



Sound-based Assistive Technology Supporting “Seeing”, “Hearing” and “Speaking” for the Disabled and the Elderly

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Abstract

With a rapid increase of a population rate of the elderly, disabled people also have been increasing in Japan. Over a period of 40 years, author has developed a basic research approach of assistive technology, especially for people with seeing, hearing, and speaking disorders. Although some of the required tools have been practically used for the disabled in Japan, the author has experienced how insufficient a function of the tools is for supporting them. Moreover, the author has been impressed by amazingly potential ability of the human brain that compensates for the disorders.

In this report, the author shows some compensation abilities formed by “brain plasticity”, and also shows extraordinary ability such as voice imitation of mynah bird and obstacle sense of the blind. Furthermore, the author introduces six assistive tools borne by solving mystery of the compensation function and the extraordinary animal. Finally, the author emphasizes that these assistive tools will contribute to design a new human interface that may support the elderly as well as the disabled.

Index Terms: assistive technology, the blind, the deaf, speech disorders

1. Introduction

As shown in figure 1, nowadays, around 1/4 of population are elderly in Japan, so actually near 30 millions people are more than 65 years old. With the rapid increase of the elderly, disabled people who need care are also increasing. Actually, in 2005, the number of the disabled was beyond 6 millions. Most of them have disability regarding hearing, speaking, reading, thinking and moving functions.

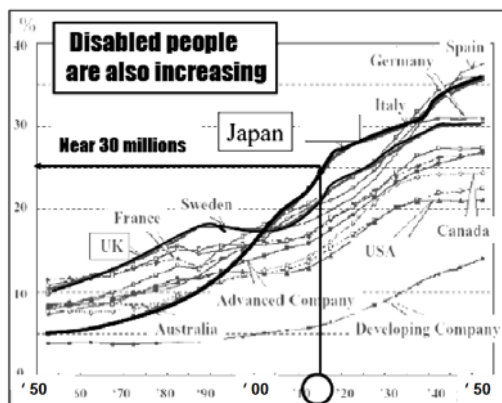


Figure 1: Population rate of the elderly from 1950 to 2050.

In this situation, assistive technologies should be urgently designed for supporting these people in addition to medical side technologies. However, the disability is so diverse and

complex that it has been difficult to construct a research approach of the assistive technology.

Our research approach has three steps as shown in figure 2. The first step is to analyze the human function such as sensory, brain and motor functions based on neuroscience and cognitive science. The second step is to design various assistive tools based on the findings obtained by the basic research. If the assistive tools are insufficient for supporting the disabled, the research should go back to the first step. The third is to apply the basic findings and the assistive tools to human interface systems such as robotics and virtual reality systems. The third step is important to open a big market and to make a price of the tools cheap [1], [2].

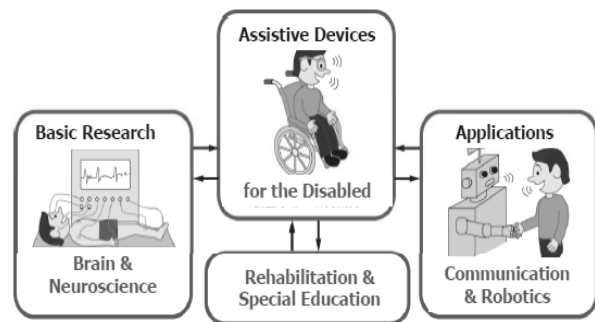


Figure 2: Three steps of our assistive technology research.

The assistive technology for elderly disabled people is mainly called “Geron-technology” that is somewhat different from “Barrier-free design” that includes supporting young disabled people. As shown in figure 3, the barrier-free design for the young should positively use “plasticity” of the human body, especially the brain because residual functions work to compensate the disordered function by the help of brain plasticity.

On the other hand, in general, the plasticity function decreases in the elderly, whereas, they will acquire abilities using their “experience”. The acquired experiences should positively be used in the geron-technology. The following examples of six assistive tools, which we have designed, were mainly designed for the young disabled.

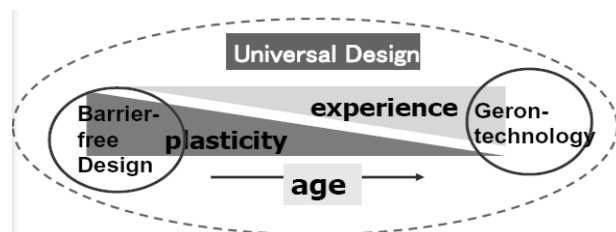


Figure 3: Barrier-free design and Geron-technology.

2. Assistive tools supporting “Hearing”

To assist “hearing” for auditory disorders, there are three approaches as shown in figure 4. One is to convert sound signals into tactile stimulations, the second is to electrically stimulate the surviving auditory nerves, and the third is to convert speech signals into letters. Two examples of assistive tools for hearing impairments are shown in this section.

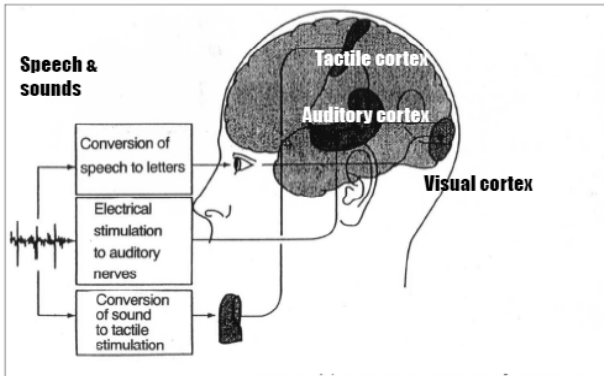


Figure 4: Three research approaches of assistive tool design for the hearing impaired.

2.1. Tactile communication aids for the deaf and/or the blind

The first topic is an assistive tool called “tactile aid” that is the author’s first research started from 1972. Tactile information is conbineant for suppoting hearing as well as seeing because it can be used together with the visual and/or hearing sense. Through fundamental research regarding similarities between auditory and tactile information processing, we developed a prototype tactile aid named “tactile vocoder”, as shown in figure 5, in 1975.

The tactile vocoder is a device which produces sound spectral patterns of which frequency analysis method is modeled after cochlear mechanism. In the tactile vocoder, spectral patterns of speech sounds were divided into 16 frequency components and each component was transmitted to lateral inhibition circuit in order to sharpen the spectral patterns. Finally, the 16 components were converted into 16 vibratory stimuli of which level of the is corresponding to each intensity of the 16 components.

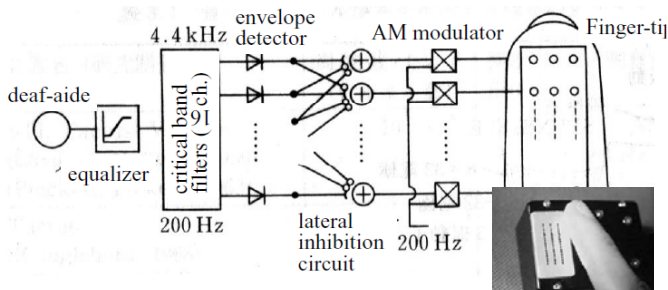


Figure 5: Block-diagram of tactile vocoder and a vibrator array (3x16).

When an index fingertip touches a vibrator array that was composed of 16 rows and 3 columns, the device made it possible to discriminate the first and the second formants of vowels as well as some consonants such as fricatives, semi-vowels and nasals [3].

The device was used for a telephone communication aid at a deaf school after deaf boys learnt tactile patterns corresponding to several words such as “hello”, “yes”, “no”, and etc. Although the device was manufactured in Japan about 30 years ago, it has not been widely used because nobody knows whether or not the tactile information is associated with speech understanding area in the brain.

After 25 years ago of the tactile aid research, the author moved to the University of Tokyo to attend at barrier-free project. The project has been conducted by a professor Satoru Fukushima who became blind at the age of 9 years old and deaf at 18 years old. From a viewpoint of the deaf-blind, he has suggested how we should perform the barrier-free research. He ordinarily communicates with us using both the tactile sense of his 6 fingers by a help of interpreters as shown in figure 6(lower left). This tactile communication method is called “finger Braille” that he first investigated in the world.

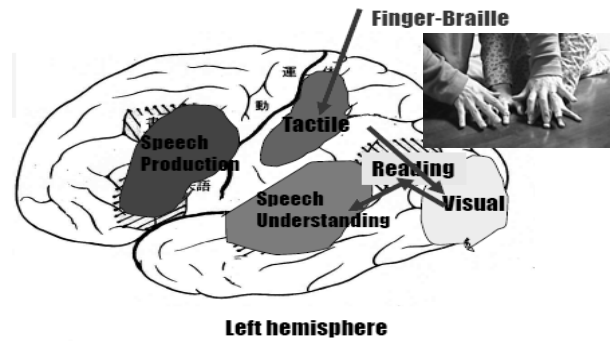


Figure 6: Finger-Braille information routs acquired by “plasticity” of the human brain.

From recent neuroscience researches, it is anticipated that the finger Braille patterns would be reached to the visual cortex through the tactile cortex and then the patterns would be associated with language understanding cortex as shown in figure 6. By the “plasticity” of neural network in the human brain, the lost functions might be compensated by the other sensory cortex. Actually, in 1998, by using a functional MRI, Swedish brain researchers showed that tactile stimulation activates the auditory cortex of the acquired deaf [4]. Furthermore, it has also been found that the visual cortex is activated by Braille stimulation on a fingertip of acquired blind subjects [5].

Encouraged by a professor Fukushima and the neuro-science results, we re-designed a new model of the tactile vocoder in 2006.

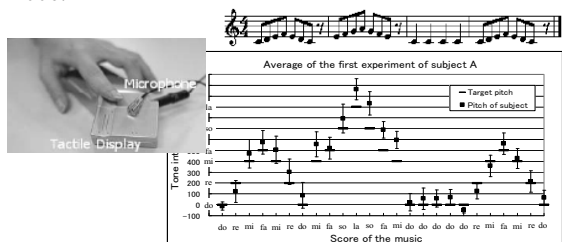


Figure 7: Left: New tactile vocoder made of a microprocessor and a vibrator array. Right: Pitch pattern of a deaf-blind produced by a “Frog’s song”

The new device consisted of a DSP and a piezo-electric vibrator array so that the signal processing can be changed only by software. For the deaf-blind use, the new device was set to transform a voice pitch frequency into musical scale that corresponds to vibrating point of a fingertip.

A lady, who has been deaf-blind since she was 40 years old and is now 67 years old, attended at our experiment. As she was a teacher of Japanese musical instrument and folk songs until she lost her visual and auditory senses, we expected that she can easily handle the tactile pitch display and can sing songs by using a feedback of the songs through her fingertip. Actually, after she learnt musical scale using the tactile device for short time, she could sing some Japanese songs as shown figure 6. This example shows that the tactile information might help to get a feedback of melodies of the songs [6]. However, congenital deaf-blind people were not able to sing any song.

These findings give us many suggestions to analyze whether or not the tactile information could be transmitted to auditory cortex and speech understanding area in the brain. It is ascertained how brain and cognitive researches are important to design assistive tools.

2.2 Captioning system for the hearing impaired

The second example is a voice recognition system to assist listening of the acquired deaf who have lost their hearing when they became adult. We were asked to design the voice typewriter by the acquired deaf group in 1975.

Fortunately, all Japanese voices are represented as a series of 68 monosyllables (/a/, /ka/, /sa/, /ta/, /na/.....) each of which consists of 5 vowels and 14 consonants and represented by one of Japanese Kana. This simplicity makes easy to design a Japanese voice typewriter that converts each monosyllable into a corresponding Kana.



Figure 8: Monosyllabic voice typewriter using a Z80 microprocessor and 32kbyte memories.

However, Japanese sentences are represented by combining Japanese Kana and Chinese characters that have different pronunciations. This complexity makes difficult to design a Japanese voice typewriter.

In 1976, we designed a monosyllabic voice typewriter system using a Z80 microprocessor and 32kbytes IC memories, as shown in figure 8, which was used together with a Japanese word processor so that Japanese monosyllabic voices are automatically converted into both Japanese and Chinese letters.

Our voice typewriter could recognize separately pronounced 68 Japanese monosyllabic voices into Kana at a correct recognition rate of 96% in the case of well trained speakers. However, as the voice typewriter system was too expensive for deaf users to buy, it was only used for an input device of printing machines in 1977 [7], not for an assistive tool for the deaf.

In 2001, 25 years after of the voice typewriter research, we were asked to design a captioning system by DPI (Disabled Peoples' International) conference held in 2002. As about 3000 disabled people from more than 100 countries attend at the conference, we had to design the captioning system that can automatically convert various languages into both Japanese and English captions. As the speech recognition technology was not perfect, we expected an ability that the hearing impaired can often guess the correct meaning of spoken sentences by observing a speaker's face and lip-movement.

With this in mind, we designed the captioning system in such a way that both the series of letters and the speaker's face simultaneously appear on a large screen. Where, we used a commercially available speech recognition software "Via Voice". Furthermore, we adopted "re-speak" method that the speaker's speeches are sent to a well trained re-speaker who repeats the speeches. In our system, the recognized outputs were checked by humans and then the corrected letters were displayed on a screen. The system was first used at a pre-conference in 2001 and then at the DPI in 2002. Both Japanese and International sign languages, both Japanese and English captions as well as speaker's face were displayed on a same screen as shown in figure 9.



Figure 9: Captions (English and Japanese) presented on a screen together with sign languages and a speaker's face at DPI conference in 2002.

From the analysis of captioning results, the accuracy of the caption was about 98% and captioning speeds were 4 sec from English to English, 11 sec from Japanese to Japanese, 12 sec from Japanese to English and 17 sec from English to Japanese. After the use at DPI, we investigated whether or not such non-verbal information as a speaker's lip-movements and facial expressions as shown in figure 10 could improve the comprehension of spoken sentences that contain incorrect words.

From the results of the speech comprehension, the improvement was observed only when the facial expression was displayed roughly one second after the incomplete presentation of a speaker's words. This fact was indirectly

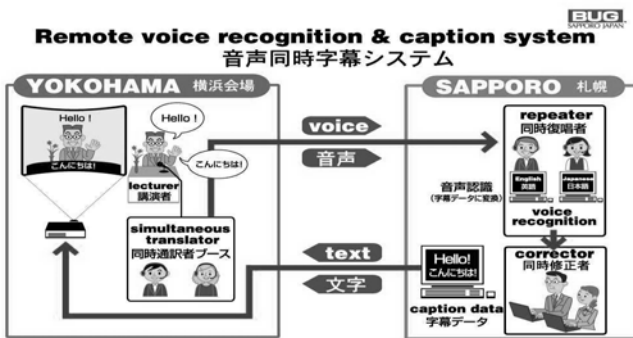
proven by an experimental result that eye balls of the deaf subject mainly stayed on the captions, not on the speaker's face [8].



Figure 10: left: Caption only, center: Caption + face, right: Caption + lip-movement.

No improvement was obtained for people with normal hearing. It is ascertained that combining both incomplete verbal with non-verbal information is indeed significant in facilitating comprehension for the hearing impaired .

After the DPI, the caption system was used in the various conferences in Japan through internet (ISDN). For example, at International Conference of Universal Design held at Yokohama in 2002, both English or Japanese speeches picked up at Yokohama were simultaneously interpreted, and then the interpreted speeches were sent to Sapporo where the speeches were converted into both Japanese and English text information which were displayed on screens at Yokohama as shown in figure 11.



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2002. 11. 30 : 国際ユニバーサルデザイン会議2002 (パシフィコ横浜)

Figure 11: Captioning system and mobile phone (lower right) using internet

Furthermore, we tried to apply the captioning system for communication aid for mobile phone in 2004 in order to be used by general people. These experiences suggest that the assistive tools should be widely used as possible as we can not only for deaf users but also for general users in order to make the system cheap and better model.

3. Assistive tools for speech disorders

Speech disorders are roughly divided into three causes shown in figure 12. The first is a caused mainly by laryngeal cancer. The laryngeal cancer patients have sometime lost their larynx by surgical operation, losing their vocal folds. Therefore, they become “laryngectomee” who lost a sound source for speech. The second is articulation disorders who are difficult to control their speech organ such as tongue, jaw and lips. The third is an aphasia that is caused by a disorder of brain nervous system in Broca area in the cortex.

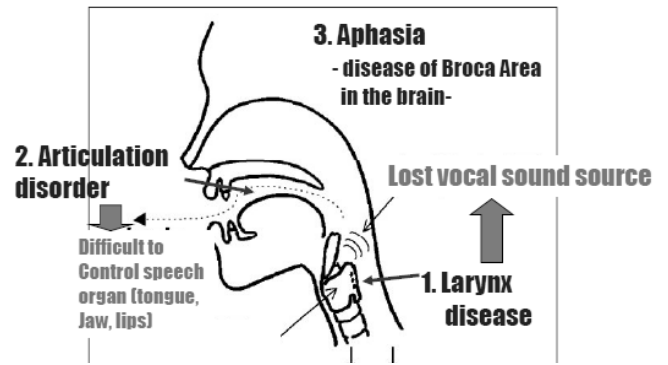


Figure 12: Three causes of speech disorders

3.1. Artificial electro-larynx for laryngectomee

An electronic artificial larynx is one of substitute vocalization methods. This method applies a vibrator to the lower jaw, which sends a vibrating sound into a voice tract through soft subcutaneous tissue. We focused on the electro-larynx because this method can be easily learned, although the voice quality is very poor like a buzzer sound.

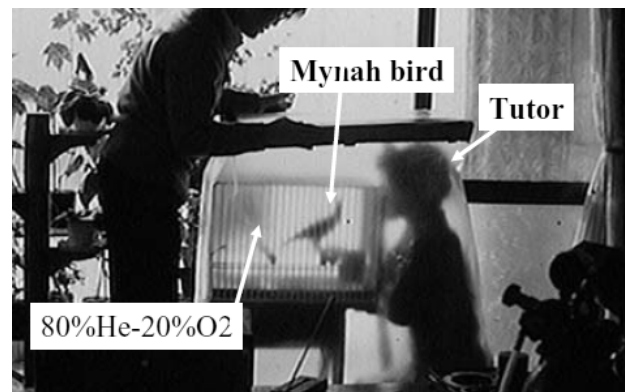


Figure 13: Mynah bird and her tutor in He-O2 gas

The ability to generate voice sounds is not limited to human beings. Among the animals which can generate voice sounds are certain birds, including mynahs, parrots, and parakeets. For researchers of speech assistive technology, it is a mystery as to why these birds, whose mouths and ears are shaped in a totally different way from humans, are capable of distinguishing and vocalizing certain human words. Especially the imitations of a mynah's voice sounds quite smooth and natural. Therefore, a research of the vocalization mechanism of mynahs might lead to new ideas for improvements of the electro-larynx.

From an analytical study of the mynah bird's voice imitations using He-O2 gas, about 30 years ago as shown in figure 13, we found that the mynah's imitations in the He-O2 gas are heard as the same as in normal air. Since it was reported that mynah bird has two sound sources (syrinx) corresponds to a human vocal fold, it was ascertained that he produces speech signals by combining the two sounds sources. Therefore, a formant pattern of the mynah was quite different from the human's formant pattern. We also found the reason why the mimicking of the mynah can be heard as natural voices is because she is able to faithfully imitate the fluctuation and intonation of the human voice [9].

After completing this basic research regarding similarity between the human voice and the mynah imitation, we designed a new electro-larynx composed of an air flow sensor, a small computer and a vibrator. An important role in the creation of voice sounds is played by the flow of air from the lungs to the larynx, determining a metrics such as a sound level, an accent and an intonation. In our electro-larynx, the intonation can be controlled by the exhalation flow detected by the air flow sensor as shown in figure 14 [10].

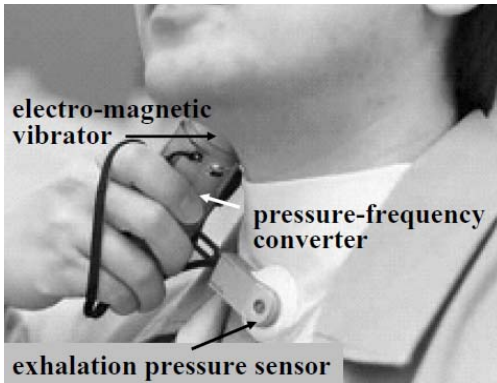


Figure.14: *Pitch controlled electro-larynx*

The electro-larynx voices can be perceived like the human voices with the intonation although the formant structure obtained by the voices is very different from the human's voices. The electro-larynx with pitch-controlled function has been manufactured and more than 4,000 patients have been using the device since 1998 in Japan.

However, since this method requires the use of a hand, it is still somewhat restricting. Many patients have strongly requested us to design a hands-free electro-larynx so that they can use it in daily life and in their office without their hands bound by the control of the electro-larynx while using it.

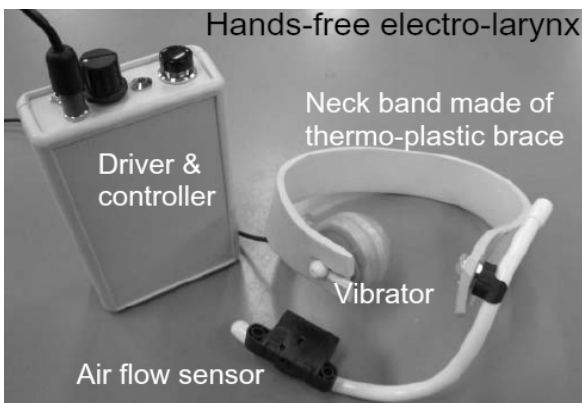


Figure 15: *Hands-free pitch controlled electro-larynx*

Furthermore, the electro-larynx sound is still not human-sounding voice. It was supposed that fluctuations of speech waves are needed to add to the electro-larynx voice.

In order to answer their request, we have designed a hands-free electro-larynx that can be attached to patient's neck. By comparing the various materials for the neck band, a thermo-plastic brace was selected. It becomes soft about at a temperature of 70 degrees centigrade while being hard at a

body temperature so that it is suitable for adjusting individual differences of a shape and hardness of the neck tissue.

We made a smaller vibrator (32mm diameter × 19mm thick and 32g weight) and a much more sensible flow sensor than the conventional one. The vibrator and the sensor can be mounted to the thermo-plastic brace. Figure 15 shows the prototype of the hands-free electro-larynx worn by a patient.

From usability tests, it was confirmed that the electro-larynx voices are heard more naturally than the conventional one and that the activity of the patients significantly improves in daily life. Furthermore, by adding a 1/f fluctuation of the pitch frequency [11] to the electro-larynx, the voice quality apparently exceeded the mynah bird's imitation [12].

3.2. Voice synthesizer for the aid of articulation disorders

In order to assist articulation disorders, we designed a speech synthesizer that can be handled by a finger as if a user is playing a musical instrument. One of students, who is difficult to control his speech organ because he has been suffering from muscle dystrophy, designed the synthesizer for himself. He has been disappointed in ordinary speech aids that do not work in real time or can not produce non-verbal information such as intonation and emotional expressions.

Our method was modeled after a speech production mechanism of a parakeet and a ventriloquist that can produce normal speech without moving their mouth. By analyzing their speech production, it was found that they produce speech sounds only by rapidly moving tongue inside the mouth.

This fact means that they can produce bilabial consonants such as /pa/, /ba/, and /ma/ by rapidly moving the tongue without closing their lips. As an analytical result of the ventriloquism vocalization mechanism, it was hypothesized that the ventriloquist quickly moves his/her tongue so that /a/ of /pa/ can be produced after putting the tongue at a front tooth; an articulation point of a consonant /t/, in the case of ventriloquist's /pa/ as shown in figure 16. Human can hear only /pa/ by this tongue movement even if the sound of the consonant /t/ exists. Almost the same mechanism as /pa/ was ascertained in the case of /ba/ and /ma/. This result means that /pa/, /ba/ and /ma/ can be heard only by the tongue movement inside a mouth.

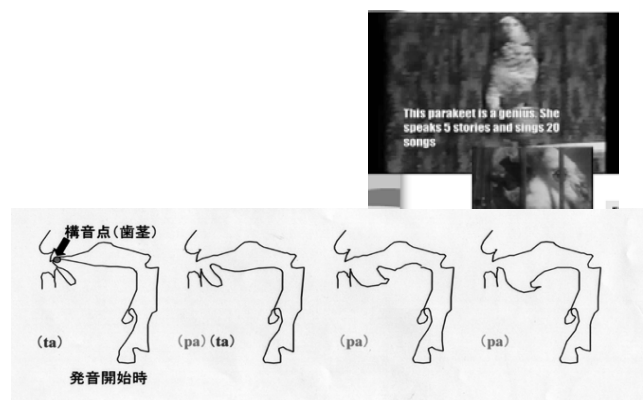


Figure 16: *Parakeet has a flexible and thick tongue (upper), so that she can produce various vowel formants by changing resonant frequencies. Ventriloquist quickly moves a tongue so that /a/ of /pa/ can be produced after putting the tongue at an articulation point of /t/ (lower).*

An idea of our speech synthesizer for the disorders is mainly based on a fact that human recognizes the bilabial consonants produced by the ventriloquist. Parameters of first formant frequency (F1) and the second formant frequency (F2) of a formant synthesis software were controlled by a position and a motion of a user's index finger without any key input. A touch pad was adopted for the input device that detects the fingertip's position and movement. The F1 and F2 that correspond to the position of the tongue were two dimensionally assigned to the plane of the touch pad as shown in figure 17.

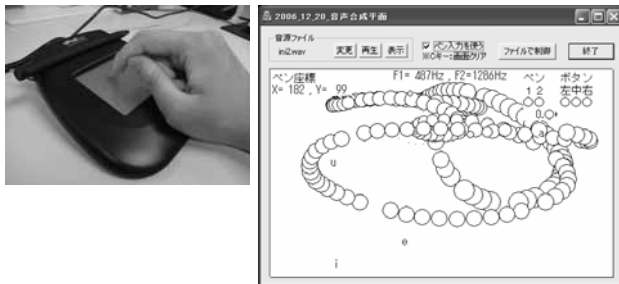


Figure: 17 A touch pad (left) where F1 and F2 frequencies were two dimensionally assigned to the plane (right).

A prototype model was designed on a personal computer using formant synthesis software to get the optimal speech synthesis method for the articulation disorders [13]. In our method, in order for the users to easily find the formant transitions to produce the desired consonants only by changing the formant transitions, "Guiding Lines" were superimposed on the pentablet display. Direction and length of each guiding line was assigned at a starting point and a locus of the formant transition on the F1-F2 plane. The starting point and the formant transition locus were decided according to an "Expanded Locus Theory" that we modified based on "Locus Theory" [14].

In the evaluation of sentence recognition, continuous speech sounds were synthesized by tracing the touch pad using the index finger as shown in figures 17 (left). After a few hours training to produce some Japanese sentences such as /ohayo-gozaïmasu/ (good morning), /kon'nichiwa/ (good afternoon), /kombanwa/ (good evening) and /arigato-gozaïmasu/ (thank you), the consonants /ha/, /go/, /za/, /su/, /ko/, /ni/, /chi/, /wa/, and etc. were apparently heard in the continuous sentences although the synthesized voices had no consonant sounds.

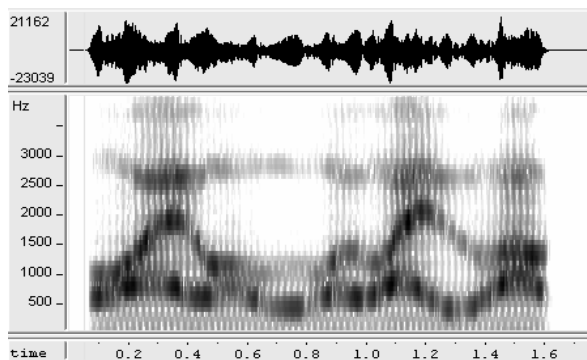


Figure 18: A sound spectrogram of /ohayo-gozaïmasu/ obtained by our synthesizer for the speech disorders.

Figure 18 shows a sound spectrogram of /ohayo-gozaïmasu/. From the evaluation results, it was ascertained that the users may more easily produce the arbitrary sentences by tracing the guide lines than conventional one [15].

Next we carried out evaluation test of randomly synthesized 100 words composed of 4 monosyllables. Although the identification of vowels and voiced consonants such as semi-vowels, nasals, showed high score around 70 %, the average identification rate showed only 33 %. It was still difficult to perceive some consonants that need random noise component such as /s/, /h/ and /z/. We have been investigating how the noise component should be added and controlled by user's finger.

By using a touch pad with a pressure sensor and by assigning the detected touching pressure to the pitch frequency, the subject could produce some emotional voices such as "laughing", "surprising" and "disappointment" by controlling the pressure of the touch and the speed of finger movement. Furthermore, by connecting this tool with a musical key-board, the subject could sing some Japanese songs after short time training.

We are planning the speech production method to apply a tool for people with aphasia and also to one of new musical instruments for general users.

4. Assistive tools supporting "Seeing"

There are three approaches for visual substitutes as shown in figure 19. One is to convert visual information into tactile stimulations, the second is to electrically stimulate the surviving visual nerves, and the third is to convert text to speech. In this session, two examples to assist the visually disabled are mentioned.

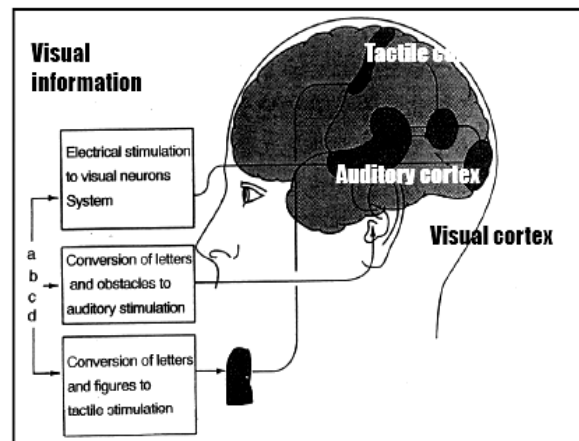


Figure 19: Three approaches supporting "seeing".

4.1. Screen reader for the blind

In 1996, we developed a screen reader, called '95-reader', which can convert text information into synthesized voices for Japanese visually impaired people as shown in figure 20 [16]. However, operating systems based on graphical user interfaces (GUIs) have spread rapidly in personal computer environments. Consequently, it is inherently difficult for visually impaired people to use the screen reader, since they are often unable to detect the necessary visual information.

With this problem in mind, we have proposed a tactile jog-dial (TAJODA) which can control the speech rates of the screen reader while displaying rich text features, such as various

fonts, letter sizes, and bold script onto the tactile sense of a fingertip.

For the design of the TAJODA, first, maximum listening tests were performed on blind users in order to investigate how many morae per minute the blind can correctly recall the presented sentences. From the experimental results obtained by about 20 subjects, it was found that the maximum recall rate for experienced users was about 1,400 morae per minute, which is 2.6 times faster than the average listening rate (550 morae per minute) of the sighted, as shown in figure 21 [17].



Figure 20: Screen reader software (left) and increase of graphical user interface (right).

ext, based on the psychophysical experiments, we determined what kind of rich texts should be presented as tactile patterns. As a result, we have determined some parameters of the prototype model that can control speech rates in real time by use of a finger while touching the rich texts with another finger, as shown in figure 22 [18].

The use of the TAJODA was well accepted by all of the blind subjects, since it allowed them to actively and flexibly navigate through the speech information by dynamically controlling the speech rate. The tactile cues also helped them to look for particular information within the overall speech information. It has been proven that document recognition rate is 2-3 faster than the conventional screen reader.

In a recent model that has been commercially available in Japan, the speech rate can be changed according to monosyllabic voice units by clicking upper button for “more quickly” or the lower button for “more slowly” using a thumb finger of the right hand. An index finger can touch the tactile.

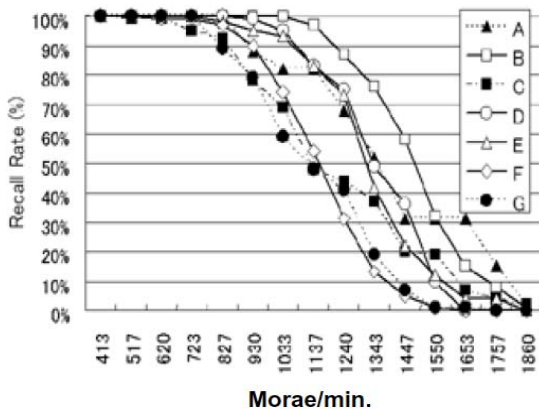


Figure: 21 Recall rate in percent as a function of speech rate in morae/min.

display which is arranged in two columns of 8 pins each, using 32 piezo-vibrator pins [19].

One of blind subjects reported “The tactile cues act like guideposts on a road. The road is like a string of speech information and the guideposts are the tactile cues”. The subject also reported that the one dimensional speech information felt as if two dimensional documents were presented. This fact anticipates that the visual cortex is activated while using the TAJODA.

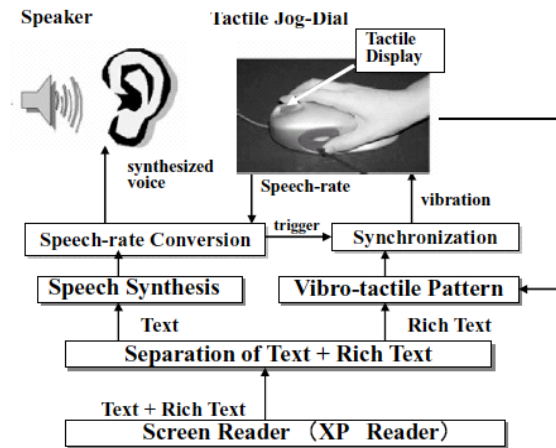


Figure 22: Block-diagram of the TAJODA interface. Speech rate can be controlled by the thumb. Rich text is displayed as vibro-tactile patterns on an indicating fingertip.

Furthermore, we have been designing a Tactile Mobile Phone for assisting “seeing”, “hearing” and “speaking for the deaf-blind” by combining the tactile aid with the TAJODA as shown in figure 23.

In the mobile phone, image and direction information are sensed by a camera and an electric compass inside the mobile phone, which signals are transmitted to a tactile display. Environment sounds including speech can also be detected by a microphone attached to the mobile phone. Furthermore, since the tactile display is utilized as a tactile matrix sensor, tactile information touched and traced by a finger can be displayed onto a receiver’s fingertip through the mobile phone. This function will be useful for the deaf-blind as well as normal users, especially in the condition when the users’ eyes and ears are bounded.

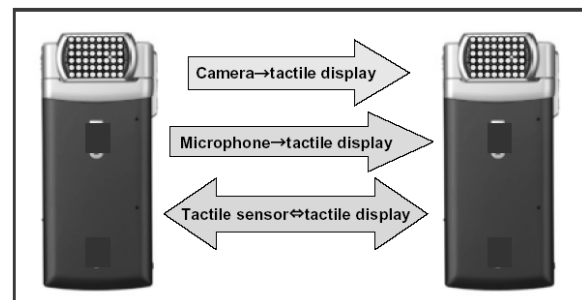


Figure 23: Tactile Mobile Phone for assisting “seeing”, “hearing” and “speaking”

4.2. Tow-dimensional image display method using

Most visually impaired people can detect obstacles by using an ability known as "obstacle sense". We have been investigating the mechanism of the obstacle sense based on psychophysical experiments using visually impaired people. By analyzing and modeling the mechanism of the obstacle sense, the resultant model could be utilized in new concepts for image display aids as well as mobility aids for the blind. From our past research [20], we have ascertained that the reason why they can detect the obstacle and guess the distance is due to their ability to discriminate tiny changes of sound spectral patterns produced by the existing of obstacle. The spectral changes are caused by phase interference between directly reached sound to ears and reflected sounds from the obstacle as shown in figure 24. This spectral change is called "coloration". If environmental noise-like sounds do not exist, the ability of obstacle sense decrease or does not work because of a lack of the phase interference.

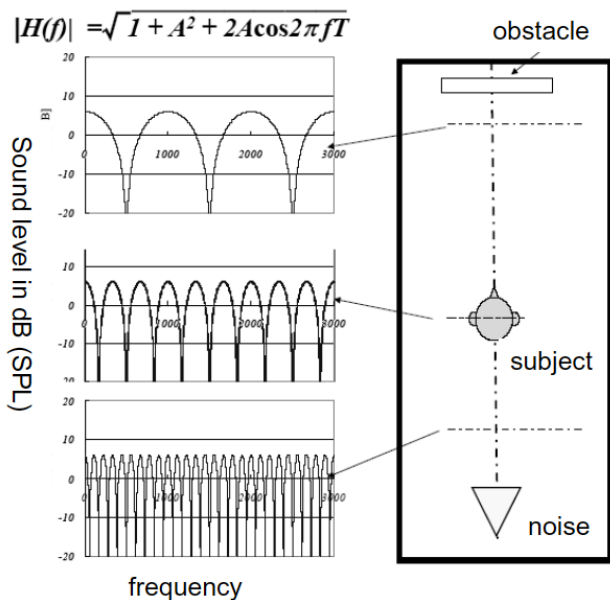


Figure 24: Spectral changes caused by phase interference between direct sounds and reflected sounds from the obstacle.

From basic experiments related to obstacle sense by the blind, we found that the discrimination ability of coloration changes is no difference between blind and sighted groups. However, the blind may detect the obstacle by perceiving the coloration difference as "sound quality change" [21]. It means that the obstacle sense would be acquired by their experience. In another word, they acquired the obstacle sense by "brain plasticity" in the central auditory system.

It is supposed that two dimensional sound images displayed using a loud speaker matrix would be more accurately perceived by the blind than by the sighted for a short training time. With this supposition in mind, we tried to convert the images into two dimensional sound images by using a loud-speaker matrix that can produce temporally and spatially controlled sound sources more than 30 years ago as shown [22].

We have investigated again how the moving sound images as shown in figure 25 are perceived by hearing in order to determine the optimal arrangement of the loudspeakers. Although this study is very preliminary, we may obtain some

suggestions how image information should be displayed in addition to speech information for the blind [23].

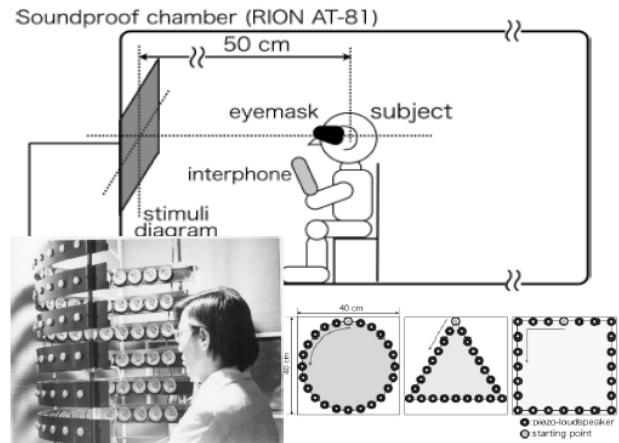


Figure 25: Speaker array for displaying two dimensional images in addition to speech information

5. Conclusion

By applying the sound-based assistive tools to the hearing impaired, the visual impaired and the speech disorders, certain basic hypotheses concerning the brain function have been lead and also the tools have lead to the design of human interfaces for general users. Furthermore, the assistive tools designed for the young disabled will be also useful for supporting the elderly with disabilities by modifying them. The research approach mentioned in this report may contribute to open new markets and to benefit a greater number of people.

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