An Assistive Technology Framework for Communication with Hearing Impaired Persons

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***Abstract*—This paper presents a novel assistive technology framework which provides an interface to support communication between hearing impaired person and ordinary person over the mobile phone. It converts the ordinary person's voice to text and afterward text to tactile feedback at the hearing impaired person's end.**

The Morse Code tactile feedback have been identified as the most appropriate method for providing the tactile feedback at the hearing impaired person's end, since it is a standard code which helps persons with impairments. The work addresses the challenge of using a set of Morse Code shorthand vibration patterns to translate the whole text message to tactile feedback to provide a simple, efficient and synchronous communication, rather than vibrating each and every character in text using Morse Code characters.

The user evaluation found that, most hearing impaired persons' preferred method of conversation is the Morse Code shorthand forms with two or three character length rather than reading the entire text message. Due to less perspicuity of a hearing impaired person's voice, the study comes up with the conversion of the hearing impaired persons' voice to text and sends it to the ordinary person synchronously as a voice reply. The results of the evaluation experiment shows that the assistive technology framework facilitates by improving the quality of communication of hearing impaired persons over a mobile device.

Keywords-Morse Code; Hearing Impaired; Assistive Technology;

I. INTRODUCTION

Communication among individuals is the bridge that lays the foundation for the improved human relationships. When ordinary persons (OPs) communicate, they can hear the other person's voice and then they can respond accordingly. However, hearing impaired persons (HIPs) are unable to hear sounds as OPs. They face different mental challenges, since most of the time the hearing impairment results in isolation [1].

"Hearing impairment" is hearing loss (HL) that prevents a person from receiving sounds through the ear [2]. A person with a "hearing impaired" means a person with a less than severe HL or a person who acquired deafness in adulthood as opposed to having grown up deafness [3].

HIPs fall under the category of impaired. There are different ways to communicate with a HIP. American Sign Language (ASL), finger spelling, lip reading, written communication and oral communication are some of these methods [4]. Similarly, there is another tool which helps to communicate not only with HIPs, but also with people with different degrees of disabilities; "Morse Code (MC)" [5].

Recently, several methods have been realized to improve phone communication between a HIP and an OP. However, they may not be the most appropriate for the required task. Telecommunications Device for the Deaf (TDD) (or Tele Typewriters (TTYs)), Telecommunications Relay Service (TRS), Video Relay Service (VRS), MobileASL and Short Message Service (SMS) are some technologies that assist HIPs to communicate via telephone or mobile phone. Nevertheless, some of these technologies do not provide the real world experience for the HIP [6, 7]. Similarly, some devices such as TTYs are not cost effectively, and the most of them are based on text messages and ASL [6, 7, 8]. Most of them cannot provide synchronous, reliable and speedy communication [7]. Hence, the purpose of this research is to come up with an Assistive Technology (AT) framework which helps to provide a synchronous, reliable and speedy communication approach for the HIPs.

This study presents a prototype of an AT framework for HIPs which can be used for their communication improvement through the phone in day to day life. This prototype is based on a mobile application. When an OP calls a HIP through a mobile phone, it converts the OP's voice into both text and tactile feedback using ATs on the HIP's side. After seeing this text or sensing this tactile feedback to the HIP, the system provides the facility for him/ her to communicate with the OP as in a usual phone call.

The goal of this work is to provide a framework for a HIP to communicate with an OP over the phone. The objectives of the studies are achieved; developing a framework to facilitate communication for HIPs, based on AT, training the users (the HIPs) to use the framework (identify what the OP says through a language or symbols), evaluating the AT framework through acquiring feedback (such as via questionnaires).

This research addresses the question of, "How to facilitate a hearing impaired/ deaf person to communicate with an OP via AT?". In order to answer this question, the expected evaluation methodology will capture feedback of the users via the designed scenario based on a small sample.

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II. Related Work

Several different communication approaches between a HIP and an OP with the help of a sign language interpreter such as TRS and VRS considered in the review. TRS allows the communication between HIPs and OPs using text and voice in real time with an interpreter [6]. One problem of TRS is illiterate HIPs cannot understand the text message [6]. A VRS or Video Interpreting Service (VIS) allows communication between a HIP and an OP exchanging video or voice messages with someone who is not signing in real time via a sign language interpreter. The need of HIP to have a high definition camera to capture the signs and a high-speed internet connection are the main problems of VRS [9].

Several attempts for Mobile Sign Language Communication are reported in the literature. MobileASL is based on a video compression project, and it allows communication through a wireless cell phone with the use of sign language [8]. One limitation of this approach is that it is not set up to handle video requests efficiently [8].

Several work is reported that use techniques which help to translate sign language without a human interpreter, but with the use of Artificial Intelligence (AI) techniques. ASRASR is one of them which is a combination of Augmented Reality (AR), Automatic Speech Recognition (ASR) and Text To Speech (TTS) [10].

Some work report technologies which provide the capability for a HIP to communicate with an OP in the face-to-face level. TExt and Sign Support Assistant (TESSA) is such an approach which aims to help the transactions between a deaf person and a post office clerk through the translation of the clerk's speech to sign language [11]. However, HIPs can cover many of the common transactions even without TESSA (e.g., buying stamps) [11]. Furthermore, there is a latency between the speech recognition and the signing phase [11].

As identified through our study, there are several limitations in existing approaches. Some of them are; some devices are difficult to carry (e.g., TTY) [6], cannot guarantee delivery (e.g., SMS) [6], cannot provide a synchronous communication [6, 7]. One problem that the authors identified is HIPs' reluctance to use most of the existing approaches in public places, since they are based on ASL (When they are using ASL, it's evident to the public that they are hearing impaired).

III. Morse Code

The MC is an effective tool that helps the hearing impaired persons to communicate, and represents different characters using a set of symbols comprising of dots (.) and dashes (-), a series of short and long sounds, vibrations or light rays [5]. According to the MC definition, both dot to dash tone ratio and dot-dash space to character space silent ratio must be 1:3 [12]. In other words, the length of a dot is one unit, the length of a dash is three units, the space between the parts of the same letter or number is one unit, the space between letters is three units and the space between words is seven units [13].

The main limitation of MC is, that is not easy to remember, especially for the hearing impaired persons [14]. Nevertheless, MC is not only a powerful data input method, but also simple, speedy, low cost and efficient AT [15].

A. *Morse Code Abbreviations and Acronyms*

MC has some abbreviations and acronyms that consist of two or three letters or two numbers [16] (table 1). Usually, the lengths of these abbreviations and acronyms are two characters or three characters. Those abbreviations and acronyms facilitate communication using MC.

These MC abbreviations and acronyms have a clear limitation. They are the insufficient of handling a normal conversation over a mobile phone. Even though these MC abbreviations and acronyms consist of more than two hundred words and phrases, they do not contain the most frequently used words in an ordinary phone conversation such as "Hello", "How are you". Therefore the MC should come up with an extended set of abbreviations and acronyms for further communication.

B. *An Extended Morse Code Abbreviations and Acronyms*

These extended MC abbreviations and acronyms are built from referring to the most common chat abbreviations and acronyms. These consist of two or three letters or two numbers or one letter with one number or three letters with one number (table 2). The lengths of these abbreviations and acronyms are two or three characters or four characters. When comparing with the MC abbreviations and acronyms, the specialty of these sets of extended MC abbreviations and acronyms is they consist of four-character abbreviations and acronyms (e.g., G2CU – good to see you) for providing further communication.

The extended MC abbreviations and acronyms will be used at the implementation stage of facilitating an easy communication for the HIPs over a phone conversation.

Table 1: Some of Morse Code Abbreviations and Acronyms

MC Shorthand Word	Message
CUL	see you later
GM	good morning
TU	thank you

Table 2: Some of the Extended Morse Code Abbreviations and Acronyms

Extended MC Shorthand Word	Message
88	bye bye
CUL	see you later
G2CU	good to see you
GM	good morning
HBU	how about you
LO	hello
HRU	how are you
I2	me too
IAF	I am fine
TU	thank you

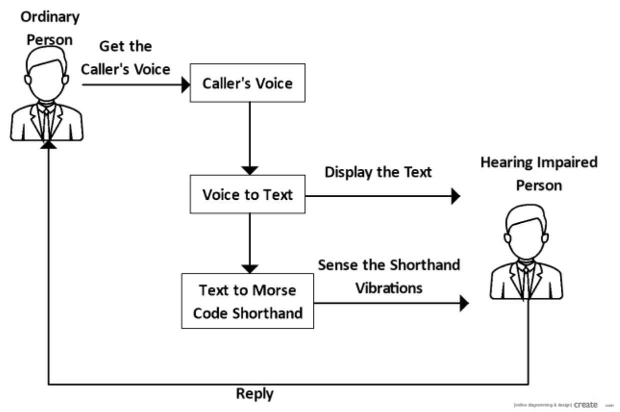

Figure 1: System Process Overview

IV. DESIGN

The proposed methodology focuses on converting the caller's (the OP's) voice to a specific tactile feedback. The system is mainly focused on the communication between a HIP and an OP over the phone via AT. The basic design approach can be divided into three parts. The first part is receiving the caller's voice. The second part is converting it into text. The third part is converting the text into a set of MC vibrations.

The proposed approach attempts of ameliorating the communication between a HIP and an OP via AT. The AT framework is implemented as an Android mobile chat application. Upon installation of the application, both users (the HIP and the OP) can chat with each other using their voices. The HIP will get the OP's voice as a text and a set of tactile feedbacks. After reading the text or sensing the set of tactile feedbacks (MC shorthand vibrations), the HIP can reply using his/ her voice as an OP does, in a normal phone conversation. Fig. 1 shows the process overview of the system.

TABLE 3: STRUCTURE OF THE DICTIONARY

MC Shorthand Word	Message
CUL:	see you later
GM:	good morning
TU:	thank you

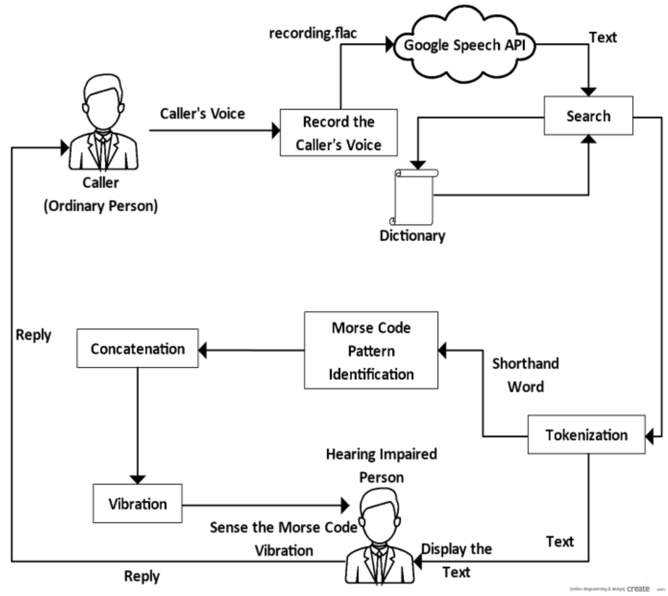

Figure 2: System Overview

A. *System Architecture*

A mobile phone is used by the user (both the HIP and the OP) in the communication. The prototype system consists of three modules. As discussed, the caller's voice is received, afterward converting it into text and converting the text into a set of MC shorthand vibrations. Fig. 2 shows the system overview.

1) *Caller's Voice Module*

This module is used to receive the caller's (the OP's) voice with the purpose of converting it into a text. In this, the caller's voice denotes a reply or a description or a question that the caller can answer or can describe or can ask respectively. When the caller is speaking over the phone, gets his/ her voice using the microphone, the collected audio is passed via an HTTPS POST to the Google Speech API as a "live" chunked stream [17, 18]. Then it makes a GET request to access the results [18]. The collected audio is encoded as a FLAC [19] file in each of the above three situations. Suppose the caller says "see you later" as his/ her message.

2) *Voice to Text Module*

The purpose of this module is to convert the audio file that is stored as a FLAC file, which is created in "Caller's Voice Module", to a text message. If the HIP's literacy is at a higher level, he/ she can read the text and then can ask or can describe or can answer, using his/ her voice as in a normal phone conversation. At this module, it identifies the relevant MC shorthand word related to text message.

"Search" stage will receive the text message as "see you later" from Google Speech API, which is related to the caller's message. In this stage, it searches the message ("see you later") in the dictionary. This dictionary has the messages with the relevant MC shorthand words [16] (table 3). If the message is in the dictionary, send its whole line ("CUL: see you later") to "Tokenization" stage. In this stage, tokenize the shorthand word ("CUL") and the text ("see you later") from ":". Then displays the text as "see you later" on the phone screen and send the MC shorthand word to the next module's first stage called "MC Pattern Identification".

3) Text to Morse Module

This module converts the shorthand word, which is the output of "Voice to Text Module" into the relevant MC vibrations. These vibrations are sensed by the HIP's hand as phone vibrations. The HIP gets both text message and its MC shorthand vibrations. If the HIP cannot read the text message (if the HIP is an illiterate person), he/ she can ask or can describe or can answer, according to the vibration pattern, using his/ her voice as an OP does during a normal phone conversation, after sensing the vibration. Otherwise (if the HIP is a literate person), he/ she can do the same thing, after reading the text message.

After getting the MC shorthand word ("CUL"), identify the MC pattern which is relevant to each letter ("C", "U", "L") in the stage called "MC Pattern Identification" (table 4). Then it sends the MC pattern of each letter to "Concatenation" stage. In this stage, all MC patterns are concatenated into a single MC pattern ("CUL" >>> -.-. ..- .-..) and sent to "Vibration" stage. In here, the phone is vibrated according to the pattern received from the previous stage. The vibration is sensed by the HIP following which he/ she could reply to the message.

V. IMPLEMENTATION

The prototype functions as an Android chat application, which converts the OP's voice message into a text through Google Voice Recognition (GVR) at the OP's side and then sends it to the HIP. The HIP will receive the message in both text and MC shorthand vibrations. After reading the text or sensing the MC shorthand vibrations, the HIP can voice the message to the OP. Then it converts the voice message into a text at the HIP's side as the converting method of the OP's side. Then it is sent to the OP and he/ she will hear the message content through Google TTS.

A. Caller's Voice Module

The implementation of this module is based on GVR. GVR is used for both users (the HIP and the OP). This module prompts the Google Speech input when clicking on the microphone button in the chat window and identifies the voice message that the user voiced (Fig. 3 and Fig. 4). The user can voice any length of a message without restrictions.

B. Voice to Text Module

This module converts both users' voices into text messages at the user's side. These messages are sent to an online database, and the user on the other side can view the set of messages with the help of the database. After the user voices the message through the microphone, the message will be displayed on the typing area of the text through this module. Then the user can click on the send button to view the new message on the chat screen (Fig. 5), which is the common procedure of this module. But there are some significant modifications of the implementation at both users' sides.

At the HIP's side, after receiving the new message from the OP, the text content of the message is searched from a dictionary and tokenized into both the text and the shorthand word. The tokenization procedure is available only for single sentences and this needs to be improved further in future.

At the OP's side, after receiving the new message from the HIP, the text content of the message is voiced through Google TTS. The main reason for voicing the message through Google TTS is, that the most of the HIPs voices are not clear, since they speak according to the way they hear.

TABLE 4: INTERNATIONAL MORSE CODE

Letter	Morse
C	-.-.
U	..-
L	.-..

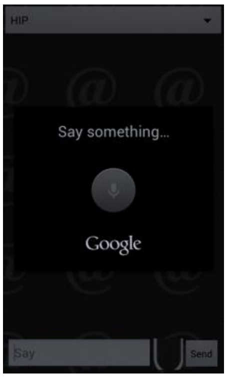

Figure 3: Voice Recognition using Google Voice Recognition at the Ordinary Person's Side

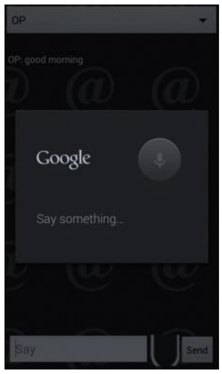

Figure 4: Voice Recognition using Google Voice Recognition at the Hearing Impaired Person's Side

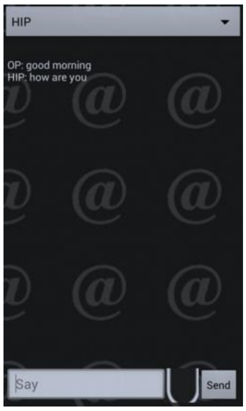

Figure 5: Conversion of Voice to Text

C. *Text to Morse Module*

This module converts the text message into MC shorthand vibrations at the HIP's side. This module identifies the MC pattern of each letter of the MC shorthand word, then concatenates the MC patterns together and afterward, vibrates the mobile phone according to the concatenated MC shorthand pattern (MC shorthand vibrations cannot be represented visually, since they are sensed by the HIP's hand). The MC shorthand words refer extended MC abbreviations and acronyms and the MC vibration pattern follows the rule of both dot to dash tone ratio and dot-dash space to character space silent ratio which must be 1:3 [12].

VI. EVALUATION AND RESULTS

This research is mainly focused on observing the user friendliness of the AT framework. The evaluation has three experimental phases. They are, finding out;

1) *The most familiar way for the conversation among text messages and MC shorthand vibrations*
2) *The use of the extended MC shorthand abbreviations and acronyms*
3) *The most suitable method for a HIP to reply over a phone by comparing GVR with a popular Voice over Internet Protocol (VoIP) call; Viber.*

A. *Subjects Selection for the Experiment*

The evaluation of text message verses MC shorthand vibrations and the evaluation of the use of extended MC abbreviations and acronyms were carried out with twenty-two users. Three out of them were HIPs. The other nineteen persons were OPs. Since most of the HIPs were faltering for representing the experiments, it befell to suit only three HIPs for the evaluation process.

The study used ten OPs with the three HIPs for the exploration of the most suitable method for a HIP to reply over a phone by comparing GVR with Viber.

B. *Evaluation Scenario*

Initially, the HIPs and all the OPs were trained to adapt the AT framework to become familiar with MC shorthand vibrations, GVR and Google TTS.

In order to fulfill the first experimental phase, a list of ten frequently used words and phrases in a usual phone conversation was given to the caller (the OP). The caller had to voice the messages in the list for three rounds. If the receiver (the HIP or the OP) correctly sensed (or identified) the MC shorthand vibration pattern of each word, he/ she had to mark in front of the word or phrase of the given document as "Yes", otherwise "No" at each time, each round. After finishing three rounds, the receiver mentioned what his/ her most preferred method for the conversation is.

For the second experimental phase, different MC shorthand vibration character lengths were evaluated with each other and the most suitable MC shorthand vibration length for the communication was identified.

To get the answer for the third experimental phase, the ten OPs had to listen to a set of recorded voices of the three HIPs over a Viber call for three rounds. The OP had to write the words or phrases that he/ she identified at each time, each round in the given document. Similarly, the speech recognition capability of GVR was checked through the same approach.

C. *Results*

1) *Experimental Phase 1*

The experiment analyzes the familiarization among text messages and MC shorthand vibrations for given ten words and phrases for all three attempts. The HIPs are familiar with the MC shorthand vibrations compared to OPs. Their familiarization with the MC shorthand vibrations has increased at each of the three attempts than the previous attempt when compared with OPs familiarization. Nevertheless, the average values for MC shorthand vibration identification of OPs are higher than HIPs at all three attempts. It proves that the OPs' MC shorthand vibration identification capability is higher than the HIPs' MC shorthand vibration identification capability. However, the standard deviation (STD) values for MC shorthand vibration identification of HIPs is smaller than the STD values for MC shorthand vibration identification of OPs which indicates that the HIPs are more consistent with the MC shorthand vibrations than the OPs. 66.67% of HIPs prefer to use MC shorthand vibrations than text messages, and 63.16% of OPs prefer to use text messages than MC shorthand vibrations (Fig. 6). In conclusion, it can be stated that the HIPs are consistent with MC shorthand vibrations than OPs. Thus, converting voice into MC shorthand vibrations is the most effective way of communicating with HIPs over a mobile phone conversation rather than converting voice into text messages.

2) *Experimental Phase 2*

Although the lengths of the sets of "extended" MC abbreviations and acronyms are two or three characters or four characters, the lengths of the sets of "standard" MC abbreviations and acronyms are two or three characters. In this phase, it is exploring the usability of constituting four characters.

According to table 5, the average values for different lengths of MC shorthand vibration identification of OPs for two characters and three characters are higher than the average values of HIPs for two characters and three characters at all three attempts. Nevertheless, it increases only for HIPs than OPs when it comes to the third attempt of four characters. Most of the average values for two characters are higher than the average values for three characters, and the average values for three characters are higher than the average values for four characters. Table 6 attests the STD values for two characters, three characters and four characters of both HIPs and OPs. Most of the time, the STD values of both HIPs and OPs for two characters are lower than the STD values for three characters and the STD values for three characters are lower than the STD values for four characters.

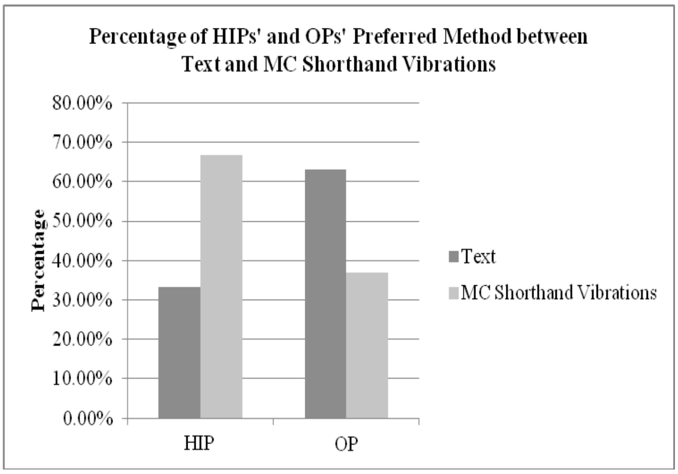

Figure 6: Percentage of Hearing Impaired Persons' and Ordinary Persons' Preferred Method between Text and Morse Code Shorthand Vibrations

It implies that both HIPs and OPs are more consistent with two characters than three characters and four characters. Similarly, they are very low consistent with four characters. It attests that containing four characters for the extended MC shorthand abbreviations and acronyms is not more suitable for further communication. If both the standard and the extended MC shorthand abbreviations and acronyms can come up with only for two characters, it is better than containing three or four characters. Similarly, the OPs are more consistent with any character length than the HIPs.

3) Experimental Phase 3

At this experimental phase, ten OPs had to listen to three sets of recorded sound clips of the three HIPs over a Viber call for three rounds. The reason for giving the OPs to listen to three times of each set of sound clips is to exercise them for a HIP's speaking and pronunciation method. The third round is taken as the results set. If an OP identified the word correctly, it was marked as "1", otherwise, "0". If he/ she identified the word list at the first round, it was taken as the results set. Similarly, the same procedure was used to check the speech recognition capability of GVR. Fig. 7 shows the identified average word count of each voice recognizer.

Even though most of the OPs had to listen to the sound clips more than two times, most of the time the GVR identified the HIPs' speech at the first time. According to Fig. 7, the GVR has got relatively higher values than most of the OPs. It is ranked second out of all. The GVR has proved the method which has a better speech recognition capability relative to human beings.

As a conclusion, it proves that the GVR has a better voice recognition capability to identify a HIP's voice when compared to the human voice recognition capability. Thus the authors can deduce that the most suitable method to a HIP for replying over a mobile phone is the "GVR" and not a VoIP method.

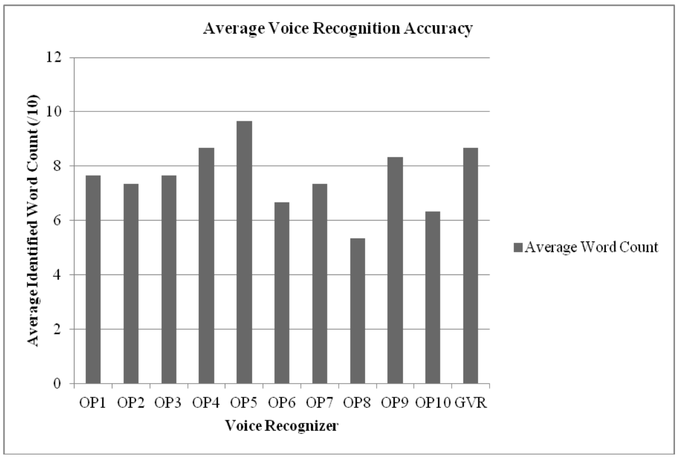

Figure 7: Identified Average Word Count for Each Voice Recognizer

TABLE 5: AVERAGE VALUES FOR DIFFERENT LENGTHS OF MORSE CODE SHORTHAND VIBRATION IDENTIFICATION

Attempt		Character Length of the Extended MC Abbreviations and Acronyms (Character)					
		2		3		4	
		HIP	OP	HIP	OP	HIP	OP
Average Values	Attempt 1	0.33	0.75	0.17	0.47	0.33	0.47
	Attempt 2	0.87	0.95	0.25	0.62	0.33	0.58
	Attempt 3	0.87	0.96	0.58	0.76	0.67	0.53

TABLE 6: STANDARD DEVIATION VALUES FOR DIFFERENT LENGTHS OF MORSE CODE SHORTHAND VIBRATION IDENTIFICATION

Attempt		Character Length of the Extended MC Abbreviations and Acronyms (Character)					
		2		3		4	
		HIP	OP	HIP	OP	HIP	OP
STD Values	Attempt 1	0.31	0.26	0.14	0.45	0.58	0.51
	Attempt 2	0.12	0.09	0.25	0.35	0.58	0.51
	Attempt 3	0.12	0.08	0.14	0.26	0.58	0.51

VII. CONCLUSION

One of the main challenge of this work was the development of a set of MC shorthand words. In tackling this challenge, the "MC shorthand abbreviations and acronyms" were referred. Nevertheless, these abbreviations and acronyms were not sufficient for further communication over a mobile phone, since they do not consist of the most frequently used words in a usual phone conversation. It became the next challenge. The work proposed here introduces a generalized set of "extended MC shorthand abbreviations and acronyms" to overcome this problem. For that, this study focuses on referring to the most common chat abbreviations and acronyms and provides further communication capability.

The evaluation is aimed to observe the user friendliness of the AT framework and is focused on finding out the most effective way of conversations among text messages and MC shorthand vibrations, the use of the extended MC shorthand abbreviations and acronyms, and the most suitable method for a HIP to reply over a phone by comparing GVR with Viber. The first experimental phase found out that the MC shorthand vibrations are the most effective way of the phone conversation for HIPs, since they are more consistent with MC shorthand vibrations than OPs. The next experimental phase showed that if the extended MC shorthand abbreviations and acronyms can be limited to the length of two characters or maximum three characters without operating four characters, it would be more useful for providing further communication. The last experimental phase bears out that the GVR has a better speech recognition capability than a human being. Accordingly, GVR is the most suitable method for a HIP to reply over a phone conversation. As a conclusion, this AT framework provides an efficient communication approach for HIPs.

Converting voice into a text, using MC and sensing vibrations are not novel approaches of AT to help the hearing impaired persons. However, combining these three with the purpose of helping HIPs for communication over a mobile phone conversation with many facilities such as cost effectiveness, speed and synchrony is a novel approach under AT.

Through this research, "extended MC shorthand abbreviations and acronyms" were introduced to provide a successful communication. The extended MC shorthand abbreviations and acronyms can be applied for further developments of AT field which uses MC and which will help not only for the HIPs, but also for many other hearing impaired persons. The AT frame work can be used for visually impaired persons too, since it converts text into vibrations.

The AT framework only supports English language and small word phrases. In future, the AT framework can be implemented for supporting many languages including Sinhala. Similarly, it can be developed into long sentences including common feature extraction methods.

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