Robust Speech Recognition and its ROBOT implementation

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Part 1

NOISE ROBUST TECHNOLOGY

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Conditions for Speech Recognition

Short Isolated Speech:
words, phrase (<2sec)

Continuous Speech:
sentences (>2sec)

Attached Mic
(several cm – 10cm)

Remote Mic:
(10cm – 5m)

Long Distance Mic:
(>5m)

Silent Room
(>20dB)

Living Room(20
～10dB)

Noisy Room:
exhibition(<10dB)

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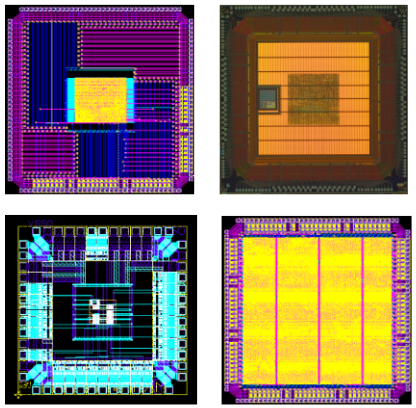
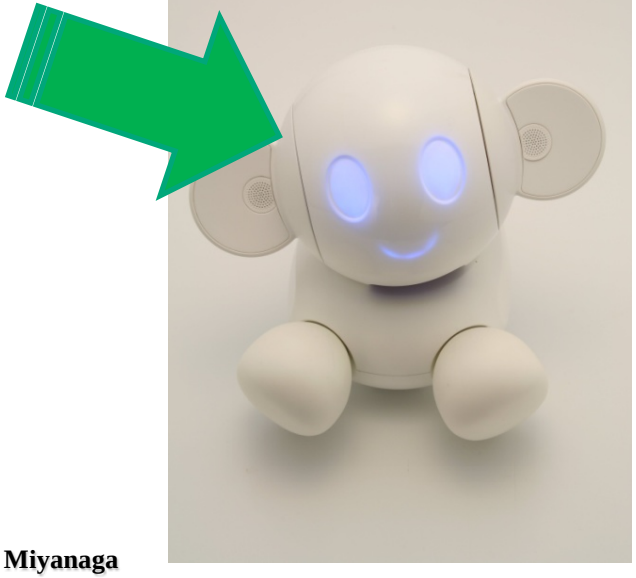
Robot Implementation

- **Autonomous Speech Recognition**
- Speech Synthesis
- Quick Response
- Control to Consumer Electronics and Machines





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Hokkaido University Speech Communication System (HU-SCS)

Short Isolated Speech: words, phrase (<2sec)

Long Distance Mic: (>5m)

Remote Mic: (10cm – 5m)

Silent Room (>20dB)

Attached Mic (several cm – 10cm)

Living Room（20～10dB)

Noisy Room: exhibition（<10dB)

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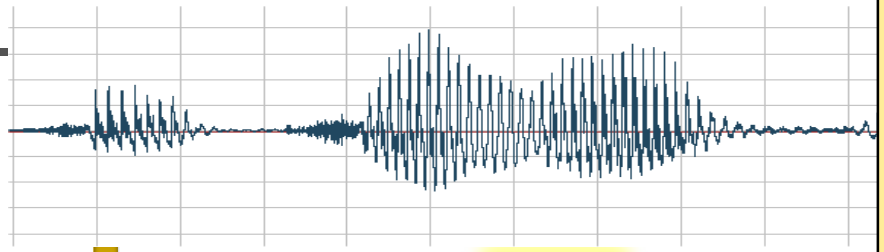
HU-SCS



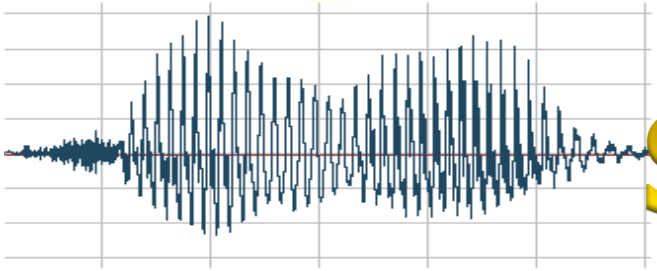
Speech

HU-SCS v4
- 99% over SNR 10dB
- BP＋Threshold Opt
- F_0 Detection

No good detection under SNR < 5dB

Automatic Speech Detection

VAD
(Voice Activity Detection)



Speech

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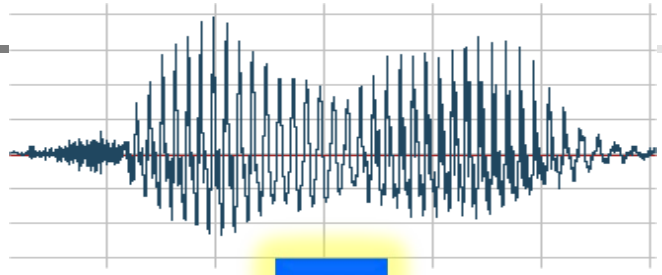
HU-SCS



Speech

Automatic Speech Recognition

Candidates of Recognition Results
(1) Good Morning
(2) See you
(3) How are you ?

Phase

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Noise modeling

- Spectrum including noise can be modeled as,

$$X(n,\omega) = S(n,\omega)H(\omega) + A(\omega)$$

Clean spectrum	Multiplicative noise	Additive noise

$$\log \quad E(n,\omega) = S(n,\omega)H(\omega)$$

$$\log X(n,\omega) = \log(E(n,\omega) + A(\omega))$$

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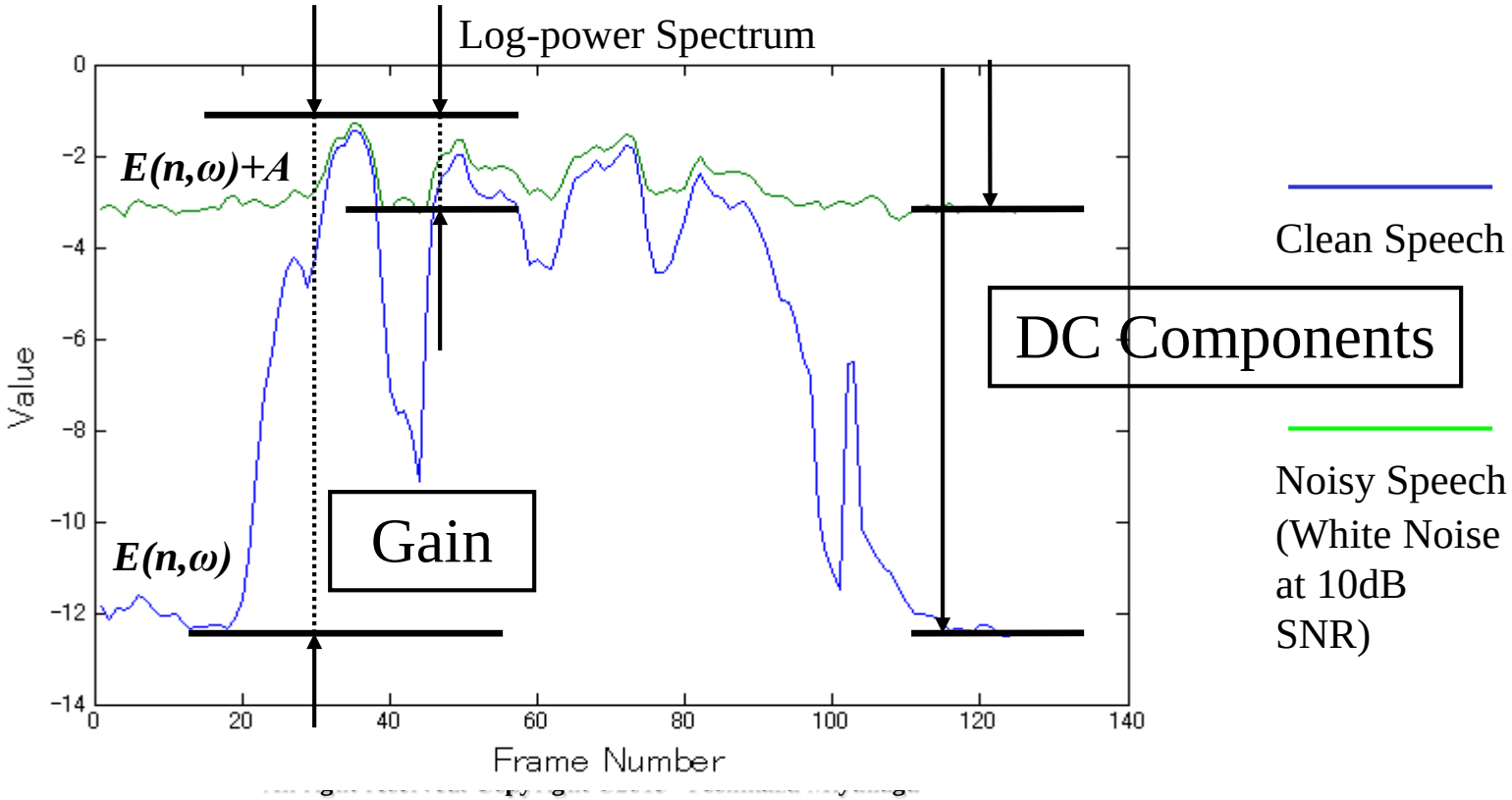
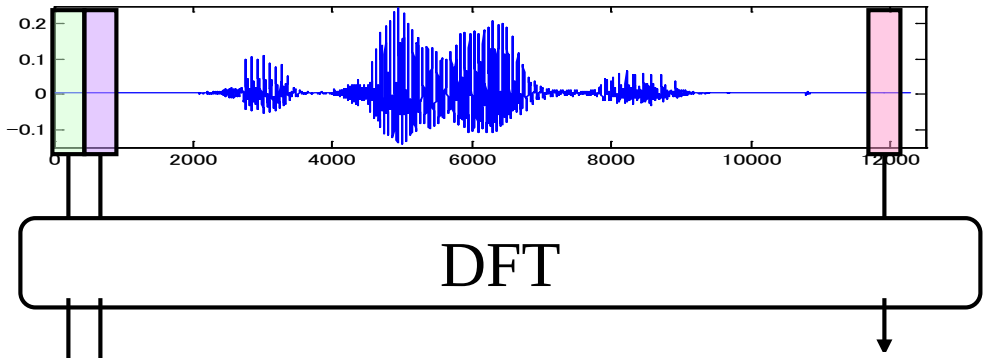
Noise Corruption in Log Power Spectrum

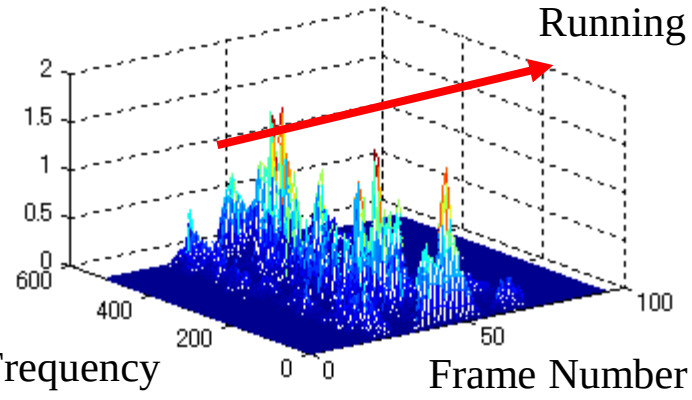
- Noise corruptions make differences on gains and DC components.



Running Spectrum

- Running spectrum is obtained by accumulating short-time spectrum





Running spectrum: time trajectory of frequency

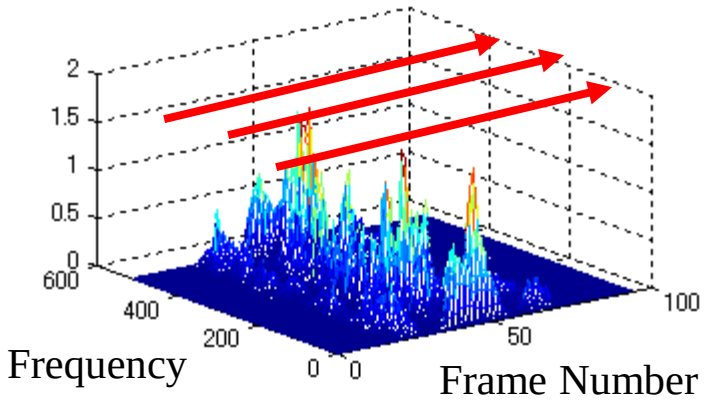
All right r

Modulation Spectrum

- RSF focuses on modulation spectrum

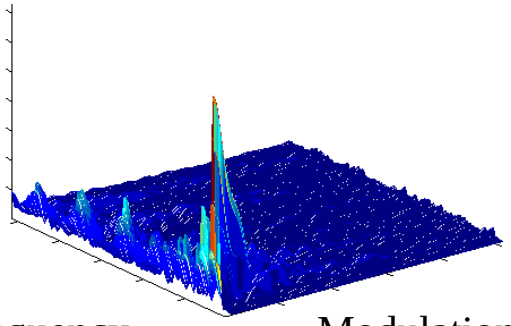
Modulation spectrum: spectrum versus time trajectory of frequency.

Running Spectrum



DFT on each frequency

Modulation Spectrum



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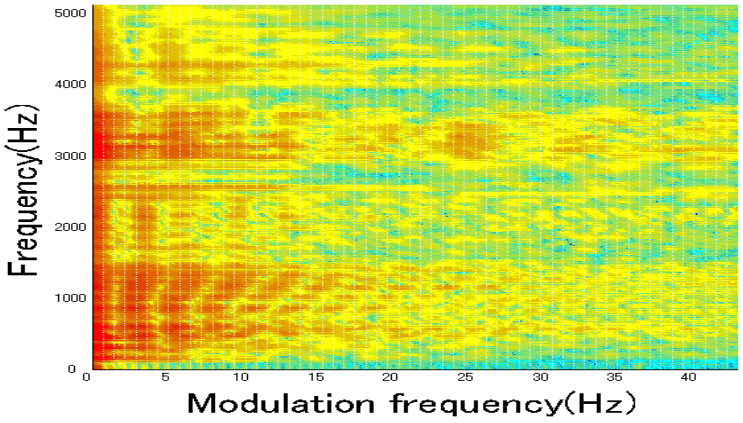
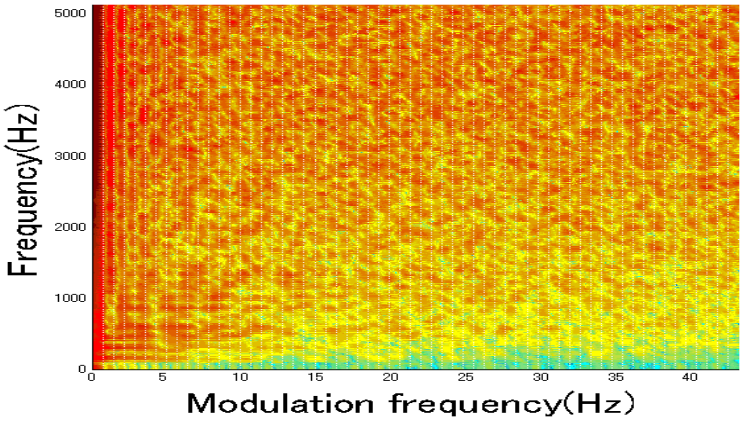
Mod-F of Clean and Noisy Speech

- Speech components are dominant around 4 Hz in modulation spectrum.

Clean



Noisy (white noise at 5 dB SNR)



Lower modulation frequency components can be assumed as noise because of little changes in noise components.

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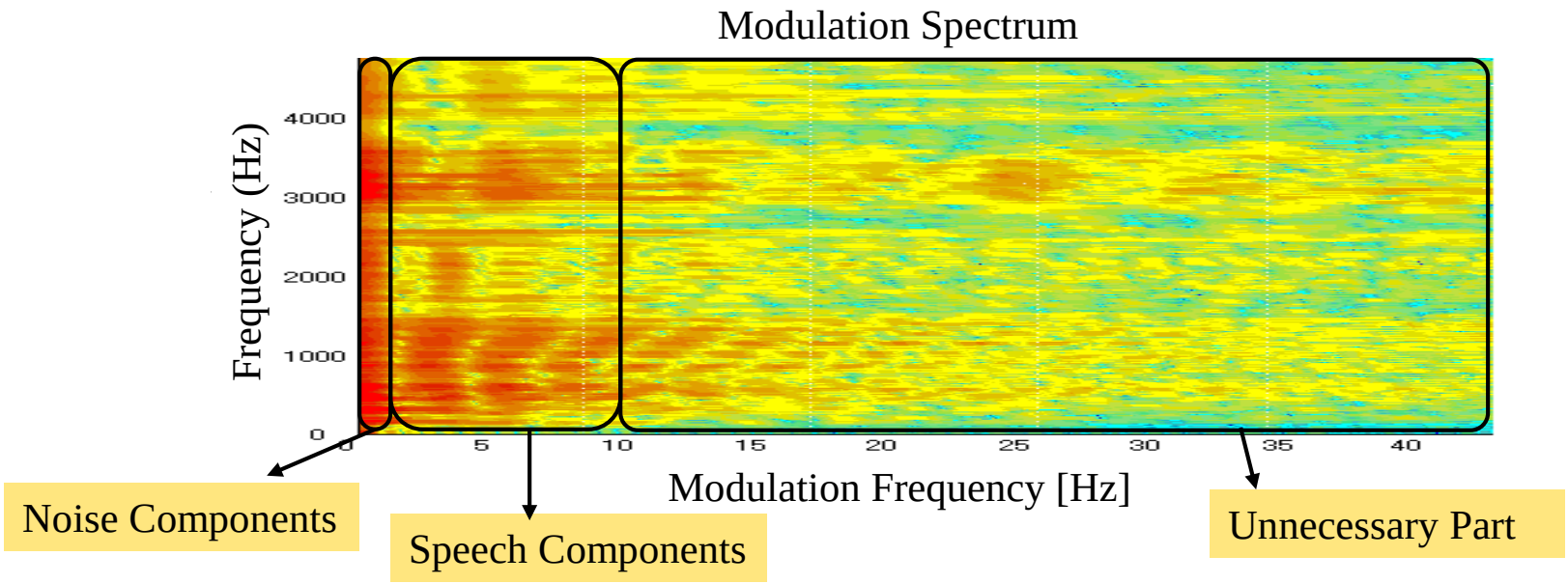
RSF (Running Spectrum Filtering)

- Speech components are dominant around 4 Hz in modulation spectrum.



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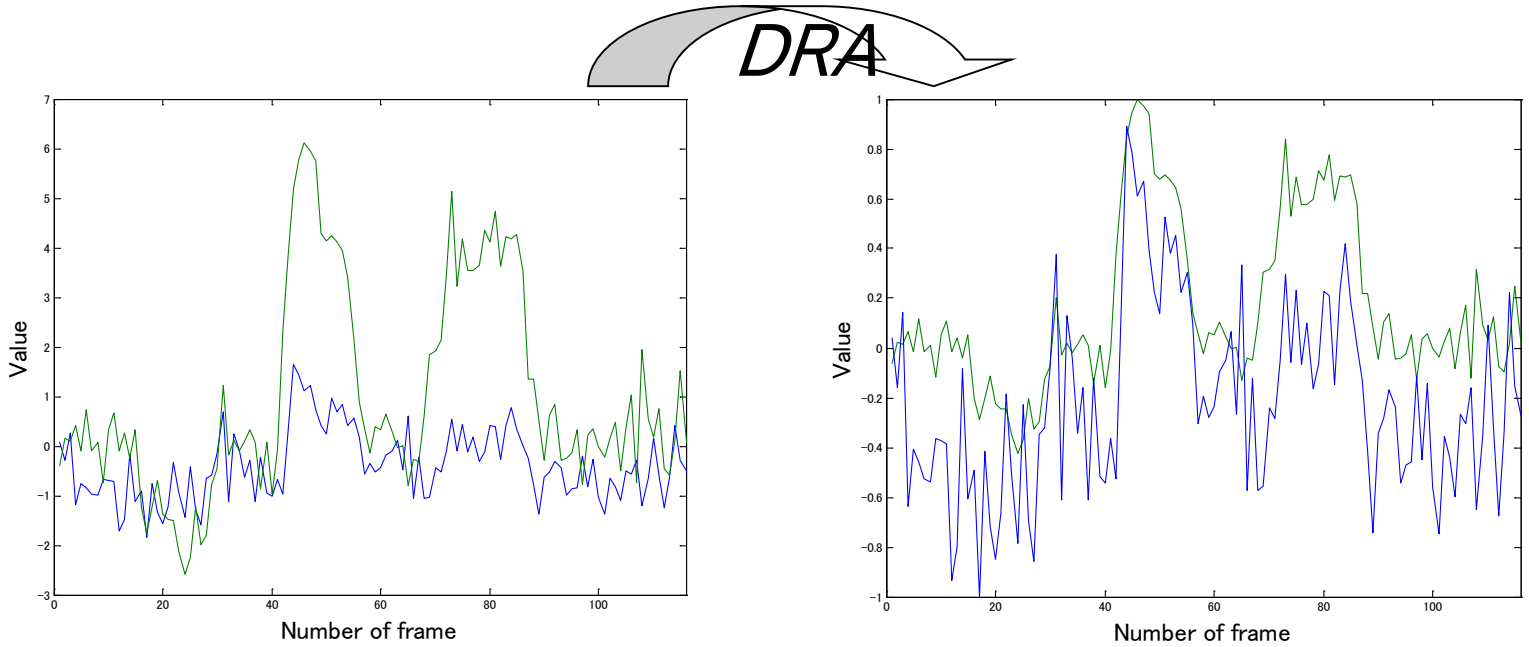
Dynamic Range Adjustment



Green shows the 4th MFCC before DRA and Blue shows after DRA

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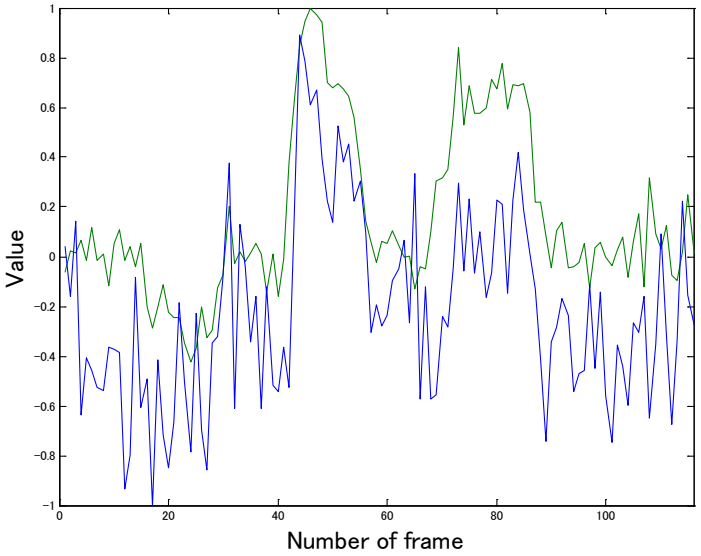
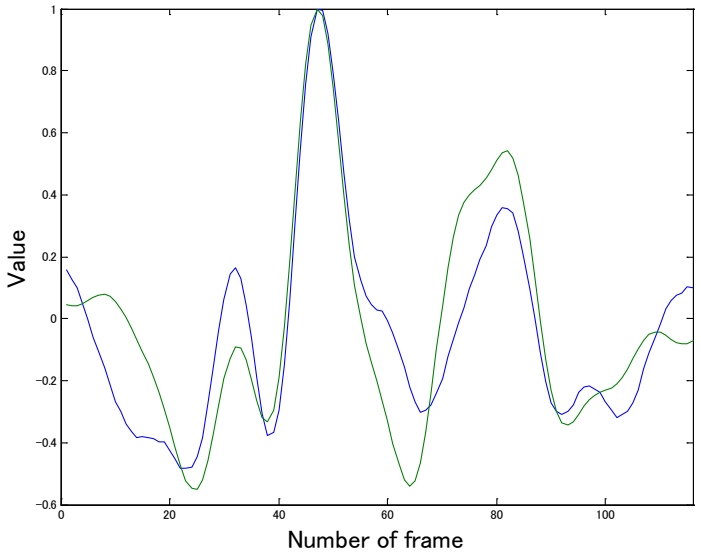
Running Spectrum Filtering





The 4th MFCC by only DRA in the left hand side, and by both DRA and RSF in the right hand side

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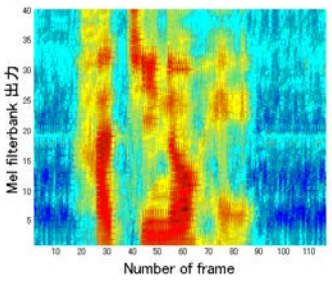
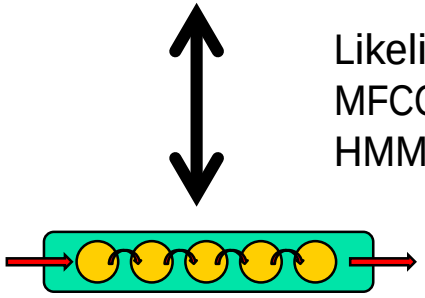
Evaluation on Likelihoods



RSF/DRA reduce noise factors.

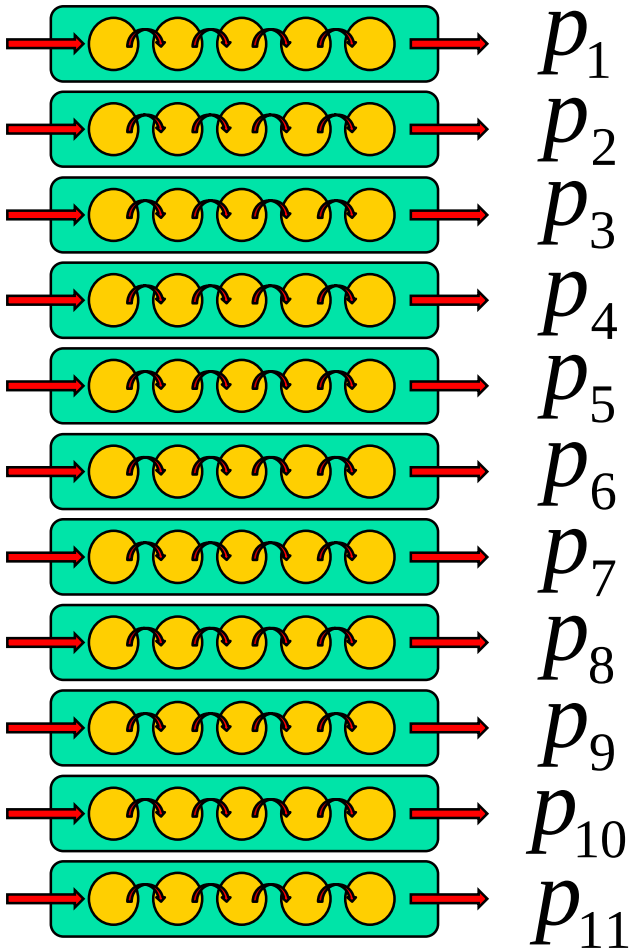
MFCC

Likelihood of MFCC into HMMs



HMM

Training HMM



The **maximum likelihood** is selected and its label is recognized as the result.

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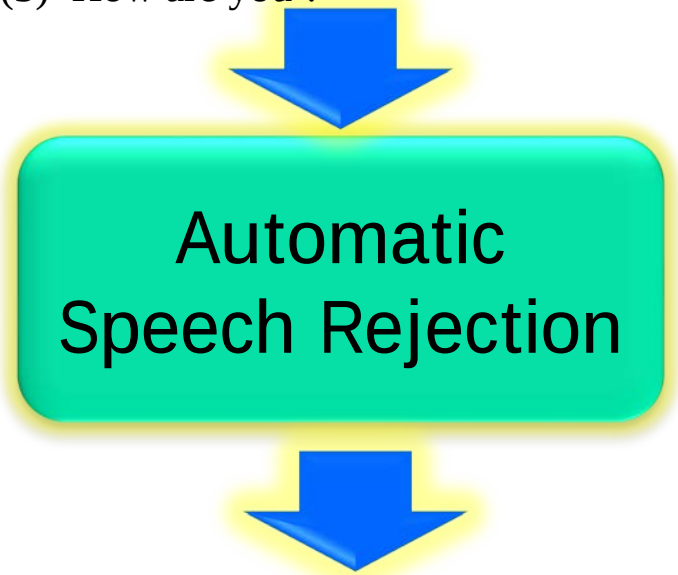
HU-SCS

Candidates of Recognition Results
(1) Good Morning
(2) See you
(3) How are you ?

Phase



Recognition Result
Good Morning

Confidential Phase

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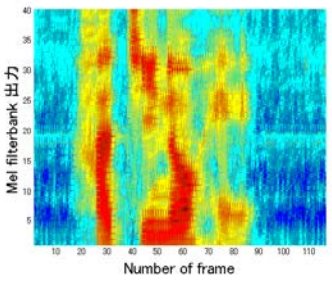
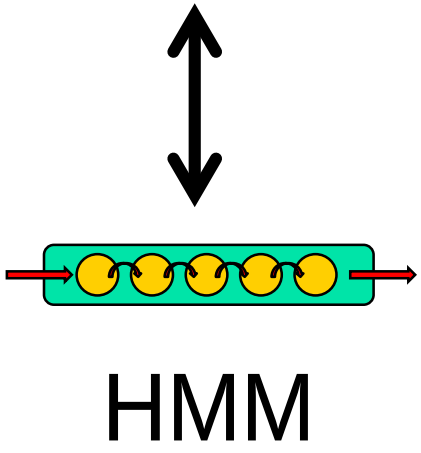
Evaluation on Likelihoods

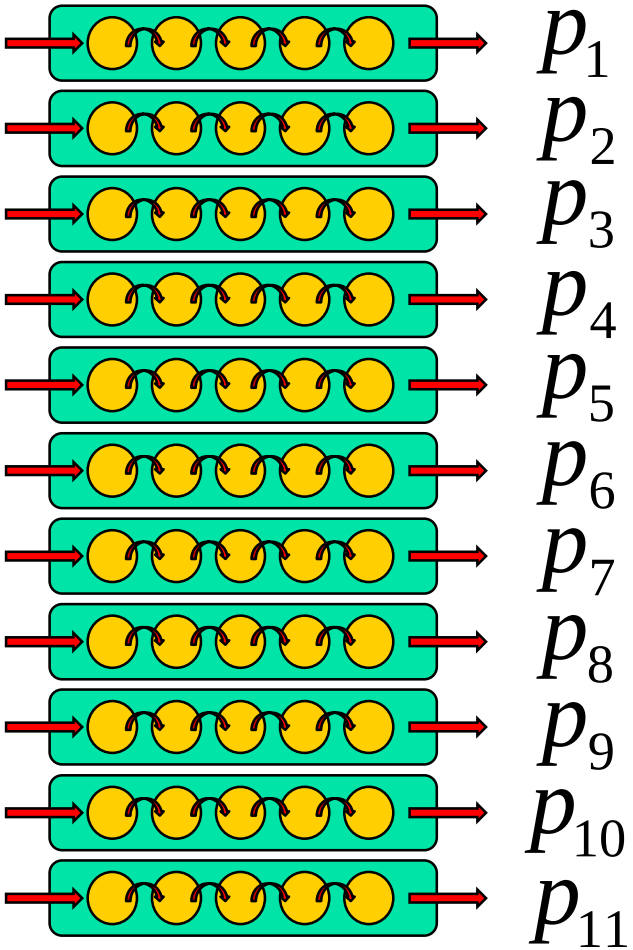
Training HMM



MFCC

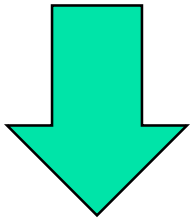


HMM



p_1
p_2
p_3
p_4
p_5
p_6
p_7
p_8
p_9
p_{10}
p_{11}

The maximum likelihood is selected and its label is recognized as the result.



The result is correct, isn't it ?

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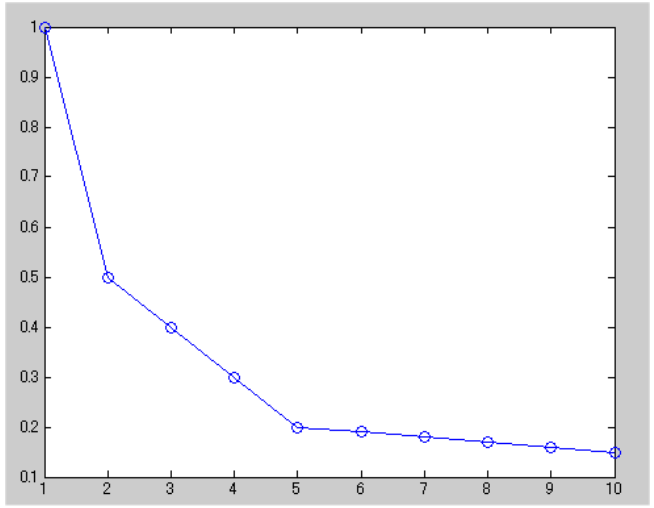
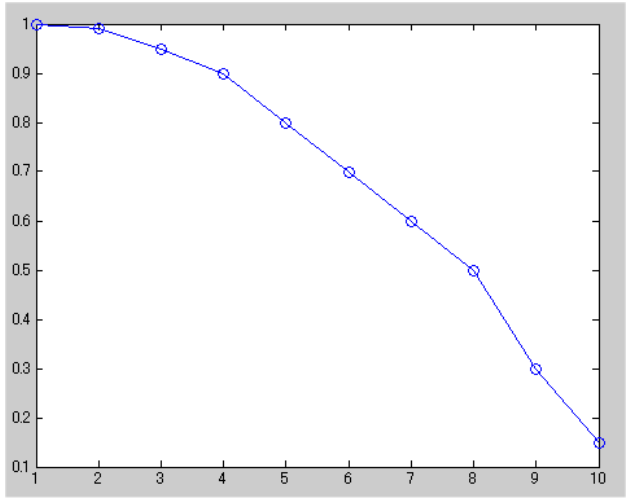
Evaluation of Reliability

Likelihood



The result of the top score is trusted.

Likelihood



The result of the top score is **NOT** trusted.

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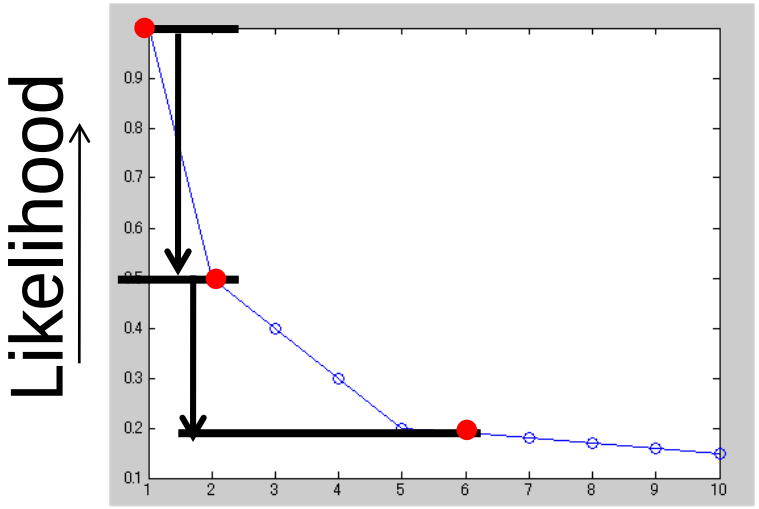
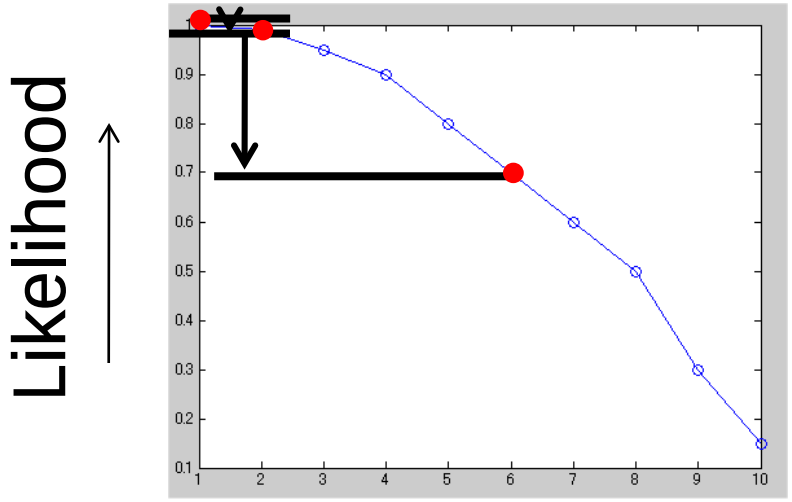
Rejection Method

1. $\frac{1}{5}\sum_{a=k-2}^{k+2}\left[\{L(p_{a1})-L(p_{a2})\}/\{L(p_{a2})-L(p_{a,T})\}\right]>\alpha$
2. $\frac{1}{5}\sum_{a=k-2}^{k+2}\{L(p_{a1})-L(p_{a2})\}>\beta$
3. $\frac{1}{5}\sum_{a=k-2}^{k+2}\{L(p_{a1})-L(p_{a,T})\}>\Delta$

$L(p_{mi})$: Likelihood





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First SCS HW

- LSI IP
- Mobile
- Intelligent Consumer Electronics etc

Fine Advantage

HW with
Low Power

(1) Mobile Appli
- Small
- Low Power

(2) PC free

- Super Low-Power Consumption Design
- Real-Time SCS
  →180nsec/word (10MHz clk) Recognition Time
- Small Scale Design with Special Designed LSI
- Noise Reduction by Array Microphone

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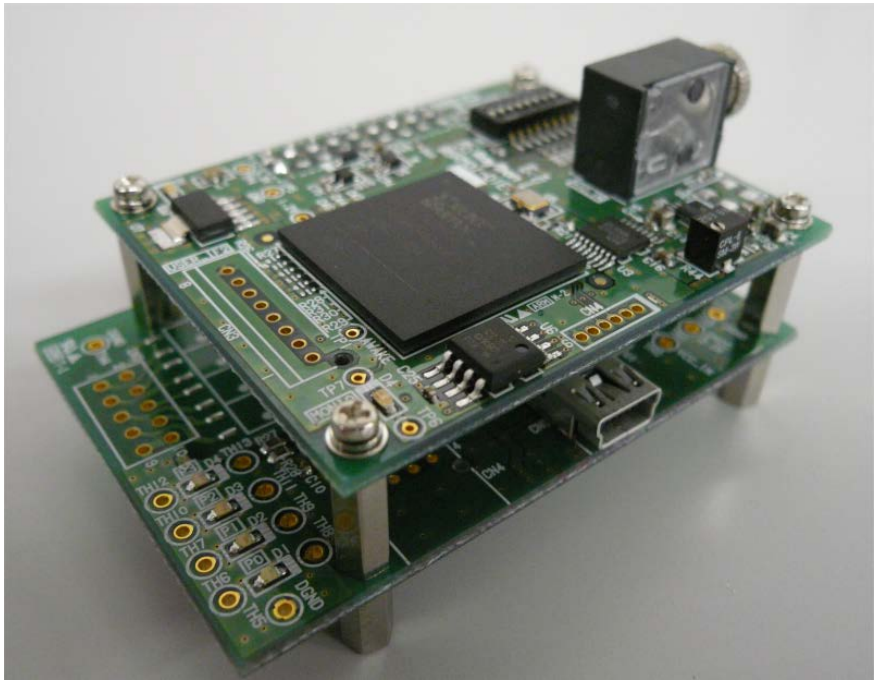
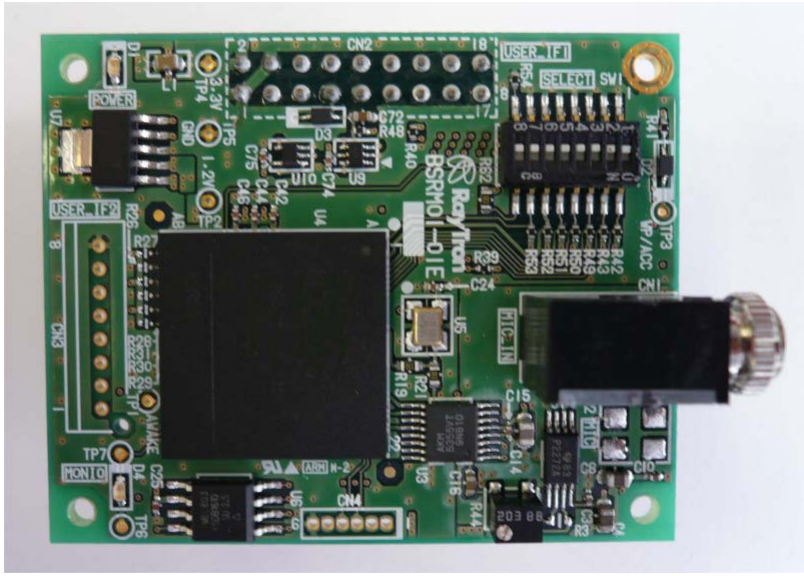
Current HU-SCS v4

PC Interface with
HU-SCS Board





HU-SCS Board

55mm × 44 mm

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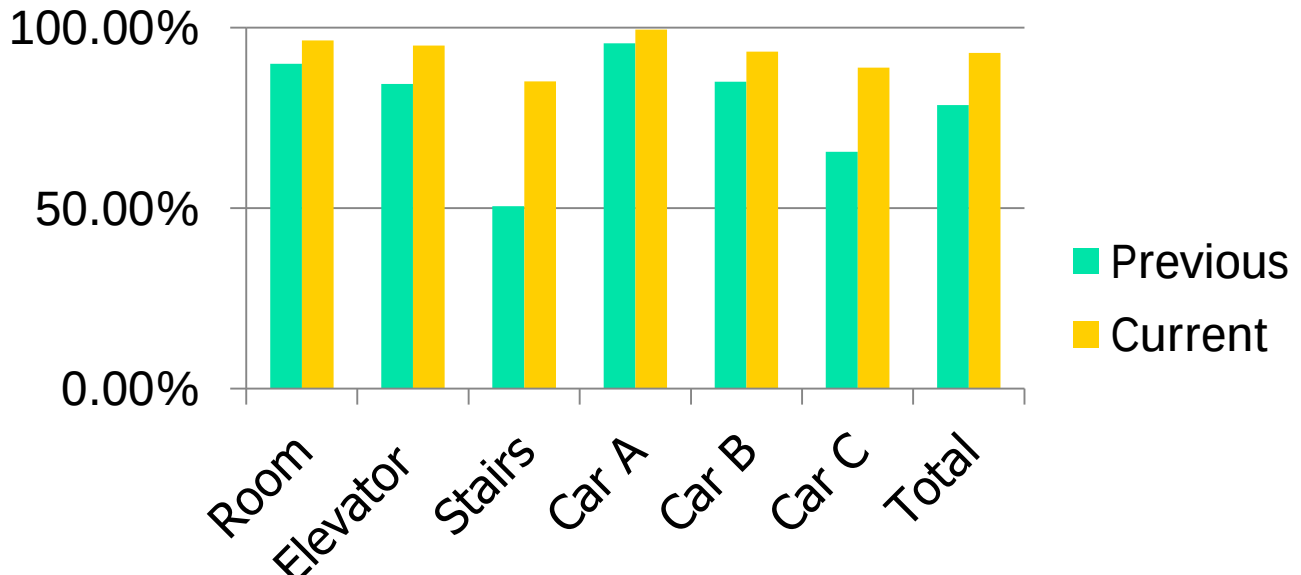
Comparison on Performance

Environment	Noise Level	Correctness	
		Current	Previous
Meeting Room	50dB	96.4%	90.0%
Elevator	50dB	95.0%	84.4%
Stairs	45dB	85.1%	50.5%
Car A（Idling, No-Moving）	50dB	99.4%	95.6%
Car B（High Speed, Open Window）	75dB	93.3%	85.0%
Car C（High Speed, Audio ON（FM））	75dB	88.9%	65.6%
Total		93.0%	78.5%
※Cruiser Board（Outside, high speed）	80dB	82.7%	-

Comparisons between HU-SCS v4 and v3



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Part 2

ADVANCED NOISE ROBUST TECHNOLOGY

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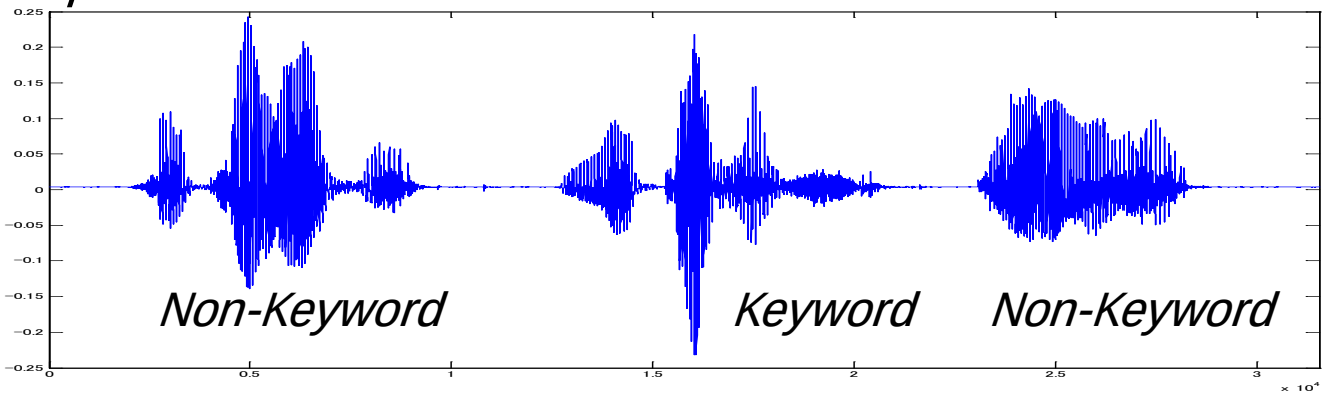
Sequential Word Stream

- Only keywords are recognized in a continuous speech under noisy environments.
  - Any words except keywords should not be recognized.
- The speech is given as a sequential word stream like voice commands.

Sequential word without noise



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Issues in This System

- Intelligent Keyword Rejection
  - Many of non-Keywords are recorded.

- High Precise Speech Detection
  - Keywords and non-Keywords are sequentially recorded into a system like continuous speech waveform.

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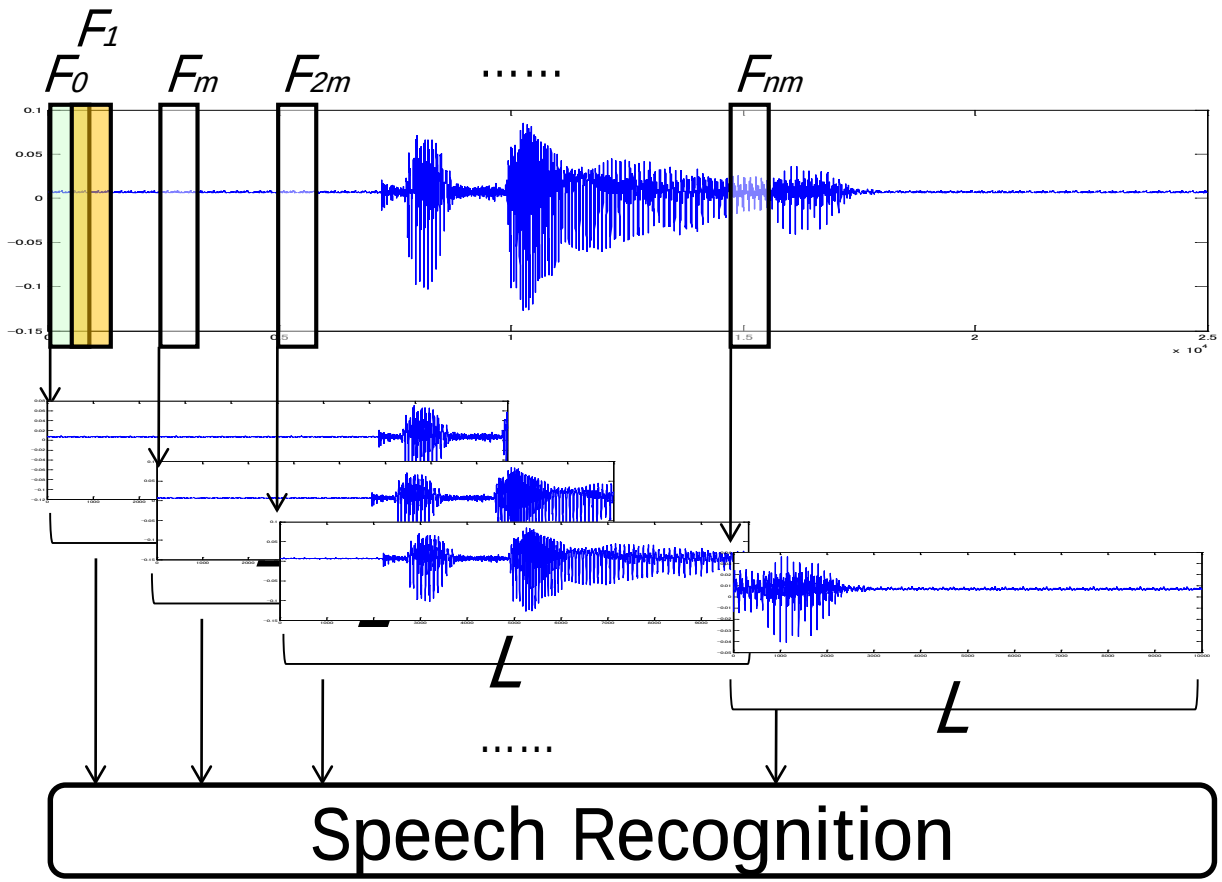
SP-ASR Recognition Processing

- Set a segment after dividing the short-time frame

Short-time Frame

Segment



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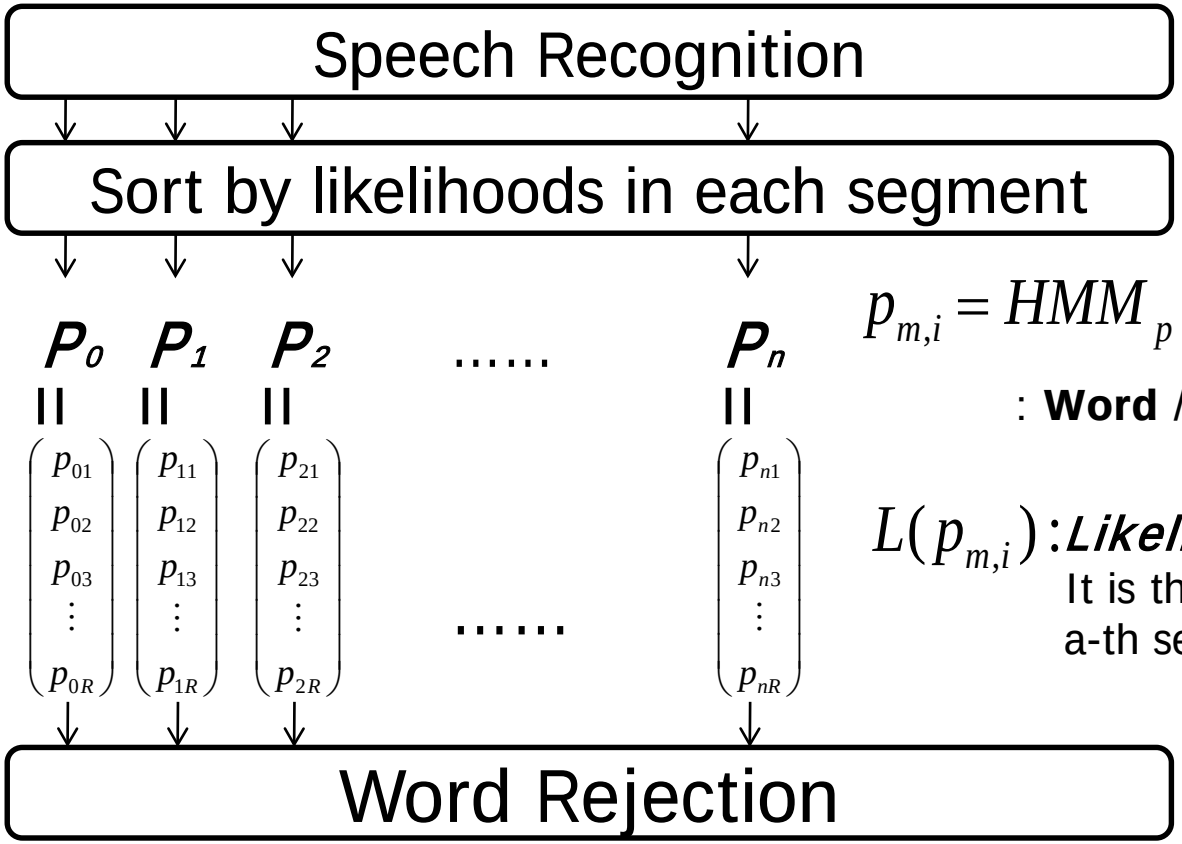
2nd Rejection Methods



$$p_{m,i} = HMM_p(m)$$

: **Word** /*p*/ at the *m*-th segment

$L(p_{m,i})$: ***Likelihood Value***

It is the i-th largest ML in the a-th segment.

m : segment index

i : ranking index

Note that the vector P_i might be similar to the vector P_j

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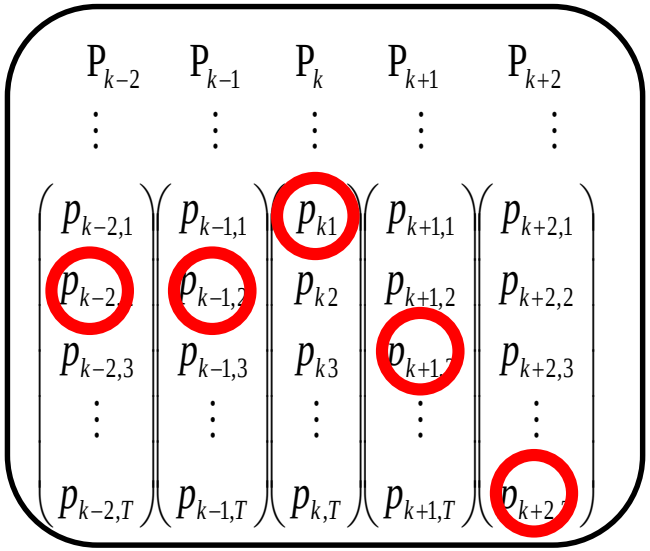
Rejection Method

Segment Stream



k: Center segment number

1. $p_{k,1} \in \mathrm{P}_r \ (r = k-2, \cdots, k+2)$

2. $L(p_{r,i}) > L(p_{r,j})$

$$\{i \mid p_{k,1} = p_{r,i}\}, \{j \mid p_{k,2} = p_{r,j}\}$$

$$r = k-2, \cdots, k+2$$

$p_{m,i} = HMM_p(m)$: **Word** */p/* at the *m*-th segment. The index *i* shows the *i*-th largest likelihood.

$L(p_{m,i})$: ***Likelihood Value*** It is the i-th largest ML in the a-th segment.

***m** : segment index,* ***i** : ranking index*

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Experiment - Conditions

- Short-time frame
  - Width: 23.2ms(256point)　Shift: 11.6ms(128point)
- Segment
  - Length(L): 1.0s(11025point)　　Shift: 8[frame]
- Speech data:
  - Connect two words.
  - Add a non-speech section of 1.4 sec to both ends and 0.5 sec between the words.
  - 100 data by random two words combination.
- White Noise：SNR=∞,20,10dB

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Results of recognition

Recognizer／SNR	∞	20dB	10dB
Isolated Word Recognition (1 word)	99.4 %	97.6 %	84.6 %
SP-ASR with 2nd Rejection (2 sequential words)	98.5 %	96.5 %	88.5 %

- The SP-ASR recognizes keywords with the same level accuracy as the past word recognition.

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Summary

Small, Fast and Low Power

Hokkaido University
Speech Communication System

Integrated Architecture of Speech Detection, Robust Speech Analysis, Speech Recognition, Speech Rejection
Higher Speed Processing than DSP and Software
Superior in Energy Saving than DSP Solutions
Improving Noise Robustness by RSF/DRA Technique

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