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Making Telecommunications Services Accessible to People with Severe Communication Disabilities

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Abstract—Since the advent of telephony in 1880s, a number of important telecommunications technologies have been invented and developed. However, people with severe communication disabilities have been left out from enjoying the electronic transmission of speech and voice due to their limitations in cognitive, social, and/or motor skills. This paper reports a cross-disciplinary endeavour in Hong Kong that aims at paving the very last mile of communication networks. A semantic image-based cloud augmentative and alternative communication system has been developed in an 18-month project. The system enables people with complex communication needs to conduct telephone conversations. The primary user group spans at least 1.3 percent of all population worldwide; including those with dementia, aphasia, developmental disorders, and those in acquired medical conditions, etc. who cannot rely on their natural speech for daily communication.

Keywords—*augmentative and alternative communication (AAC); semantic images; telecommunications services; complex communication needs*

I. INTRODUCTION

Human communication is a fundamental need in all aspects of life. According to the International Classification of Functioning, Disability and Health (ICF) framework published by the World Health Organization (WHO) [1], human communication is one of the health-related domains which measures the functioning and disability of individuals as well as a population. People have stayed socially connected since the hunters-and-gatherers period. Effective communication enables individuals to express needs, desires, and beliefs to each other in the society. Purposes of human communication (see e.g., [2], [3], and [4]) include:

1. The fulfillment of needs and wants.
2. The transfer of information.
3. To achieve social closeness.
4. To express social etiquette.

Communication needs can occur in any social environments; while the communicating parties may locate in the vicinity or across a distance. However, people with communication disabilities do not have the necessary abilities, including cognitive, social, and/or motor skills to carry out communication to meet their daily needs. Communication disabilities may result from a variety of physical, sensory, and environment causes and can restrict an individual's independent functioning in the modern society. The estimated prevalence of severe communication disabilities is at least 1.3 percent of all individuals (2005 figure) [5]. However, according to the data collected from the 2012 US National Health Interview Survey [6], approximately 10 percent of the US adult population self-reported difficulties in speech, language, and voice; while only 2 percent reported that they were receiving a diagnosis. In particular, some population has significantly high rate of communication disabilities or complex communication needs. They include:

- People with developmental disabilities (e.g., cerebral palsy, autism spectrum disorders, and/or intellectual disability). For example, it has been estimated that up to 25 percent of people with cerebral palsy have little or no functional speech; and between 17 to 25 percent of children with autism spectrum disorders fail to develop functional speech [7].
- People with cognitive and linguistic impairments (e.g., aphasia and/or dementia).
- People in acquired medical conditions (e.g., spinal cord injury, amyotrophic lateral sclerosis, and/or head and neck cancer) that lead to severe speech and language limitations [8].

While advances in information and communication technologies (ICTs) have revolutionized our everyday lives, people with communication disabilities do not possess the required cognitive abilities and/or motor skills to make use of telephony and telecommunications services. They are often excluded from the benefits brought by the advancement of

communication technologies. This issue has recently attracted much attention of major international organizations including the International Telecommunication Union (ITU) [9], [10]. The Hong Kong Government also calls for the development of ICT as a tool to support underprivileged groups [11].

This paper reports a cross-disciplinary collaboration between communication engineers and speech therapists. The research team developed a semantic image-based cloud augmentative and alternative communication (Cloud AAC) system. The system is based on the designed proposed by Chan in 2014 [12]. While telecommunications services for the deaf such as teletypewriter (TTY) and telecommunications device for the deaf (TDD) have been in place for decades, our work is amongst the pioneer in terms of providing telephone-like conversation experience to people with complex communication needs through the use of AAC symbols. A pilot version of the system has been completed and tested by 19 users with complex communication needs, including those with a variety of types and levels of difficulties such as cerebral palsy, hearing loss, and/or mental retardation, etc. The system is expected to launch in Q1 of 2017 at a non-government organization in Hong Kong that serves over 8,000 families having member(s) with special needs.

II. BACKGROUND

A. Communications Technology and Needs of Users with Severe Communication Disabilities

Telephone services had been in place since 1880s when Alexander Graham Bell realized that telegraph line could also transmit human speech (the readers are invited to see a review provided by the IEEE Communications Society [13]). In fact, one of the reasons for Bell's interest in telegraphing vocal sounds was his passion and experience in teaching people with hearing disabilities to speak (see e.g., [14]). Since then various technical difficulties have been overcome; with a number of important telecommunications technologies being invented and developed. These technological breakthroughs include but not limited to optical communications, digital telephone network, cellular mobile telephony, and the Internet. Nowadays, telecommunications technology connects millions of families, friends, co-workers, and partners over a long distance. It is an important building block for knowledge advancement, as well as the success of the modern society.

Although telecommunications policy (such as the US Communications Act of 1934) would have had offered accessibility guidelines for communications technology; until the mid-1980s, it only focused on the technical aspects such as network connectivity, and incorporated few accessibility features for people with disabilities [15]. One of the reasons can be the division of telecommunication services between the media (such as the web content) and carriers (such as telephone which only connects users to one another without providing additional content) [16]. Until now, users with

severe communication disabilities are left out of telecommunication services and in particular those supporting telephone conversations, as phone conversations basically assume the users' ability in speech production and hearing.

B. Augmentative and Alternative Communication

Augmentative and alternative communication (AAC) corresponds to tools and strategies for supplementing or substituting verbal communication such as speech or writing [6]. AAC enables people whose verbal communication ability cannot support their daily communication needs to express themselves, for example, to express their needs and wants and to socially interact with the others. AAC is also a clinical practice which provides communication interventions for people with various levels of communication disabilities. Throughout the past few decades, a variety of AAC tools and solutions (electronic and non-electronic) have been developed, such as those for picture card exchange and speech generation (e.g., [17], [18]). Furthermore, there are a growing number of AAC mobile applications being developed over the recent years. Examples include TalkAbout [19] and Marcopolo [20] which were designed for users with aphasia. However, to our best literature search, there exist no delegated AAC mobile applications that support network connectivity and interactions between two remote devices (as of a review on literature up to June 2016). Nevertheless, a design of cloud AAC system was presented by Chan (the first author) at *IEEE Global Communications Conference (GlobeCom) 2014* [12] which is one of the two flagship conferences of the IEEE Communications Society. The current work is an implementation of Chan's design.

C. Semantic-Image Based Cloud AAC System: The Current Project and Stage of Development

A university-community partnership is formed between a research university (The Chinese University of Hong Kong) and a social service provider (SAHK) in Hong Kong. The research and development team consists of communication engineers, speech therapists, and a graphic designer. As a participatory design strategy, target users who have complex communication needs are also invited to provide input to the usability design. The project serves as an exemplar for cross disciplinary and cross sectional collaboration for social benefit. The project spans 18 months from July 2015 to December 2016 with phases including system design, early implementation, user testing, and evaluation. A prototype of semantic image-based cloud AAC system has been developed (as of June 2016) and a complete deployment is expected in Q1 of 2017. The system is based on the designed proposed by Chan in 2014 [12]. To our best literature search (as of June 2016), our system is the first implementation of Chan's cloud AAC which enables people with complex communication needs to conduct telecommunications conversation over two different devices. Figure 1 on next page shows the overall project milestones, deliverables, and stages of development.

Fig. 1. Overall project milestones, deliverables, and stage of development.

III. SYSTEM DESIGN AND IMPLEMENTATION

Our system objective is to provide an AAC method which allows users to conduct telephone-like communication over a distance. Traditionally, people with complex communication needs depend on alternative means such as communication boards and picture card booklets to communicate. Figure 2 shows a scenario in which a speech therapist communicate with two AAC users using custom-made picture card booklets. Conventional AAC methods are mostly offline and limited to the communication partners located in the vicinity. The key technical enhancement that our system has made over the existing solutions is to enable remote communication between two AAC users over the Internet.

Fig. 2. A speech therapist communicates with the AAC users using paper-based picture card booklets.

A. System Overview

The overall system architecture is shown in figure 3. It includes the following service components:

1. The **mobile Android client application (the app)** with adaptive user interface (UI). The app provides basic AAC functions e.g., symbols selection, input, and the display of messages made up by AAC symbols. The AAC symbols are displayed in form of digital picture cards. The app uses sockets to communicate amongst the peers and also the server. Furthermore, a Text-to-Speech (TTS) module, which converts the semantic meaning associate to an AAC symbols (e.g. "happy") to voice output for playback. This component is implemented with commonly available TTS utility such as the Cantonese TTS system of Google.
2. **Database** for storing (1) the chat records and (2) user credentials and login information. These databases are installed at the server side.
3. Computational logics which are **machine learning algorithms** (hosted at the server side) to study users' patterns of AAC symbol usage so that a list of most probable succeeding symbols can be provided upon the selection of a particular symbol.
4. A web-based **administration console** for viewing the chat records between different mobile clients. It also provides general administrative functions such as the management of the AAC symbols.

Fig. 3. Overall system architecture.

B. Implementation

The current work is an ongoing project (as of June 2016). A preliminary version of our system has been developed. Our prototype has been installed and tested on a number of tablets with different sizes and resolutions, including 8" Xiaomi Tab2 tablet, 10" Huawei T1-A21W tablet and 7" Samsung Galaxy Tab 2. These tablets were installed with Android 4.1 or higher OS with wireless network connectivity. We tested the app with different screen resolutions and have verified that the app can be adaptive to a range of screen conditions.

C. AAC Symbols, Semantic Concepts, and Symbol Selection

The AAC symbols are displayed in the format of digital picture cards, which represent semantic concepts necessary for simple daily communication. In the current version, the system maintains 500 semantic concepts. These semantic concepts are adopted from the existing set of printed picture cards designed and developed by the SAHK professional speech therapists [21].

The semantic concepts are associated to 15 semantic categories and are assigned to different colors according to Minspeak system [22]; while Minspeak is an acronym for

minimum effort speech and is a semantic compaction system that makes self expression easier for individuals with communication difficulties. For example, a yellow bar is marked on the top of the AAC picture cards belonging to the "people" category e.g., "father" and "teacher", etc. To select a particular AAC symbol, users first choose the category of the semantic concept (e.g., "people") from the app interface, and then select among the subset of picture cards (e.g., "father") under that category. Sentences can be constructed using a succession of picture cards, for example, the consecutive selection of the three digital picture cards that represent "father", "eat" and "apple", respectively corresponds to the expression of "father eats an apple".

D. AAC Symbol-to-Speech Conversation and the Communication Process

Our app enables users to communicate over a distance by implementing a process similar to making a phone call. Instead of communicating through speech, users with communication disabilities and special needs can produce a "voice conversation" by selecting the AAC symbols (i.e. the digital picture cards) from the app interface. The communication process begins when a registered user (the

sender) selects another registered user (the receiver) from the receiver list. After that, a communication request is sent from the mobile app of sender to that of the receiver by means of Android sockets. The receiver can either accept or decline the call (figure 4). If he/she accepts the call, a network connection between the sender and the receiver devices is established and the symbol selection board is displayed.

Fig. 4. (Upper) The user Jessica is calling Gary. (Lower) Gary can choose to accept or decline the conversation.

Once the connection is made, the panel which implements the AAC symbol selection board is returned (figure 5).

Fig. 5. AAC symbol selection board displays after the phone conversation connection has been established.

The communicating parties (i.e. the sender and the receiver) can then select the picture cards to construct the messages. The user first selects a category (e.g., “drinks”) and then selects the picture cards under the corresponding category (figure 6).

Fig. 6. This screen capture shows the AAC symbol selection after the user has selected the category “drinks” Subtitle texts are printed in traditional Chinese language.

Once a message is constructed, it can be sent to the communicating partner by clicking the “Speak” button (available at the lower right hand corner of the app interface). Meanwhile, the AAC symbols of the message will be displayed on the receiver’s app interface (figure 7). A synthesized speech (produced by the TTS module resides on the mobile device) will also be played automatically on the receiver’s phone. Likewise, the receiver can also response by selecting the desire symbols. In this way, a two-way telecommunications conversation using AAC symbols is established.

Fig. 7. (Left) The sender has selected 3 AAC symbols (in forms of digital picture cards) for communication, expressing the phrase “father eats an apple”. (Right) After pressing the “Speak” button (at the lower right hand corner of the app interface), the symbols will be displayed on the receiver’s app, with the corresponding voice (in Cantonese) automatically produced by the TTS module.

The conversation continues until either of the communication parties opt to terminate it by clicking the “end call” button. The AAC symbols exchanged between the sender and the receiver are stored on the server for further analyses and/or diagnoses.

IV. USER TESTS AND RESULTS

We have conducted a series of user tests at special education schools and rehabilitation centers of SAHK. The tests involved a total number of 19 participants (14 males, 5 females) with complex communication needs. All of the participants had severe communication difficulties caused by different levels and aspects of physical and cognitive impairments, including cerebral palsy, mild to moderate mental retardation, and deafness, etc.

Four types of user tests have been performed; which include:

1. **(Test 1) AAC symbols selection with visual cue.** A sample message which consisted of a number of symbols was provided to the participant. The participant was required to follow the example and select the symbols from the app interface to construct the same message.
2. **(Test 2) AAC symbols selection under a specified context without visual cue.** The participant was required to construct messages according to a context predefined by the speech therapist. Unlike test 1, no sample message is provided to the participant.
3. **(Test 3) Free conversation.** The participant constructed context-free messages by selecting the symbols from the app interface.
4. **(Test 4) AAC-based phone call and free conversation.** The participant conducted a phone call-like conversation with a communication partner (who can be a speech therapist, a caregiver, or a peer participant) using a pair of connected mobile devices with the app installed.

Data collected from the user tests included:

1. The usage pattern of communication symbols.
2. The time required by the participant to construct a message from the symbols.
3. Subjective judgment (by speech therapists) of the correctness of message construction.

It has been observed that majority of the participants were able to master the app very quickly and conducted AAC-based phone conversation with very little assistance from the speech therapists. Figure 8 shows a pair of participants who have normal intelligence but very limited motor ability trying our app. They managed to conduct telecommunications conversation by exchanging AAC symbols between two mobile devices. Table I shows the results from 17 out of the 19 participants who had returned the signed consent forms. A total number of 183 messages have been collected and analyzed. The message construction time (in seconds) is defined as the time between the clicking of the first AAC symbol and the “send” button.

Fig. 8. Two users trying our app to conduct AAC-based phone conversation.

TABLE I. DESCRIPTIVE STATISTICS AND RESULTS

	*Number of participants (N = 17)	No. of message constructed by group (N = 183)	Message construction time Mean (SD)
Personal Characteristics			
Sex			
Female	4	30	110.03 (161.38)
Male	13	153	81.43 (98.08)
Age			
20 or below	2	39	37.08 (40.30)
20 - 29.9	3	29	117.90 (96.51)
30 - 39.9	5	41	104.81 (204.16)
40 - 49.9	3	46	179.85 (192.84)
50 or above	4	28	65.82 (63.65)
Clinical Conditions			
Language Level (Age-Equivalent Level)			
2 or below	4	58	143.16 (183.88)
3	4	68	79.24 (82.20)
4 or above	9	57	98.02 (176.56)
Intelligence Level			
Normal Intelligence	5	27	132.59 (246.00)
Mild Mental Retardation	4	68	53.38 (55.29)
Moderate Mental Retardation	8	88	137.14 (158.55)
Diagnosed Impairments**			
Hearing Impairment/Deafness	5	51	52.39 (58.14)
Down's Syndrome	1	11	57.09 (54.90)
Cerebral Palsy (Spastic)	2	31	145.94 (108.24)
Cerebral Palsy (Dyskinetic)	7	47	138.06 (194.87)
Cerebral Palsy (type unspecified)	8	105	78.71 (138.11)
Overall	17	183	105.34 (152.95)

Notes: 1. Only participants with signed consent forms are included.

2. A single participant may subject to more than one type of impairments.

V. DISCUSSION

A. Time Required for Message Construction

The overall average time for message construction is 105.34 seconds, suggesting a room for improvement of the user interface. It is noted that participants in the youngest age group (37.08 seconds) outperform their peers. A large standard deviation (152.95 seconds) was recorded amongst participants. This indicates a large variation in the operational

and interaction ability across participants. In practice, a user can be associated to multiple conditions, e.g., a user with normal intelligence may also suffer from Dyskinetic Cerebral Palsy. This suggests why a single clinical dimension (e.g., intelligence level) may not predict the necessary time for message construction. This also suggests a need for personalization of the application amongst users with different clinical conditions.

B. Observations from User Tests

In one of the cases a user (the son) with high language ability but severe communication difficulty conducted AAC-based phone conversation with a caregiver (the mother). The son lived in a hostel with residential and training service where the mother visited him from time to time. When they were apart, they used to communicate with each other using generic desktop-based messaging applications, which require tremendous effort for the son to input the texts because of his severe limitation in motor ability. In the test when using our app, the son was very delighted and well engaged in the conversation with his mother. We believe our system is a better option over the desktop-based methods as the son needed to spend tremendous time to input his intended messages before, while our app interface is more convenient and adaptive for users with special needs. It also broadens the social circle of the son because now he can also conduct phone-like conversation with some of his friends from the hostel who are AAC users with lower language ability levels. Indeed the son expressed that he preferred using our app over the desktop-based communication methods.

However, it was also observed that some of the participants had spent a lot of time to explore each of the categories at the beginning to find out what they wanted to express. Nevertheless it was observed that a majority of the participating users could master the symbols within 10 minutes. Overall, it was observed that the app interface was convenient and friendly to the participants.

C. Feedback from Users and Speech Therapists

During the user tests, the research team has collected a number of constructive feedbacks from the users and the speech therapists. Instead of a verbal interview, our participating users provided their feedback by various means such as conventional AAC boards and text messaging (at a very slow speed). They are summarized below.

1) Selected Feedback from Users with Complex Communication Needs:

- “The current set of AAC symbols was insufficient. I hope to have a system with more symbols.” (From a user with normal intellectual ability, high language level, but severe limitation in speech production).
- “There is no evening dress picture card under the clothes category!” (From a school girl with

dyskinetic cerebral palsy, mental retardation, and moderately severe hearing loss who loves drawing very much and wishes to become a designer in the future). The project team has invited the girl to outline her design of the “evening dresses” picture card and will incorporate it into the production version of the system.

2) Selected Feedback from Professional Speech Therapists:

- The current TTS output is a female voice. In the future version, both male and female voices should be available according to the gender of the users.
- The Android buttons should be disabled because the users often clicked those buttons and escape the app accidentally.
- Chat record and history should be available to users so that they can follow and response according to the previous message(s) received from their communicating partners.
- Since semantic categorization is an abstract concept, it may be too difficult for the users to manage AAC symbol selection in the current configuration. A customized version without categorization of symbols should be available. (Remark: The project team will implement this feature in Q3 of 2016 and will implement machine learning algorithms that are designed according to social connectionist theories and principles [24]–[26] for AAC symbol recommendation.)

D. Importance of Cloud AAC System Compare to Alternate Solutions

AAC symbols are key media of daily communication amongst people with complex communication needs and their caregivers. The usage of AAC symbols and methods are being taught in formal language lessons within the special education curriculum in many countries/regions such as UK and Hong Kong. Furthermore, AAC also serves as a speech-language intervention to promote social interactions and communication for patients with communication difficulties [23]. Therefore, a telecommunications service which can integrate AAC symbols and mobile network connectivity is vital to users with severe communication disabilities. This also explains the importance and need of developing our system when compare to other existing solutions such as texting via emojis or the conduction of video calls.

E. Limitation, Follow Up Works, and Future Development

As a limitation, the current version of our system can only support users who can see and touch the screen of the mobile devices. There are still classes of users such as those with visual disabilities and/or very limited motor abilities (such as

those who are paralyzed) cannot utilize our services. The project team will continue to improve the interaction interface of the client side so as to address the needs for a wider population of users. The project team will also continue to improve the overall system based on the observations and feedbacks obtained from the user studies. It is expected that the system can be deployed for public trials in Hong Kong in Q1 of 2017.

VI. CONCLUSION

This paper has reported the implementation of the Cloud AAC system which aims to provide telephone conversation-like telecommunications services for people with severe communication disabilities. The paper has presented the theoretical background, prototype development, and user tests of the system. By implementing the system, people with complex communication needs can make phone calls to the beloved ones and families, as well as for emergency situations. By engaging communication engineers and professional therapists, the project directly realizes initiatives that would harness cross-platform technologies to achieve social inclusion.

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