Application of Speech Technology to the Assistance of Speech and Auditory Training

Hsiao-Chuan Wang
National Tsing Hua University, Hsinchu

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Think about those people with hearing and speaking difficulties.

We can do something to help them by using speech technologies.

It may open a new field of speech processing research.
Problems on Deaf and Hard of Hearing

Children need speech and auditory training

There are 6~8% of population suffering from deaf and hard of hearing (D/HH), i.e. with hearing loss of more than 25 dB.

About 5% of them (about 0.35% in the whole population) are children who need therapy programs for speech and auditory training in order to overcome their inherent defects and get progress in their language learning.

*Pure Tone Average (PTA)*

Hearing loss is measured by the threshold figure of pure tone average (PTA). It is the average of hearing thresholds at 500 Hz, 1000 Hz, and 2000 Hz.
Special educational programs

The screening procedures and special education systems should be well designed to help those hearing-impaired children.

In U.S., there are 28 auditory/speech therapists per 100,000 populations. Most of hearing-impaired children have been benefited by the special educational programs.

Sign language

Sign language can be helpful for those D/HH people, but is difficult for communicating with normal-hearing people.
It is our obligation and opportunity to serve those D/HH people

The speech technology would be helpful in developing those assistant equipments and educational systems.

We can and have to help D/HH people in improving their language learning and in communicating with normal-hearing people.

It is a business in developing hearing aids and speech/auditory training systems.
## Hearing Loss

### Definition of hearing loss in Taiwan

<table>
<thead>
<tr>
<th>Definition of hearing loss</th>
<th>Hearing level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild</td>
<td>25 ~ 39 dB</td>
</tr>
<tr>
<td>Moderate</td>
<td>40 ~ 59 dB</td>
</tr>
<tr>
<td>Severe</td>
<td>60 ~ 89 dB</td>
</tr>
<tr>
<td>Profound</td>
<td>≥ 90 dB</td>
</tr>
</tbody>
</table>
# Definition of hearing loss in USA

<table>
<thead>
<tr>
<th>Definition of hearing loss</th>
<th>Hearing level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild</td>
<td>26 ~ 40 dB</td>
</tr>
<tr>
<td>Moderate</td>
<td>41 ~ 55 dB</td>
</tr>
<tr>
<td>Moderate Severe</td>
<td>56 ~ 70 dB</td>
</tr>
<tr>
<td>Severe</td>
<td>71 ~ 90 dB</td>
</tr>
<tr>
<td>Profound</td>
<td>≥ 91 dB</td>
</tr>
</tbody>
</table>
Example of hearing level (severely hearing loss)

Feeling

Threshold of hearing-impaired

Threshold of normal-hearing
Some numbers

It is estimated that about 560 millions of population suffer from hearing loss in the world by 2005. Many of them lost their hearing because of age, disease, or injury.

- in industrialized countries – 190 millions
- in other countries – 370 millions

Percentage of D/ HH people using hearing aids

- in industrialized countries -- 20%
- in other countries -- 3%

In Taiwan: D/ HH population -- 1.7 millions (children 81,000)
Example: Reading sounds

Context: 拜年 (bai4 nian2)

拜年
bai4 nian2

大年初一，一大早，我和弟弟就被鞭炮聲鬧醒了。
da4 nian2 chu1 yi1, yi2 da4 zao3, wo3 han4 di4 di jiu4 bei4 bian1 pao4 sheng1 nao4 xing3 le.

媽媽看見我們起得那麼早，笑著說，原來鞭炮比鬧鐘還管用呢。
ma1 ma1 kan4 jian4 wo3 men qi3 de na4 mo zao3, xiao4 zhe shuo1, yuan2 lai2 bian1 pao4 bi3 nao4 zhong1 hai2 guan3 yong4 ne.
爸爸說，我知道他們為什麼起得那麼早，是急著要去拜年拿紅包吧。
說得我們都不好意思了。

ba4 ba shuo1, wo3 zhi1 dao4 ta1 men wei4 she2 mo qi3 de na4 mo 
zao3, shi4 ji2 zhe yao4 qu4 bai4 nian2 ba. shuo1 de wo3 men dou1 
bu4 hao3 yi4 si le.

我們穿上新衣服，先給爺爺奶奶拜年。
wo3 men chuan1 shang4 xin1 yi1 fu2, xian1 gei3 ye2 ye nai3 nai 
bai4 nian2.

爺爺要我們比去年更用功、更懂事。
ye2 ye yao4 wo3 men bi3 qu4 nian2 geng4 yong4 gong1, geng4 
dong3 shi4.
奶奶摟著我們說，又長一歲了，快要跟奶奶一樣高啦。
nai3 nai lou3 zhe wo3 men shuo1, you4 zhang3 yi2 sui4 le, kuai4 yao4 gen1 nai3 nai yi2 yang4 gao1 la.

吃過早飯，爸媽帶我們先到李爺爺家去拜年。
chi1 guo4 zao3 fan4, ba4 ma1 dai4 wo3 men xian1 dao4 li3 ye2 ye jia1 bai4 nian2.

李爺爺家門上貼著大紅的春聯，屋裡也有許多春字和福字，都是倒過來貼著。
Li3 ye2 ye jia1 men2 shang4 tie1 zhe da4 hong2 de chun1 lian2, wu1 li3 ye3 you3 xu3 duo1 chun1 zi4 han4 fu2 zi4, dou1 shi4 dao3 guo4 lai2 tie1 zhe.
拜年
大年初一，一大早，我和弟弟就被鞭炮聲鬧醒了。媽媽看見我們起得那麼早，笑著說，原來鞭炮比鬧鐘還管用呢。爸爸說，我知道他們為什麼起得那麼早，是急著要去拜年拿紅包吧。說得我們都不好意思了。
我們穿上新衣服，先給爺爺奶奶拜年。爺爺要我們比去年更用功、更懂事。奶奶摟著我們說，又長一歲了，快要跟奶奶一樣高啦。吃過早飯，爸媽帶我們先到李爺爺家去拜年。李爺爺家門上貼著大紅的春聯，屋裡也有許多春字和福字，都是倒過來貼著。
Sound B: by a hearing-impaired child with severely hearing loss

媽媽看見我們起得那麼早，笑著說，原來鞭炮比鬧鐘還管用呢。爸爸說，我知道他們為什麼起得那麼早，是急著要去拜年拿紅包吧。說得我們都不好意思了。我們穿上新衣服，先給爺爺奶奶拜年。爺爺要我們比去年更用功、更懂事。奶奶摟著我們說，又長一歲了，快要跟奶奶一樣高啦。
Speech Perception and Speech Intelligibility

A child’s ability to produce intelligible speech is related to his ability to perceive its spectral and prosodic qualities.

Many hearing-impaired children learn to produce numerous speech qualities they cannot hear.
Auditory speech-feature recognition

Visual Perception

Hearing-impaired children are unable to perceive all sounds of speech accurately through aided hearing and so substitute visual perception of articulation for the auditory perception of certain phonemes.

The linguistic symbols they seem to use in lipreading are the visually observable positions of the lips, teeth, tongue, and the surrounding facial surfaces.

The visually observable units of speech articulation are visemes. These visemes can convey linguistic information in a way similar to the phonemes of a language, however, they are less efficient language symbols.
Confusion matrix of Visual identification of 20 consonants

/ a /-C-/ a /

(from N. P. Erber, Auditory Training, 1982)
Confusion matrix of Visual identification of 10 vowels

/ b / - V - / b /

Auditory Perception

Most Hearing-impaired children do more than lipreading when they communicate through speech. They also carefully listen to the acoustic cues that pass through their hearing aids.

Children with sensorineural hearing disorders do not simply perceive sounds as weaker than normal. Instead, their ears distort sound in unusual ways. The loudness may increase very rapidly near the threshold of audibility.

Also, the normally distinctive qualities of speech may be changed, so that acoustically different words sound similar.
Confusion of vowel /i/ with vowels /i, e/, and also with vowels /u,u/.

Confusion matrix of **auditory** identification of 8 stop and 2 nasal consonants

/ a / -C- / a /

Combined auditory-visual perception

Most moderately and severely hearing-impaired children are able to achieve high levels of oral communication skill because they can perceive

(1) the place-of-articulation for consonants and lip shape cues for vowels through lipreading, and also

(2) complementary voicing, manner-of-articulation, and formant information through intact low-frequency hearing.
# Articulation Disorders

## Articulation Disorders in Mandarin (for hearing-impaired children)

(from “Speech therapy for hearing-impaired children” by Y. M. Chung, 1995)

### Vowels

<table>
<thead>
<tr>
<th>Pinyin Symbol</th>
<th>Articulation Disorders</th>
</tr>
</thead>
<tbody>
<tr>
<td>yi</td>
<td>Substitution error, Nasalized</td>
</tr>
<tr>
<td>wu</td>
<td>Substituted by /o/ or /hu/, Nasalized,</td>
</tr>
<tr>
<td>yu</td>
<td>Substituted by /yi/, /wu/, or /e/</td>
</tr>
<tr>
<td>Symbol</td>
<td>Substitution</td>
</tr>
<tr>
<td>--------</td>
<td>--------------</td>
</tr>
<tr>
<td>a</td>
<td>Substituted by /o/, /ai/ or /ao/</td>
</tr>
<tr>
<td>o</td>
<td>Substituted by /a/, Nasalized</td>
</tr>
<tr>
<td>e</td>
<td>Nasalized</td>
</tr>
<tr>
<td>e(eh)</td>
<td>Substituted by /e/ or /ei/</td>
</tr>
<tr>
<td>ai</td>
<td>Delete ending, Substituted by /a/+/i/</td>
</tr>
<tr>
<td>ei</td>
<td>Delete ending, Substituted by /e/+/i/</td>
</tr>
<tr>
<td>ao</td>
<td>Lasted ending, Deleted ending, Substituted by /a/+/o/</td>
</tr>
<tr>
<td>ou</td>
<td>Substituted by /wo/ or /eo/, Delete ending, Substituted by /o/+/u/</td>
</tr>
<tr>
<td>an</td>
<td>Substituted by /ang/, Delete nasal ending</td>
</tr>
<tr>
<td>------</td>
<td>------------------------------------------</td>
</tr>
<tr>
<td>en</td>
<td>Substituted by /eng/, Delete nasal ending</td>
</tr>
<tr>
<td>ang</td>
<td>Substituted by /an/, Delete nasal ending</td>
</tr>
<tr>
<td>eng</td>
<td>Substituted by /en/, Delete nasal ending</td>
</tr>
<tr>
<td>er</td>
<td>Substituted by /e/</td>
</tr>
</tbody>
</table>
Consonants

<table>
<thead>
<tr>
<th>Consonant</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>b</td>
<td>Substituted by /p/ or /m/, Deleted</td>
</tr>
<tr>
<td>p</td>
<td>Substituted by /b/ or /h/, Deleted</td>
</tr>
<tr>
<td>m</td>
<td>Substituted by /b/, Deleted</td>
</tr>
<tr>
<td>f</td>
<td>Substituted by /b/ or /hu/, Deleted</td>
</tr>
<tr>
<td>d</td>
<td>Substituted by /t/ or /g/, Deleted</td>
</tr>
<tr>
<td>t</td>
<td>Substituted by /d/, /g/, /k/ or /l/, Deleted</td>
</tr>
<tr>
<td>n</td>
<td>Substituted by /l/, Deleted</td>
</tr>
<tr>
<td>l</td>
<td>Substituted by /n/ or /d/, Deleted</td>
</tr>
<tr>
<td>Symbol</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>g</td>
<td>Substituted by /k/, or /d/, Deleted</td>
</tr>
<tr>
<td>k</td>
<td>Substituted by /d/, /t/, /g/ or /h/, Deleted</td>
</tr>
<tr>
<td>h</td>
<td>Substituted by /b/, /g/, or /k/, Deleted</td>
</tr>
<tr>
<td>j</td>
<td>Substituted by /q/, /x/, /d/, /t/ or /g/, Deleted</td>
</tr>
<tr>
<td>q</td>
<td>Substituted by /j/, /x/, /d/, /t/, /g/ or /h/, Deleted</td>
</tr>
<tr>
<td>x</td>
<td>Substituted by /j/, /q/, /d/, /t/, /g/ or /k/, Deleted</td>
</tr>
<tr>
<td>Character</td>
<td>Description</td>
</tr>
<tr>
<td>-----------</td>
<td>------------------------------</td>
</tr>
<tr>
<td>zhi</td>
<td>Substituted by /j/, /d/, /t/ or /g/, Deleted</td>
</tr>
<tr>
<td>chi</td>
<td>Substituted by /zhi/, /d/, /t/, /g/ or /k/, Deleted</td>
</tr>
<tr>
<td>shi</td>
<td>Substituted by /d/, /g/, /k/ or /l/, Deleted</td>
</tr>
<tr>
<td>ri</td>
<td>Substituted by /l/, Deleted</td>
</tr>
<tr>
<td>zi</td>
<td>Substituted by /ci/, /d/, /t/, or /g/, Deleted</td>
</tr>
<tr>
<td>ci</td>
<td>Substituted by /zi/, /d/, /t/, /g/ or /k/, Deleted</td>
</tr>
<tr>
<td>si</td>
<td>Substituted by /zi/, /ci/, /d/, /t/, /g/ or /k/, Deleted</td>
</tr>
</tbody>
</table>
Tones

It is hard for those hearing-impaired children with severely or profoundly hearing loss to correctly handle the tones.
Objective

To help hearing-impaired children learn to communicate through speech.

Auditory training

Auditory training means the teaching methods specifically designed for improving a child’s auditory speech perception performance.

The goal is to help the hearing-impaired children apply their impaired auditory sense to the fullest capacity in language communication.
A general sequence for auditory evaluation and training

1. Preliminary audiologic evaluation
2. Select an adjusted amplification system
3. Distinguish auditory from intensity-pattern perception
4. Auditory/vibrotactile evaluation and instruction
5. Evaluate and practice combined auditory-visual perception
Adaptive communication

stimulus-response matrix

Screening Auditory Abilities

Tests

Many tests are designed for describing a child’s auditory speech perception abilities and for pointing out the particular strengths and weaknesses exhibited.

GASP (Glendonald Auditory Screening Procedure)

Arbitrarily choose to test at three specific stimulus-response locations: (1) phoneme detection, (2) word identification, and (3) sentence comprehension.

The GASP test results can help direct auditory training plans for each child.
Relative positions of the three GASP subtests

Examples

If the child cannot detect any speech sounds at all (subtest 1), he or she will be unable to categorize words into stress patterns.

If half of the speech sounds can be detected, the child may be able to categorize, and even to identify words (subtest 2) as well as some sentences.

If the child can reliably identify fewer than about half the test words, it is unlikely that he or she will be able to identify or comprehend even simple sentences (subtest 3) correctly.
Auditory Training

Three auditory training methods

*Natural conversational approach*

The teacher speaks to the child in as natural a way as possible.

The auditory speech-perception tasks are chosen from any cell in the stimulus-response matrix.

The teacher adapts to the child’s responses by presenting remedial auditory tasks in a systematic manner.
**Moderately structured approach**

The teacher applies a closed-set auditory identification task, but follows this activity with some basic speech development procedures and a related comprehension task.

The teacher selects the nature and content of words and sentences on the basis of recent class activities.

A few neighboring cells in the stimulus-response matrix are involved.
Practice on specific tasks

The teacher preselects the set of acoustic speech stimuli and also the child’s range of response, and plans the development of the task.

Attention is directed to a particular listening skill represented by a single cell in the stimulus-response matrix.
Verbotonal method

The verbotonal method simulates the patterns of language development observed in normal-hearing children.

The hearing-impaired child may not receive the spectrum of sounds that normal hearing children do, he usually is sensitive to frequencies below 500 Hz, through which we can transmit most of the cues for rhythms and intonation.

Verbotonal techniques reinforce this auditory sensitivity with vibrotactile stimulation to help the child receive normal rhythm and intonation patterns and to ensure that he relies on his auditory mechanism to develop speech normally.
**SUVAG**

SUVAG (System Universal Verbotonal Audition Guberina, designed by Peter Guberina in Yugoslavia) is an auditory training unit which is used during most of the group activities and during initial individual therapy sessions when the child is learning rhythm and intonation patterns.

Through intensive intervention the rhythm and intonation patterns and the listening skills develop simultaneously.

The goal is to integrate hearing-impaired children into regular educational and social situations.
What can we do with speech technologies?

Speech technologies are definitely helpful for developing the auditory and speech training systems.

**Audiologic evaluation**

speech/ tone signal generation

**Speech signal amplification and compression**

speech signal amplification
filterbank design
reduction of dynamic range
frequency compression
Stimulus-response model for auditory training

- speech synthesis
- speech coding

Speech training

- speech signal analysis
- pitch detection
- speech recognition
- speech coding
Sign language conversion

  speech synthesis

  speech coding

Hearing aids

  filterbank design

  noise reduction
Examples

TaiSign Communicator
-- a sign language learning system, developed by National Cheng Kung University

Spectral Conversion of Mandarin Base-Syllables
-- a voice conversion system, developed by National Chiao Tung University

Frequency Compensation and Compression
-- a auditory testing system, developed by National Tsing Hua University
Filterbank Design for Auditory Training
-- a filterbank design system, developed by National Tsing Hua University

Utterance Verification Technique for Speech Training
-- a speech training system, developed by National Tsing Hua University
TaiSign Communicator

This is an augmentative and alternative communication system for language learning and communication. It is designed for sign language, lipreading, and pronunciation training.

Many computer techniques are involved, such as computer graphics, speech synthesis, and speech recognition.
Function selection
Sign language training
Grammatical Sign language training
Lipreading
Spectral Conversion of Mandarin Base-Syllables

This is a technique for enhancing the hearing-impaired speech, especially the fricatives and affricates.

The mapping functions based on statistical models and Gaussian mixture models (GMMs) are proposed.

The principal component analysis to reduce the dimension of characteristic features is applied.
The sinusoidal synthesis technique is applied for speech synthesis.

The correspondence between source and target speech is achieved by DTW.
Results of mapping

![Graph showing cepstral distances and mapping functions]

- Cepstral distance of source speech and target speech
- Mapping function based on statistical modeling
- Mapping function based on GMM
Mapping with dimension reduction
### Examples

<table>
<thead>
<tr>
<th>syllable</th>
<th>Source sound (by hearing-impaired)</th>
<th>Converted sound (based on statistic models)</th>
<th>Converted sound (based on GMMs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>xi</td>
<td><img src="sound_icon.png" alt="Sound" /></td>
<td><img src="sound_icon.png" alt="Sound" /></td>
<td><img src="sound_icon.png" alt="Sound" /></td>
</tr>
<tr>
<td>fo</td>
<td><img src="sound_icon.png" alt="Sound" /></td>
<td><img src="sound_icon.png" alt="Sound" /></td>
<td><img src="sound_icon.png" alt="Sound" /></td>
</tr>
<tr>
<td>sha</td>
<td><img src="sound_icon.png" alt="Sound" /></td>
<td><img src="sound_icon.png" alt="Sound" /></td>
<td><img src="sound_icon.png" alt="Sound" /></td>
</tr>
<tr>
<td>ji</td>
<td><img src="sound_icon.png" alt="Sound" /></td>
<td><img src="sound_icon.png" alt="Sound" /></td>
<td><img src="sound_icon.png" alt="Sound" /></td>
</tr>
<tr>
<td>ca</td>
<td><img src="sound_icon.png" alt="Sound" /></td>
<td><img src="sound_icon.png" alt="Sound" /></td>
<td><img src="sound_icon.png" alt="Sound" /></td>
</tr>
<tr>
<td>qi</td>
<td><img src="sound_icon.png" alt="Sound" /></td>
<td><img src="sound_icon.png" alt="Sound" /></td>
<td><img src="sound_icon.png" alt="Sound" /></td>
</tr>
</tbody>
</table>
Frequency Compensation and Compression

Sinusoidal synthesis technique is applied since it is easy for band amplitude adjusting, frequency compression, and pitch modification.

Speech signal represented by sinusoidal synthesis mode

\[ s(n) = \sum_{m=1}^{M^k} \hat{A}_m(n) \cos[\hat{\theta}_m(n)] \]
Non-uniform frequency compression

\[ f_{out} = \frac{f_s}{K \pi \tan^{-1} \left( \frac{1 + A}{1 - A} \tan(\pi \frac{f_{in}}{f_s}) \right) } \]
The original and frequency compressed spectrograms
Frequency compensation

\[ c = \Delta^* / \Delta \]
\[ \delta^* / \delta = \Delta^* / \Delta \]
\[ A^* = cA + T_{im} \]
\[ G = A^* - A \]
Spectra of original and compensated signal (/qi/)
Filterbank Design

The technique of finite impulse response (FIR) filter design is applied.

Both the range and the gain of each band can be adjusted.

The resulted speech would be frequency compensated to fit the auditory characteristics of the hearing-impaired child.

Equation of low-pass filter in time domain

\[
c(i) = \frac{\sin[\pi \frac{2Fc}{Fs} (i - \frac{L}{2} + 0.5)]}{\pi(i - \frac{L}{2} + 0.5)}
\]
In order to eliminate Gibb’s effect, we multiply the impulse response of this low-pass filter by a Hanning window.

Then the impulse response is shifted by 400 sampling points to obtain a causal system.

\[
c_w(i) = c(i) \cdot 0.5 (1 - \cos(\frac{2\pi}{L} \cdot i))
\]

Subtracting two low-pass filters, we can obtain a bandpass filter.

\[
b(i) = c_{w,2000}(i) - c_{w,1000}(i)
\]
Example:

The impulse response of the band-pass filter (1000 ~ 2000 Hz, )
Example:

Filtered signal in frequency domain (2400 ~ 4800 Hz)
Example:
Result of frequency compensation.
System interface window

<table>
<thead>
<tr>
<th>Depth (ns)</th>
<th>Start (ns)</th>
<th>End (ns)</th>
<th>Gain (dB)</th>
<th>Play Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>150</td>
<td>300</td>
<td>+3</td>
<td>1</td>
</tr>
<tr>
<td>D2</td>
<td>300</td>
<td>600</td>
<td>+0</td>
<td>2</td>
</tr>
<tr>
<td>D3</td>
<td>600</td>
<td>1200</td>
<td>+12</td>
<td>3</td>
</tr>
<tr>
<td>D4</td>
<td>1200</td>
<td>2400</td>
<td>+30</td>
<td>4</td>
</tr>
<tr>
<td>D5</td>
<td>2400</td>
<td>4800</td>
<td>+45</td>
<td>5</td>
</tr>
<tr>
<td>D6</td>
<td>4800</td>
<td>9600</td>
<td>+51</td>
<td>6</td>
</tr>
</tbody>
</table>
The *hidden Markov model* (HMM) method is used to describe the movement of vocal track during speech production.

Each subsyllable of Mandarin speech is represented by a HMM. The model of a syllable or a word is the concatenation of *subsyllable models*.

The decision of acceptance or rejection depends on the *normalized log likelihood score* against a preset threshold. It tells the speaker whether his/her utterance input is correct or not.
Hidden Markov models (HMM) are used to model the basic units of Mandarin speech, i.e. RCD-initials and CI-finals.
For each target word, we choose a set of confusion words or syllables with respect to this target word.

These confusion words or syllables are those frequently confused pronunciations made by hearing impaired students.

**Example:** “bei fang” (north)

<table>
<thead>
<tr>
<th>Target word</th>
<th>Confusion words or syllables</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Bei fang”</td>
<td>“pan fan” “mei fan” “gei bang” “mei bang” “ei ang”</td>
</tr>
</tbody>
</table>
The models of these confusion words or syllables are used to construct the anti-model with respect to the target word.

When an utterance of target word is tested on the target word model, a log likelihood score is computed. This same utterance is also tested on the anti-model to obtain another log likelihood score.

The *normalized log likelihood score* is obtained by subtracting anti-model score from the target model score.

A score value that makes the probability of fault acceptance equal to the probability of fault rejection is called the threshold of equal error rate.

We use this threshold value for the utterance verification.
Prototype of speech training system

This system is set up on a personal computer (PC) with Windows operating system in traditional Chinese version, and equipped with a microphone and a video camera.

A reference utterance for each target word is recorded. Simultaneously, the corresponding mouse motion is recorded in video.

The demonstration of sign language is also included.
Training for Mandarin Phonetic Symbols

Sign Language Demonstration
(1) Frequency Compensation
(2) Speech Training
References


Tzong-Ren Ho, *A Study of Spectral Conversion of Mandarin Base-Syllables*, MS Thesis (instructed by Prof. W. W. Chang), National Chiao Tung University, 2002

Yuan-Chia Lu, *Using confidence measures for Mandarin speech training system*, MS Thesis (instructed by Prof. Hsiao-Chuan Wang and Prof. Yueh-Chin Chang), National Tsing Hua University, 2002.

Thank You!