USER INTERFACE TECHNOLOGY FOR THE HEARING IMPAIRED PEOPLE IN ASIA: A SYSTEMATIC LITERATURE REVIEW

Minmin Zhou*
Universiti Sains Malaysia, Penang
min145051@gmail.com

Kamal Sabran
Universiti Sains Malaysia, Penang
kamalsabran@gmail.com

Abstract: The interface as a medium for information exchange allows users to achieve the purpose of interaction conveniently and effectively. It has profoundly affected many aspects of people's lives. As a large number of particular groups, the hearing impaired people can be helped to solve some practical problems in life by the development a targeted user interface for them. Since hearing impaired people generally have mild to severe hearing loss, they rely more on visual channels for information, so technology plays a crucial role in the development of user interfaces. Based on the literature review, this study explores what user interfaces have been developed by researchers focusing in Asia for the hearing impaired people. Besides, several technology types, including gesture recognition, speech recognition, wearable device, and sign language recognition, help hearing impaired users enhance their interactivity and understanding. This review shows that the future user interface needs to improve the traditional design methods and incorporate appropriate interactive technologies to maximize the learning and daily life of the hearing impaired people to provide positive results.

Keywords: Deaf, hearing impaired, technology, user interface

1. Introduction

According to statistics from the World Health Organization, approximately 466 million people worldwide suffer from hearing loss, which is more than 5% of the world's population, of which 34 million are children. It is estimated that by 2050, this number may increase to more than 900 million (WHO, 2020). Sound is the most direct way of human expression, but many hearing impaired people are troubled by it. The hearing impaired in this study mainly refers to hard of hearing and deaf, that is, people whose hearing loss ranges from mild to severe. People with hearing difficulties need hearing aids, cochlear implants and other assistive devices. Deaf people usually have little or no hearing and need to communicate using sign language. The current communication methods for the deaf or hearing impaired include sign language, assistive hearing aids and hearing devices (Dalebout, 2009). Sign language can help them communicate their intentions, but they cannot talk to people who don't understand sign language. Hearing aids and hearing devices can amplify sound signals, but they cannot solve inaudibility. Hearing impaired people bring considerable pressure to the family and society in communication and life.

In the past ten years, smart terminals and mobile Internet have changed people's lives. The lives of the disabled, including the hearing impaired, have not been significantly improved before due to advances in technology (Vash & Crewe, 2003). How to enable more and more hearing impaired people to enjoy the convenience of the intelligent age, and to solve some practical problems for them while improving the quality of life is the direction that needs to be considered in the development of interface technology in recent years.

The study on user interface development in Asia for the hearing impaired people was included in the review to understand the current research focus and the current status of technology use. To successfully and effectively serve the hearing impaired, technology should actively adapt to their physical and cognitive abilities (Tzovaras, 2008, p. 251). The review found that many factors need to be considered in the user interface, more than perceiving user actions, recognizing user psychology and information presentation to construct interactive pages useful for the hearing impaired. Perceiving the

* Corresponding author: Minmin Zhou, Universiti Sains Malaysia, 11800 Gelugor Penang, min145051@gmail.com

movements and hearts of the hearing impaired requires high-precision technical support. The study usually provides suitable sensing solutions by analysing the user's tasks and usage scenarios. Also, cost-controllable and easy-to-deploy hardware solutions are issues that require additional consideration.

The results of the systematic literature review will provide a valuable reference for the future development of user interfaces for hearing impairment to help people who are deaf or hearing impaired in their lives. This study introduces the literature research methods in the second part; the third part analyses the literature data and discusses the results; finally, the future work and conclusion are discussed in the fourth section.

2. Method

2.1 Research questions

This study is based on a systematic literature review that explores techniques used in user interfaces developed for the deaf and hard of hearing in Asia. The main objective is to answer the following research questions:

RQ1: What has user interface development in Asia helped the hearing impaired?

RQ2: What technologies are used in the user interface for the hearing impaired in Asia?

2.2 Search process

The systematic review followed the PRISMA guidelines. The selected studies were those published from 2015 to 2020. Scopus, ACM digital library, and IEEE Explore databases were used for searching. The review is intended to include a broader range of hearing impaired people in the discussion, hence, "deaf" and "hearing impaired" are included in the search. The basic form of the search string is "User interface" + "deaf" OR "hearing impaired".

Based on the above string, a search was performed in title, keyword, and summary. The study focuses on the discussion of Asian user interface technologies, in order to discover the current research problems and what needs to be implemented. This will be compared further with Western research and used to guide future development of the interface. By focusing on the Asian region, the researchers would be able to further discover the gaps and needs of current Asian interface technology.

2.3 Inclusion and exclusion criteria

The studies included in the literature review met the following criteria:

- The research was published from 2015 to 2020;
- The research focuses on developing user interfaces for the hearing impaired.

The exclusion criteria are as follows:

- The article is not in English;
- The area is not an Asian country.

2.4 Data extraction

The literature review was searched in December 2020. After passing the above exclusion criteria and inclusion criteria, 70 studies were obtained from Scopus, ACM Digital Library, and IEEE Explore databases. After deleting studies excluded as they were not relevant, 18 papers were finally selected for review. All 18 studies were peer-reviewed, three of which were based on the same study (Petry et al., 2018; Petry et al., 2016; Petry et al., 2016). Figure 1 is the PRISMA flowchart showing the inclusion of studies. The studies excluded from the review were those that fell under one of the following categories: (1) it did not focus on the deaf or hearing impaired people and might consist of other disabled persons; (2) the main content of the research was the content design of the interface, with no or less discussion of technology; (3) the studies focused on education for the deaf.

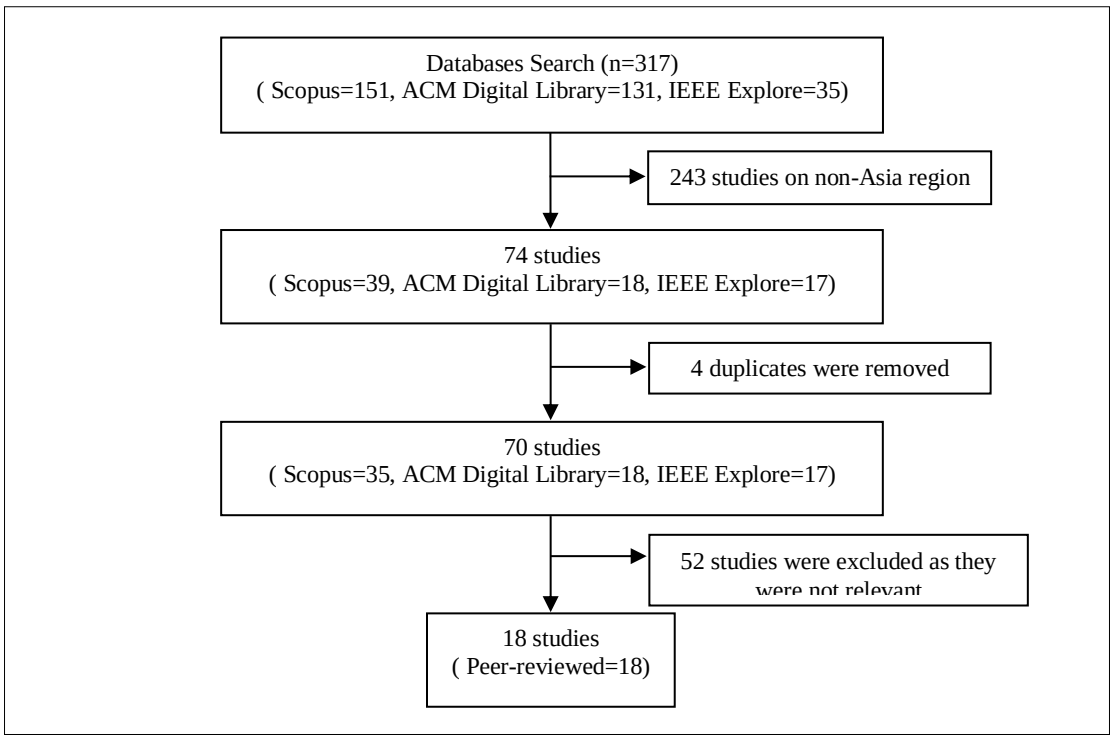

Figure 1: PRISMA Flowchart Showing the Inclusion of Studies

3. Result

3.1 RQ1: What has user interface development in Asia helped the hearing impaired?

Communication is one of the challenges for the hearing impaired. On the one hand, the sign language they use cannot be understood by hearing people. On the other hand, communication between hearing impaired people is not as simple as imagined. Figure 2 shows that eight studies help the hearing impaired people realize communication, and the research institute accounts for the largest proportion. First, to promote the dialogue between the deaf or hearing impaired and the average hearing person, the interface mainly solves the two critical problems of sign language recognition for the deaf and speech recognition for the hearing person. Smart devices could increase the participation of the hearing impaired in society. Based on their study, Limpiti et al. (2019) developed a portable dialogue box that detects the sign language of deaf people by using a camera to capture hand images. The audience's answers were received through the microphone and interpreted through the Google Cloud Voice API. Another study was conducted by Lee et al. (2013) which helped to communicate intentions efficiently in both directions between the average hearing person and the hearing impaired. A clear understanding of a person's voice with normal hearing could reduce the burden of hearing loss. Interface design is a viable way to realize effective and efficient intelligent agents because it reduces the workload required for hearing impaired users interacting with hearing people.

Due to the difficulty of obtaining sound, hearing impaired people often need auxiliary systems such as subtitles. A study by Peng et al. (2018) challenged traditional subtitles and developed a real-time subtitle interface on a head-mounted display of SpeechBubbles to enhance group conversation experiences for the deaf and hard of hearing. Research on wearable devices also included providing dialogue information for the hearing impaired, and developing a portable caption support system (Suemitsu et al., 2016) through a see-through head-mounted display (HMD). Chattoraj et al. (2017) focused on the development of gesture recognition human-machine interface systems to recognize different gestures used by deaf people for communication, hence, enabling deaf people to communicate more efficiently with others. In addition, end-to-end American Sign Language (ASL) recognition could also be achieved at the word and sentence level through a lightweight wearable device (Zhang et al., 2019). A new system for converting Arabic sign language from gestures to characters was also proposed (Kammoun et al., 2020). Accessible communication makes life more satisfying for the hearing impaired

and improves their quality of life (Anegundi et al., 2019).

Hearing loss can affect the use of smartphones and applications. There are thousands of words in sign language worldwide, and a study by Saqib et al. (2018) helped deaf people use spell-based gestures when using smartphones and laptops. Besides, Chuan et al. (2017) conducted a study intended to build a social media application for the deaf community in Malaysia to help them interact online using specific gestures. Meanwhile, Wang et al. (2018) carried out a study to solve the difficulties encountered by the hearing impaired because they could not get the sound of the smartphone. The research proposed a mobile phone system that could combine Chinese speech recognition and sign language animation. There was one study that helped the hearing impaired learn. The study by Alcazar et al. (2016) introduced an e-learning system which was specially developed for deaf voice tutors. This system includes an English course management module, a speech recognition module and an evaluation module. As a new teaching aid, this is beneficial to the development of education for the deaf.

There were also studies conducted to help the hearing impaired to better cope with meetings. Due to the 2019 coronavirus, many schools or companies choose to hold online meetings. A study by Oomori et al. (2020) provided help for the hearing impaired with an emoji-based captioning system in online meetings. The voice-only online forum could not capture the facial expressions of the speaker, hence, the hearing impaired could not hear the speaker's voice. It is more difficult to judge the emotional state only through pure subtitles. The addition of emoji helps the deaf and hearing impaired to understand the speaker's feelings more accurately in this situation. Another study that helped the hearing impaired cope with meetings was conducted by Suzuki (2020) who proposed a multi-person simultaneous voice captioning system. When there are multiple speakers in a meeting, the system can recognize the speech's voice and display the text. This system has been verified by hearing impaired and hearing impaired companies.

Although the deaf and hard of hearing people have different degrees of hearing loss, it does not affect their appreciation of music. There have been many studies to provide hearing impaired people with ways to appreciate music and dance. There are four papers included in the review; three of which belong to different stages of the same research content (Petry et al., 2018, 2016a, 2016b). These three studies help deaf people perceive music and learn music in stages, and further propose playing music in music classes in schools for the deaf. Shibasaki et al. (2016) designed a system that enables the hearing impaired to enjoy tap dance performances. The system transmits the touch of tap dance from the stage to the audience, hence allowing the hearing impaired to feel the vibration of the dance with the help of wearable devices. The system has been validated through various activities.

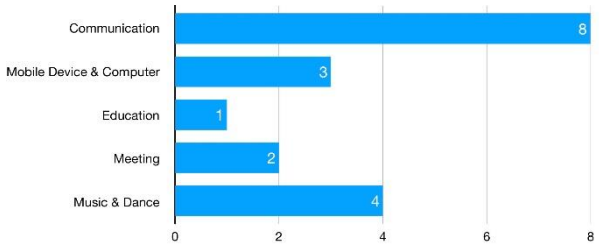

Figure 2: Application Fields

3.2 RQ2: What technologies are used in the user interface for the hearing impaired in Asia ?

The study reviewed the technologies used in the user interface for the hearing impaired in Asia and categorized them according to these technologies (Figure 3). These 18 studies mainly used four technologies, which are gesture recognition, speech recognition, wearable devices and sign language recognition. It should be noted that four studies (Limpiti et al., 2019; Suemitsu et al., 2016; Peng et al., 2018; Zhang et al., 2019) did not only mention one user interface technology, so there will be duplicate records in these four categories.

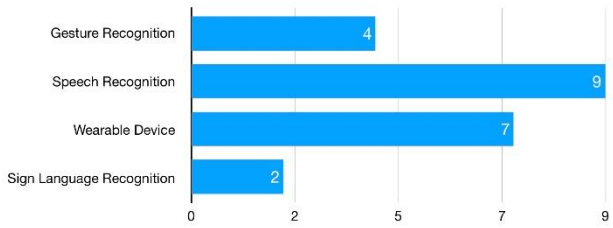

Figure 3: Used Technologies

a) Gesture recognition

Gesture recognition is a non-verbal physical action in human-computer interaction, which includes the tracking of gesture actions and subsequent computer data processing (Chuan et al., 2017). Regarding gesture motion capture, it is mainly realized by optical and sensor. Gesture input provides us with a natural interactive interface. Its advantages are safety, general, no contact, and fast development (Saqib et al., 2018).

Kammoun et al. (2020) recognized Arabic sign language gestures by capturing hand and finger movements and then converts the recognized gestures into a processing module for letters. Chuan et al. (2017) described the communication between users and the system through an accessible model. Although the gesture interaction of deaf people may be different from ordinary people, they can use gesture language proficiently and be evaluated in the model to enhance the barrier-free use of gestures for the hearing impaired in the mobile space. Saqib et al. (2018) introduced a gesture-based communication form, which has the advantage of being able to interact with smartphones and laptops without touching and relying on spelling gestures. To help the hearing impaired communicate with the general public, gesture recognition technology needs to accurately perform gesture processing and reduce processing time, making the recognition more efficient (Chattoraj et al., 2017).

Table 1: Details of Gesture Recognition Reviewed

Author(s)	Fields	Develop	Findings
Kammoun et al. (2020)	Communication	A new system to convert Arabic sign language from gesture to written text	The Leap motion controller as a gesture recognition device can capture the movement of hands and fingers
Chuan et al. (2018)	Communication	The 'Gesture-Specific Heuristics' (GSH) evaluation model with deaf users	The current 'Gesture Interaction' implementation in mobile applications is sufficient for deaf users.
Saqib et al. (2018)	Communication	Spelling-based gestures communication	Spelling based gestures are effortless to learn and generate, helping the hearing impaired to communicate with smartphones and laptops
Chattoraj et al. (2017)	Communication	Hand gesture recognition and human-computer interface system	The scale-invariant feature transform algorithm has been used to reduce the delay time and improve the accuracy of the results

b) Speech recognition

Speech recognition is currently a technology widely used in user interfaces. In recent years, the speech recognition technology in the hearing impaired user interface mainly assists in spoken language, daily conversation and real-time translation (Table 2). In order to make it easier for the hearing impaired to use the interface, the existing research mainly solves the following speech recognition problems: the speech signal will be affected by the scenario and change (Anegundi et al., 2019; Suemitsu et al., 2016); psychological changes of the speaker will bring about changes in speech (Oomori et al., 2020; Peng et al., 2018); the difference in pronunciation and population will cause various speech phenomena, and lead to a different distribution of speech features in the parameter space (Peng et al., 2018; Limpiti et al., 2019).

Table 2: Details of Speech Recognition Reviewed

Author(s)	Fields	Develop	Findings
Suzuki (2020)	Meeting	The user interface of subtitle displaying	This system dictates voices talked in that situation and displays dictated texts
Oomori et al. (2020)	Meeting	An advanced system	It is necessary to design emoji expressions, graphic user design, and emotion recognition methods to help deaf or hard of hearing (DHH) people participate in group meetings.
Limpiti et al. (2019)	Communication	A portable dialogue box	The portable dialogue box allows the hearing impaired to use sign language to help the face-to-face dialogue between the deaf and hearing person.
Anegundi et al. (2019)	Communication	A computer-based application of speech recognition	The application facilitates speech recognition in a multi-speaker environment.
Wang et al. (2018)	Communication	A framework of speech based Chinese Sign Language (CSL) Animation System on Smart Phones	This model for Android phones supports deaf people to answer phone calls from any phones (not only smartphones).
Peng et al. (2018)	Communication	A real-time speech recognition interface: SpeechBubbles	SpeechBubbles uses a bubble display and provides potential captioning solutions for enhancing DHH individuals' group conversation experience
Lee et al. (2016)	Communication	A portable device with directional sound selection capability	The proposed interface design reduces the workload required for hearing impaired users who interact with hearing people
Alcazar et al. (2016)	Education	An e-learning system	The developed system integrates all modules into an e-learning system which allows interaction to its users through speech and produce its visual or pictorial equivalent as an output in the user interface
Suemitsu et al. (2015)	Communication	A wearable dialogical information support system	The see-through head-mounted display (HMD) and the microphone array are used to provide a portable solution to people with hearing difficulties

c) Wearable devices

Wearable devices include sensor modules with multiple sets of sensors, which make users feel small and able to provide all kinds of information at any time. Wearable devices do not only become an extension of the capabilities of the hearing impaired (Zhang et al., 2019; Peng et al., 2018; Suemitsu et al., 2016) but also bring a better perception experience (Shibasaki et al., 2016). Related studies include the use of wearable devices to recognize American Sign Language (ASL) automatically. This device is not easily affected by the surrounding environment and the diversity of users, hence, it can facilitate communication between deaf and hearing people.

There were two studies focusing on head-mounted displays. Peng et al. (2018) provided real-time subtitles through a head-mounted display. Another study was conducted by Suemitsu et al. (2016) which reported that in addition to using a transparent head-mounted display to receive voice signals, it was also possible to obtain more detailed information of the speaker through the camera. Besides, wearable devices can also help hearing impaired people enjoy music and dance. This is possible, for example, by using handheld output devices to provide tactile feedback to enjoy tap dance (Shibasaki et al., 2016). Petry et al. (2018) provided a visual and vibratory tactile music sensor alternative device that can be connected to the palm to help deaf people distinguish rhythm.

Table 3: Details of Wearable Device Reviewed

Author(s)	Fields	Develop	Findings
Zhang et al. (2019)	Communication	A lightweight wearable device: Myo armband 1	MyoSign enables the deaf and hearing people to communicate in a more natural and intuitive way
Peng et al. (2018)	Communication	A real-time speech recognition interface: SpeechBubbles.	SpeechBubbles uses a bubble display and provides potential captioning solutions for enhancing DHH individuals' group conversation experience
Petry et al. (2018)	Music and Dance	A visual and vibrotactile music-sensory-substitution device: MuSS-Bits++	The music-sensory-substitution systems hold a lot of potential for music-making
Petry et al. (2016)	Music and Dance	Music Sensory Substitution: MuSS-Bits	MuSS-Bits is intended to allow deaf users to explore and develop a conceptual model of musical sounds and provides the feedback to cater to individual requirements and preferences
Petry et al. (2016)	Music and Dance	A music sensory substitution system	MuSS-Bits provides real-time rhythm information to a deaf user
Shibasaki et al. (2016)	Music and Dance	Karada Tap system	Hearing impaired people realize the fun of tap dancing through haptic feedback from a handheld output device
Suemitsu et al. (2015)	Communication	A wearable dialogical information support system	The see-through head-mounted display (HMD) and the microphone array are used to provide a portable solution to people with hearing difficulties

d) Sign Language Recognition

Asian countries have diverse languages and cultures. The study of this review as seen in Table 4 involves the sign languages of these diversified Asian countries. There is no uniform standard for sign language globally since different regions have different sign language systems (Matamala & Orero, 2010). This increases the difficulty of sign language recognition technology. Sign language carries a wealth of information and has well expressive skills. The study of sign language recognition can facilitate the communication between the hearing impaired and the hearing person. This can be done for example, through a lightweight wearable device, end-to-end ASL recognition at the word and sentence level (Zhang et al., 2019); or use a web camera to capture video images of the deaf in a conversation; other select hands in the area within the image to detect the sign language of the deaf person (Limpiti et al., 2019).

Table 4: Details of Sign Language Recognition Reviewed

Author(s)	Fields	Develop	Findings
Limpiti et al. (2019)	Communication	A portable dialogue box	The portable dialogue box allows the hearing impaired to use sign language to help the face-to-face dialogue between the deaf and hearing person.
Zhang et al. (2019)	Communication	A lightweight wearable device: Myo armband 1	MyoSign enables the deaf and hearing people to communicate in a more natural and intuitive way

4. Discussion and Conclusion

Through a systematic literature review, it was found that the four user interface technologies discussed all provide positive help for the learning and daily life of the hearing impaired. People who are deaf or hard of hearing suffer from hearing loss due to various reasons and cannot communicate through natural sound symbols. In this sense, hearing loss is not their most serious problem, but the difficulty they encounter in developing appropriate communication methods. Through the above literature review, it was found that there are numerous studies on promoting communication between the hearing impaired and the hearing person. Therefore, helping to improve the communication problems of the hearing impaired is still a hot spot.

The review also focuses on the communication between the hearing impaired and the computer. The purpose of this part of the research is to help the hearing impaired use mobile devices and computer conveniently and effectively. The primary method is to take advantage of the hearing impaired in sign language gestures and to make up for the lack of sound perception. Also, due to the development of intelligent interactive media, learning is no longer limited to special education schools and traditional classrooms. Unfortunately, learning applications rarely consider the particular learning needs of the hearing impaired and design a unique interface for them. Despite the fact that the importance of the deaf in learning has received widespread attention, study in this area is still lacking. A teaching aid system developed for deaf voice tutors would be useful for everyone.

In addition to the right to education, the hearing impaired people also have the right to enjoy art and entertainment. The early entertainment industry mainly helped the hearing impaired to enjoy programs by providing subtitles in various fields. However, this method only allows them to receive information through another channel, and the deaf or hearing impaired still could only imagine the sound. In particular, the studies mentioned in the review literature are mainly in music and dance, which seem to be entertainment items that the deaf or hearing impaired cannot access. Now due to the emergence of wearable device technology, it has brought possibilities for them. It also shows that wearable devices have specific development potential in improving the entertainment experience of hearing impaired in the future.

A systematic literature review was conducted by selecting 18 studies related to the research question from 2015 to 2020. It was found that communication is one of the primary purposes of interface research. Speech recognition technology and wearable devices have a wide range of applications and can provide almost all aspects of assistance to the hearing impaired. The future user interface needs to improve the traditional design method and combine with appropriate interactive technology, to maximize the positive effects for the learning and daily life of the hearing impaired.

References

Alcazar, V. J. L. L., Maulana, A. N. M., Mortega, R. O., & Samonte, M. J. C. (2016). Speech-to-visual approach e-learning system for the deaf. *ICCSE 2016 - 11th International Conference on Computer Science and Education, Iccse*, 239–243.

Anegundi, A., Chalana, D. A., Pawale, V. V., Vinay, G., Rudraswamy, S. B., & Manohar, N. (2019). A computer-based application for speech recognition in multi-speaker environment to assist hearing impaired people. *International Journal of Recent Technology and Engineering*, *8*(1C), 177–185.

Anindhita, V., & Lestari, D. P. (2016). Designing interaction for deaf youths by using user-centered design approach. *4th IGNITE Conference and 2016 International Conference on Advanced Informatics: Concepts, Theory and Application, ICAICTA 2016*, 1–6.

Chai, X., Li, G., Chen, X., Zhou, M., Wu, G., & Li, H. (2013). VisualComm: A tool to support communication between deaf and hearing persons with the Kinect. *Proceedings of the 15th International ACM SIGACCESS Conference on Computers and Accessibility, ASSETS 2013*, 3–4.

Chattoraj, S., Vishwakarma, K., & Paul, T. (2017). Assistive system for physically disabled people using gesture recognition. *2017 IEEE 2nd International Conference on Signal and Image Processing, ICSIP 2017*, 2017-January, 60–65.

Chuan, N. K., Fatimah, W., Ahmad, W., Sivaji, A., Nathan, M. S., & Loo, F. A. (2017). *Evaluating \'Gesture Interaction\' Requirements of Mobile Applications for Deaf Users.* 90–95.

Dalebout, S. (2009). *The Praeger Guide to Hearing and Hearing Loss: Assessment, Treatment, and Prevention.* ABC-CLIO.

Gumay, M. R. A., Effendy, V., & Junaedi, D. (2020). Modeling user interface design for panic button application for deaf people using user-centered design method. *IOP Conference Series: Materials Science and Engineering*, 830(2).

Kammoun S., Darwish D., Althubeany H., & Alfull R. (2020) ArSign: Toward a Mobile Based Arabic Sign Language Translator Using LMC. In: Antona M., Stephanidis C. *(eds) Universal Access in Human-Computer Interaction. Applications and Practice. HCII 2020. Lecture Notes in Computer Science*, vol 12189. Springer, Cham.

Lee, S., Kang, S., Ko, H., Yoon, J., & Keum, M. (2013). Dialogue enabling speech-to-text user assistive agent with auditory perceptual beamforming for hearing-impaired. *Digest of Technical Papers - IEEE International Conference on Consumer Electronics*, 360–361.

Limpiti, T., Khamyan, S., Chumsaeng, S., & Puttarak, N. (2019). A smart dialogue box for the hearing impaired. *Proceeding - 5th International Conference on Engineering, Applied Sciences and Technology, ICEAST 2019*, 2019–2022.

Liu, Z., Tang, W., & Xu, J. (2010). A study and application of speech recognition technology in primary and secondary school for deaf/hard of hearing students. *I-CREATe 2010 - International Convention on Rehabilitation Engineering and Assistive Technology*, 53–55.

Matamala, A., & Orero, P. (2010). *Listening to Subtitles: Subtitles for the Deaf and Hard of Hearing.* Peter Lang Publishing.

Mokhtar, S. A., & Anuar, S. M. S. (2015). *Learning application for Malaysian sign language*. 1–6.

Nanayakkara, S., Wyse, L., & Taylor, E. A. (2012). The haptic chair as a speech training aid for the deaf. *Proceedings of the 24th Australian Computer-Human Interaction Conference, OzCHI 2012*, 405–410.

Ohtaki, T., Imai, K., Yoshimura, S., & Hashimoto, K. (1981). Three months subacute toxicity of captopril in beagle dogs. *Journal of Toxicological Sciences*, *6*(Suppl. 2), 247–270.

Oomori, K., Shitara, A., Minagawa, T., Sarcar, S., & Ochiai, Y. (2020). A Preliminary Study on Understanding Voice-only Online Meetings Using Emoji-based Captioning for Deaf or Hard of Hearing Users. *ASSETS 2020 - 22nd International ACM SIGACCESS Conference on Computers and Accessibility*.

Peng, Y., Hsu, M., Taele, P., Lin, T., Lai, P., Hsu, L., Chen, T., Wu, T., Chen, Y., Tang, H., & Chen, M. (2018). SpeechBubbles: Enhancing Captioning Experiences for Deaf and Hard-of-Hearing People in Group Conversations. *CHI '18: Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, 1–10.

Petry, B., Illandara, T., Elvitigala, D. S., & Nanayakkara, S. (2018). Supporting rhythm activities of deaf children using music-sensory-substitution systems. *Conference on Human Factors in Computing Systems - Proceedings*, 2018-April, 1–10.

Petry, B., Illandara, T., Forero, J. P., & Nanayakkara, S. (2016). Ad-hoc access to musical sound for deaf individuals. *ASSETS 2016 - Proceedings of the 18th International ACM SIGACCESS Conference on Computers and Accessibility*, 285–286.

Petry, B., Illandara, T., & Nanayakkara, S. (2016). MuSS-Bits: Sensor-display blocks for deaf people to explore musical sounds. *Proceedings of the 28th Australian Computer-Human Interaction Conference, OzCHI 2016*, 72–80.

Sahid, A. F. B. M., Ismail, W. S. W., & Ghani, D. A. (2017). Malay Sign Language (MSL) for Beginner using android application. *ICICTM 2016 - Proceedings of the 1st International Conference on Information and Communication Technology*, May, 189–193.

Saqib, S., Kazmi, S. A. R., Masood, K., & Alrashed, S. (2018). Automatic sign language recognition: Performance comparison of word based approach with spelling based approach. *International Journal of Advanced Computer Science and Applications*, *9*(5), 401–405.

Shibasaki, M., Kamiyama, Y., & Minamizawa, K. (2016). Designing a haptic feedback system for hearing-impaired to experience tap dance. *UIST 2016 Adjunct - Proceedings of the 29th Annual Symposium on User Interface Software and Technology*, 97–99.

Suemitsu, K., Zempo, K., Mizutani, K., & Wakatsuki, N. (2016). Caption support system for complementary dialogical information using see-through head mounted display. *2015 IEEE 4th Global Conference on Consumer Electronics, GCCE 2015*, 368–371.

Suzuki, T. (2020) Simultaneous Speech Subtitling Systems for Multiple Speakers. In: Stephanidis C., Antona M. (eds) *HCI International 2020 - Posters. HCII 2020. Communications in Computer and Information Science, 1226*. Springer, Cham.

Tzobaras, D. (2008). *Multimodal User Interfaces: From Signals to Interaction*. Springer Science & Business Media.

Vash, L. C., & Crewe, M. N. (2004). *Psychology of Disability.* Springer Publishing Company.

Wang, W., Zhang, W., & Sun, B. (2018). A sign language smart phone based on realistic animation. *MATEC Web of Conferences*, 189.

World Health Organization. (2020). *Deafness and hearing loss*. https://www.who.int/news-room/fact-

sheets/detail/deafness-and-hearing-loss

Zhang, Q., Wang, D., Zhao, R., & Yu, Y. (2019). MyoSign: enabling end-to-end sign language recognition with wearables. *In Proceedings of the 24th International Conference on Intelligent User Interfaces (IUI '19)*. Association for Computing Machinery, New York, NY, USA, 650–660.