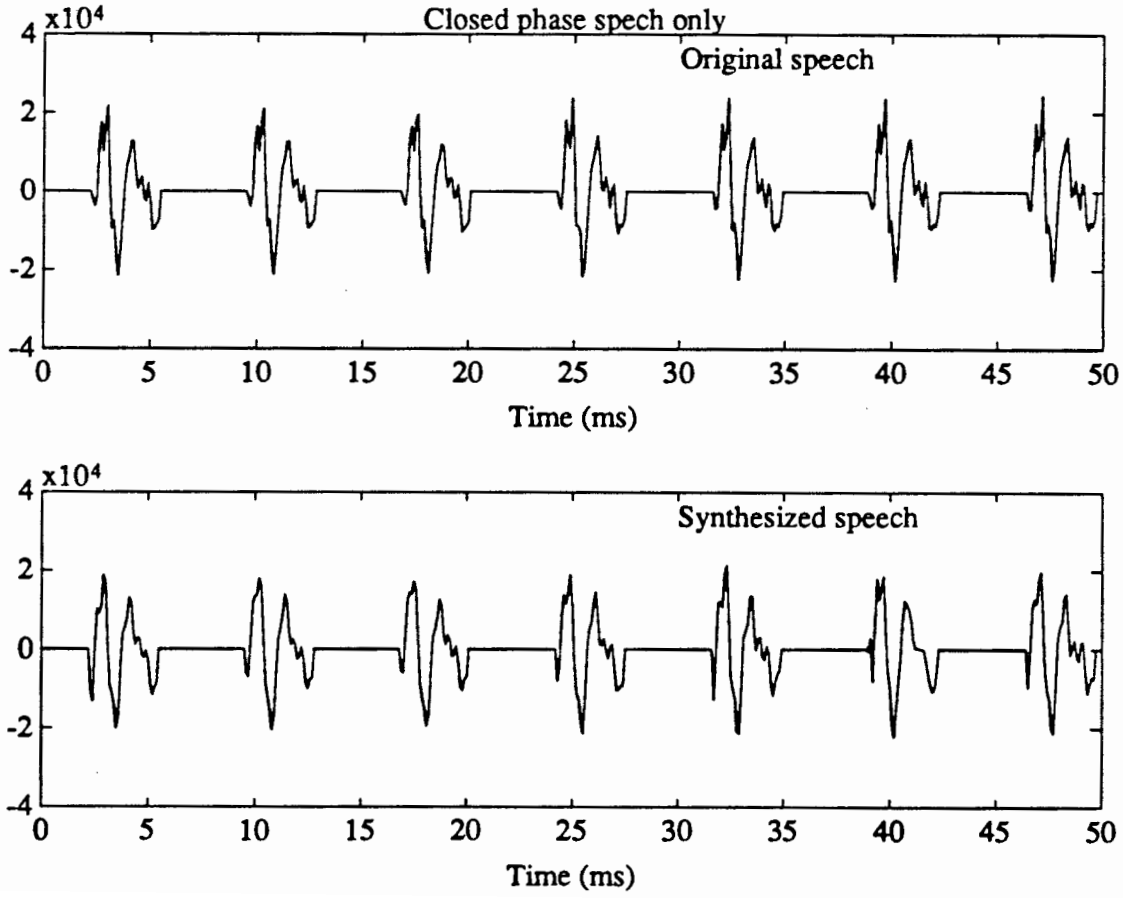
Formant contour, 20 dB SNR



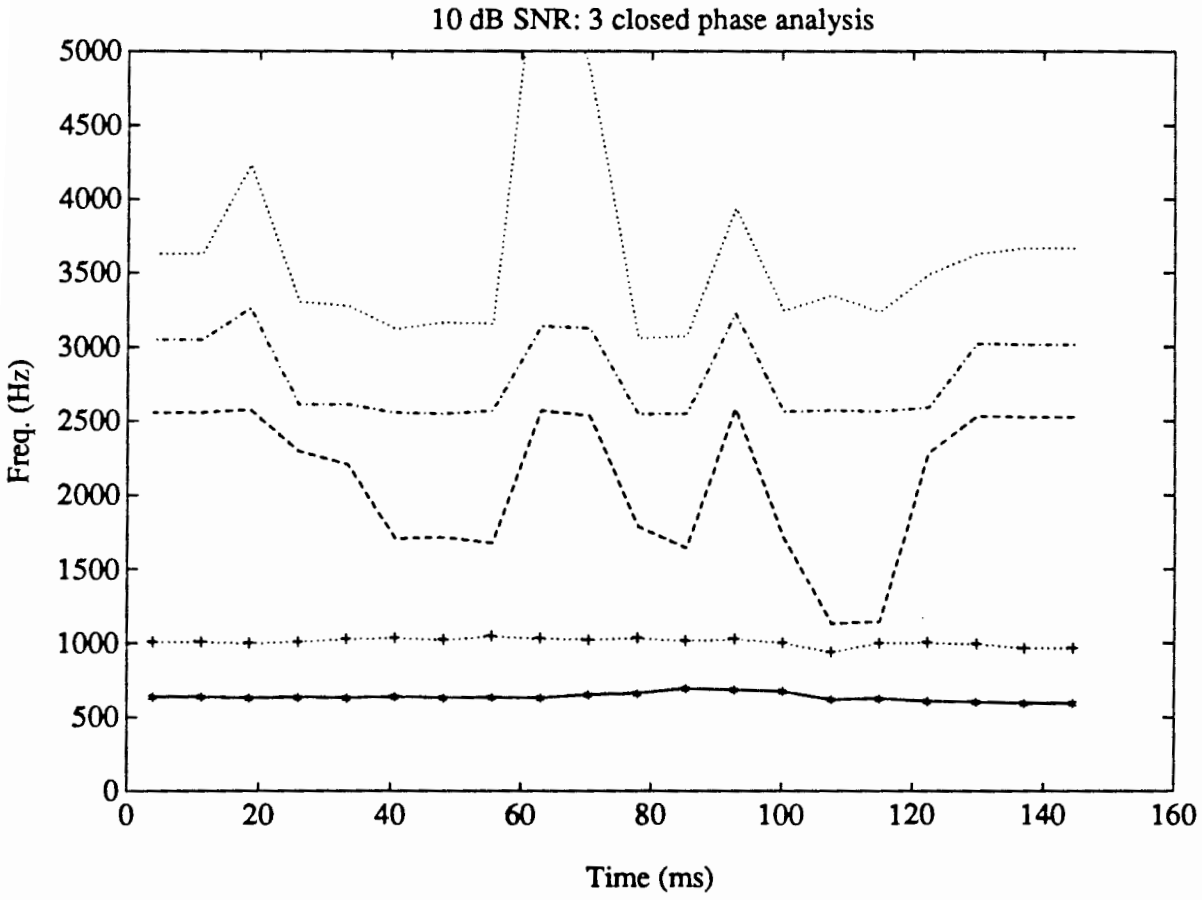
Comparison of original and synthesized speech

20 dB SNR.

Only 3 highest energy formants used in synthesis.



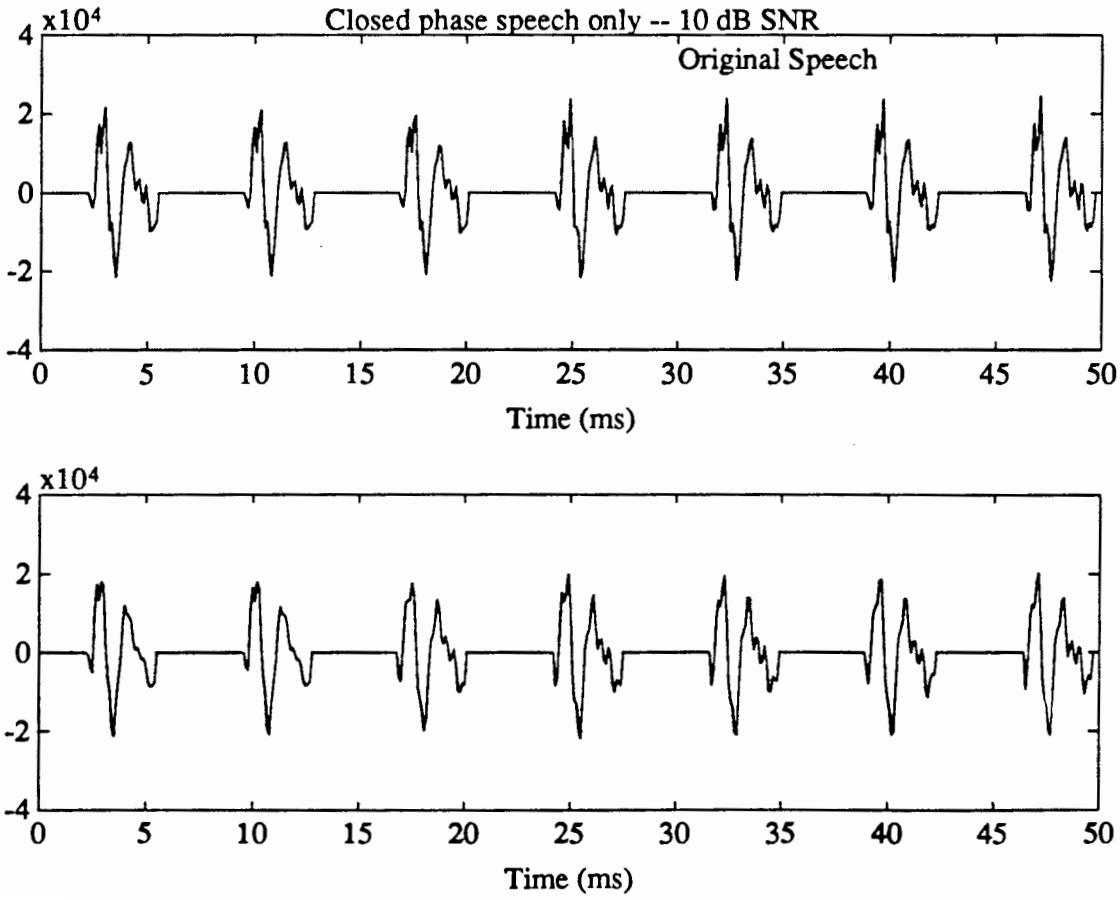
Formant contour, 10 dB SNR



Comparison of original and synthesized speech

10 dB SNR.

Only 3 highest energy formants used in synthesis.



Conclusions

- Very effective method of formant estimation for clean speech signal.
- Three formants appear to account for most (90 %) of the energy in the closed phase for vowels.
- Performance is good with noisy speech signals upto 20 dB SNR.