Accessible System and Social Media Mobile Application for Deaf Users

ASM4Deaf

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ABSTRACT

Usability, accessibility and inclusion are major concerns and have a huge impact for many people with special abilities. Specifically, people who are Deaf have a serious and unfair disadvantage in regards to different social aspects of everyday life. Explicitly, in terms of access to technology, products are stereotypically designed for hearing people. There are important parameters to consider in designing technological products for deaf people: i) providing the ability to interact using sign language, ii) the first language for many people who are Deaf is the sign language of their country and iii) one may find multiple dialects of sign language within a country. Adhering to these parameters, can alleviate barriers and impact positively the integration of the Deaf and hearing communities for a more inclusive society. This work contributes to the aforementioned from a social dimension perspective. Social media applications, e.g., WhatsApp, Messenger, Telegram, are the number one communication channels for people in today's fast-paced world. Even within these mainstream social media apps (MSMAs), persons who are Deaf are not provided with the rights and means to interact in their preferred way. This work supports integration of Deaf and hearing communities in MSMAs. This is done via: i) development of the Connect Deaf app that enables use of fingerspelling keyboards in 13 sign languages in MSMAs and ii) a Low-Fidelity (Lo-Fi) prototype that aims to enhance the Connect Deaf app with additional features, i.e., the ability to browse, search and edit animated (i.e. not static) GIFs in American Sign Language (ASL). This provides the full set of features offered by social media apps to Deaf end-users and their friends and family. This paper presents the ASM4Deaf system architecture, i.e., the cloud-based backend and mobile application, the technical approaches and the Lo-Fi prototypes defined and evaluated in the workshop conducted with users who are Deaf and their family and friends. Finally, it presents and analyses the results of the workshop that contributed to this work towards the definition of the final ASM4Deaf system.

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KEYWORDS

Inclusive design, accessibility, Deaf end-user, mobile app

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1 INTRODUCTION

People who are Deaf have been at an unfair disadvantage with regards to education, employment and technology access [1]. This occurs because they are typically designed with hearing end-users in mind, resulting in limited interactive technologies that address usability and accessibility concerns. Hence, challenges experienced stem mainly from literacy-related barriers. Accessing content online and using ICTs is problematic for many Deaf end-users since as pupils, are educated by curricula oriented for auditory learners and designed by those that hear with little to no knowledge of deafness. Thus, many leave school with language deprivation [1]. Equally important is the fact that the first language for many people who are Deaf is their national sign language [1, 2]. Moreover, there are countries with multiple dialects of the national sign language. Providing information in sign language helps alleviate such barriers and impacts positively in the integration of the Deaf and hearing communities for a more inclusive and accessible society [1].

Cyprus is at an infancy level in terms of proper culture and attitude of hearing people towards Deaf people [3]. In fact, the study in [3] identified prejudices of Cypriot hearing people against the Deaf people, as well as lack of state support toward the Deaf community. Moreover, the research in [4] created a mobile application for the Cypriot Sign Language (CSL) and the results were highly positive, as participants were interested and found the application very useful. It is evident though that technologies in Cyprus are at an infancy level and state support is rather limited. Therefore, it is important to promote initiatives making Deaf persons first class citizens. In an attempt to accomplish just that, the European Union of the Deaf (EUD) declares three objectives [5]: 1) recognition of right to use sign language, 2) use of communication and information for empowerment, and 3) equality in education and employment.

Support for the right to use sign language is recognised in international and European legal documents too, such as the Brussels Declaration on Sign Languages in the EU (2010) and the United Nation Convention on the Rights of Persons with Disabilities (2006) [1]. Furthermore, the international organisation, World Federation of the Deaf (WFD) announced a charter on the Sign Language Rights for All [6]. Aligned with the results of the aforementioned research studies and EUD main objective, the ASM4Deaf project aims to develop a cloud-based system and an innovative mobile application that will support the use of multiple sign languages within MSMAs, including WhatsApp, FB Messenger, Google Hangouts, Telegram etc. Even within these popular, mainstream and fun social media apps, being typically designed with those that hear in mind, Deaf people are not provided with the rights and means to interact and communicate with friends and family in national sign language. This work supports the inclusion of the Deaf and hearing communities in social media apps.

In this paper, we present the Lo-Fi prototype of the ASM4Deaf mobile app and report on findings from the workshop conducted with end-users. Additionally, a technical description of the system, including, its architecture and face swapping approaches are provided. The paper consists of six sections; Section 2 discusses Background and Related Work, Section 3 describes the methodology, while Section 4 presents the ASM4Deaf system from a technical perspective. Results from the workshop are discussed in Section 5 and the paper closes with Conclusions and Future Work in Section 6.

2 BACKGROUND AND RELATED WORK

Most Deaf individuals use a national sign language as a first language and majority, up to 80%, cannot successfully understand written content, making it a real challenge to experience the full benefits of the Web and ICTs in general, e.g. social media and social networking platforms [1]. Shockingly, this large sample of persons is not provided with access to education and in fewer cases, where educational opportunities exist, only 1-2% will receive it in sign language. The unacceptable outcomes of this situation translates to majority being deprived access to first language, absence of literacy foundation, and prevention in full potential achievement. Family and community also have an equally significant role in the positive educational outcomes of the estimated 32 million children who are Deaf, hard of hearing, or deaf-blind. As such, they have a similar impact to that of the education system [7].

It must be noted that 90-95% Deaf children have hearing parents [8, 9], many of whom are ill-informed about national sign language, with no exposure. For the majority of Deaf children, this results in no easy and ready access to language within their own homes and communities. Since this occurs during a critical language acquisition period, likelihood increases of them experiencing a lifetime of psycho-social challenges, limited schooling and employment potential, and stunted language abilities - including reading [10]. ICTs not supporting sign language content combined with literacy difficulties experienced have prevented the inclusion of many Deaf end-users into the information society. Therefore, in addition to existing disadvantages experienced in education and employment, there is also the serious disadvantage with information and technology access as well [1].

Efforts have been undertaken over the past twenty years in improving accessibility and inclusivity of the Web and ICTs for people with disabilities. Noticeable are the Web Content Accessibility Guidelines (WCAG) of the W3C [11], DictaSign [12, 13], ViSiCAST [14], eSign [15], SignLinkStudio [16], the European Echo Project [6], SignStream [10, 17], the University of Bristol's British Sign Language (BSL) Moodle system [18], Ohio State University's digital storytelling system [18], the South African Sign Language (SASL) machine translation project of Stellenbosch University [19] and Paula of DePaul University [20].

2.1 Comparison of related applications

Table 1 presents a comparison of the most recent and relevant applications to ASM4Deaf.

The limited number of related applications is evident, highlighting the need for more work in this area. A major step made towards providing inclusiveness and accessibility for Deaf end-users, as well as their friends and family that in many cases want to learn how to interact and communicate in the first language that is natural to Deaf persons, is the Connect Deaf app, which supports the use of fingerspelling keyboards in MSMAs for 13 national sign languages. In fact, the Connect Deaf app provides on Android and iOS, keyboard services that can be used within social media apps for the benefit of Deaf end-users and their friends and family. The first step of the work in this paper is the Connect Deaf app[1] and the second step is the Lo-Fi prototype presented, aiming to enhance these keyboard services with additional interaction and communication features, i.e., the ability to browse, search and edit animated GIFs in ASL in order to provide the full set of features offered by social media apps, but in this case, through the final ASM4Deaf app, to Deaf end-users and their friends and family. This highlights the contribution of this work.

[1]Sign App Google Play and Apple Store - Post sign language alphabets in social media apps - https://connectdeaf.com/

Table 1: Related applications to ASM4Deaf

Work	Type	Description	AI	Other Features	Status	Cost
SLAIT	Mobile Application	Real-time ASL to text and speech to text translation	Yes	Video communication	Beta version coming soon	Unknown
Hand Talk Translator	Mobile Application	Real-time text and audio to ASL and Brazilian Sign Language	Yes	Avatar as a signer	Beta version available	Free
Connect Deaf	Mobile Application	Fingerspelling keyboards for 13 countries	No	Posting of fingerspelling GIFs and images and Sign Language stickers to mainstream chat apps	Available	Paid
Signily	Mobile Application	ASL keyword	No	Posting of (color) customized fingerspelling messages	Retired	Paid
"ASL to English" by Priyanjali Gupta	GitHub project	Real-life ASL to text translation, only for six specific sign-language words and phrases	Yes	-	Available	Free

3 METHODOLOGY

Feedback will be collected from four different end-user groups throughout the project activities. With the aim to implement an experimental evaluation approach yielding a collection of quantitative feedback but also be more heavily reliant on qualitative feedback, a set of three testing phases have been defined in order to adequately monitor, discuss, evaluate and collect feedback based on co-creation and development activities. A phased approach towards end-user involvement is adopted in the project. To this extent, a "base-line" of methods that constitute a phased approach has been defined, with each phase using several methods and approaches. The three phases are: 1) Initial investigations, 2) Co-creation approaches and 3) Evaluations.

Initial investigations were conducted in the first phase to ensure that the idea of how the mobile app should function and look are first technically viable and secondly, in line with the aspirations of the primary end-users. Co-creative methods are applied in the second phase, which rely heavily on stimulating interaction with the end-user groups. This is in the form of workshops and focus group sessions. In the third phase, more structured approaches are used to evaluate the mobile app prototypes and to collect feedback from end-user groups. Instruments are vital for this purpose, which also act as "design guidelines". Development and evaluation of the ASM4Deaf mobile app will be based on using several of the following structured instruments and guidelines: User Experience Questionnaire (UEQ), System Usability Scale (SUS), Usability Heuristics for User Interface Design, Universal Design, Web Content Accessibility Guidelines (WCAG) and HCI checklist for designers, developers and test leaders. Table 2 presents several methods that were used to date in phases 2 (Co-creation) and 3 (Evaluation) respectively.

Section 5 presents results from the first testing phase, which includes the design of the Lo-Fi prototypes and their evaluation with primary and secondary end-users using focus groups and user surveys (based on SUS). The feedback collected in Phase 1 was reviewed by the ASM4Deaf team to determine which recommendations would be implemented and how to address specific considerations pointed out by end-users for the Phase 2 testing, i.e. Hi-Fi prototype.

The following end-user groups have been defined: 1) **Primary:** Deaf end-users who use sign language as a first language, 2) **Secondary:** Non-deaf end-users who are in direct contact with primary end-users, 3) **Tertiary**: Public and private organisations who are in direct contact with primary users and 4) **Other:** any other end-user interested in the proposed solution. Also, explicit criteria have been determined as a recruitment strategy for the sample of end-users to participate in the evaluation activities but are not elaborated due to space limitations.

Table 2: Testing phases for the experimental evaluation and feedback activities

Testing phase	Evaluation tool	Method	End-user group
1	Lo-Fi prototype	Focus group, user survey	1, 2
2	Hi-Fi prototype (semi-functioning mock-ups)	Focus group, user survey	1, 2
3	System demonstrations	Focus group, workshops	1, 2, 3, 4

4 ASM4DEAF SYSTEM

The ASM4Deaf cloud-based system, combined with its innovative mobile app, will at first release support the use of ASL GIFs within MSMAs. The intention is to expand the system and to include GIFs from more national sign languages in future releases.

4.1 Basic Requirements and Architecture

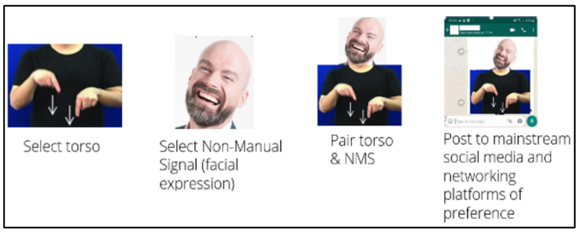

Figure 1: The end-user journey broken down into 4 main steps

The system's main requirements are to provide ASL GIFs for the most commonly used daily communications. This includes producing a total of 1000 words, 100 phrases and 50 facial expressions, signed by multiple signers to support diversity. The end-user journey steps can be summarised in selecting a preferred torso and facial expression, combining the selections, and if satisfied with the result, posting it to an MSMA or repeating the process until a satisfactory combination to post is achieved.

4.2 Architecture

The ASM4Deaf system architecture is composed by two main parts: 1) the frontend that will include the mobile application that the user will interact with and 2) the backend that will include the Web APIs for invoking from the mobile application the selected Face Swapping processing functionality and returning the final GIF back to the mobile application. The backend also includes the web platform that enables the administrator to upload the original ASL GIFs and add relevant information (e.g., keywords), as well as manage these GIFs and their details. The GIFs and their information are stored respectively in the filesystem and a MySQL database. The content management system (CMS), implemented as one of the Python modules of the web platform, allows managing the GIFs, whereas the information of the GIFs will allow searching from the mobile application for specific GIFs, via the relevant Web APIs that will be implemented on the backend and invoked from the mobile application. Figure 2 presents the high-level architecture of the ASM4Deaf system.

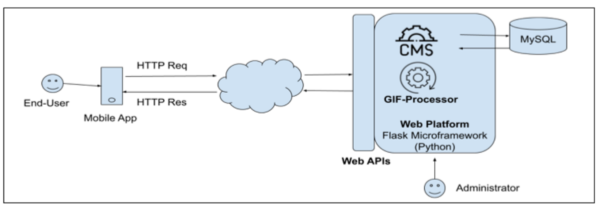

Figure 2: ASM4Deaf System Architecture

The end-user through the smartphone is using the ASM4Deaf mobile application (i.e., keyboard service) within the major social media applications (e.g., WhatsApp, Messenger) that offers the capability to type in the preferred sign language alphabet, while at the same time it can browse or search (e.g., by keyword - "Good morning") and then select a GIF. In the case of the browse action an HTTP GET request is sent to invoke the appropriate Web API endpoint, to retrieve all GIFs and present them to the end-user in a list. In the case of the search an HTTP GET request is sent with the input data (i.e., keywords) so that the relevant GIFs are returned by the invoked Web API endpoint. The end-user then selects the GIF and a face or emoticon from the available ones in the mobile application or takes a picture of his/her face and an HTTP POST request is sent to the relevant Web API endpoint including the face and GIF to be processed and transformed by the second Python module of the web platform, the GIF-Processor, and the final processed GIF is returned in the HTTP response to the mobile application (i.e., keyboard service) in order to be posted to the current social media application. The different face swapping approaches are illustrated in subsection 4.3. Currently, the three approaches have been implemented and tested as independent Python modules and based on the final decision, one approach will be adopted as the one to be enforced by the GIF-processor Python module and integrated in the platform.

4.3 Face Swapping Approaches

Three alternatives have been studied for the creation of the end-result GIF.

The first alternative is to use manual video **pre-processing**, and have the GIFs of all the possible head-torso combinations already created and stored in the system's database. This approach is highly expensive, both in terms of time and storage. Video-editing time depends on the video content itself, and, therefore, editing a single video/GIF might take from a few to several minutes- a processing time that turns into hours, days or months depending on the target GIF pool. Also, the memory demands of this alternative are quite high, as a single GIF with N available heads and K torsos maps to N*K pre-processed videos of 2-3 MBytes each. Due to these, and considering future GIF pool mass updates, video pre-processing is deemed not to be a very sustainable solution.

The second alternative makes use of a video-editing technique called **Masking**. In our case, a mask is a grayscale image that helps "merging" a GIF with another video or image. Specifically, black color is used to denote which areas of the original GIF to keep (in the final result), while white color denotes the area to be replaced with the matching one from the new video/image. This approach allows the user to capture an image or a video of their own head which will replace the signer's in a shape of choice (circle, heart, etc.). Using a Python (OpenCV) script and the correct directive mask image, the GIF result is created on-demand with an average processing time of about 5 seconds. In terms of cost, Masking is less expensive than pure video pre-processing, as the only necessary pre-processing involved is creating the shape (directive) masks for each GIF in the GIF pool. This results in less storage - needed for the system's data, but still a considerable amount of time required for the mask creation stage. Additionally, some challenges of this alternative include matching the (pixel) dimensions of the user's input to the mask's and GIF's, as well as matching the user's figure position and size to the signer's (in the GIF).

The third alternative uses the **Face Swapping** technique, from the artificial intelligence and machine learning fields. Two face-swapping Python based tools have been examined, both of which have the same advantages and disadvantages. The main advantage is sustainability, as nothing but the selected GIF and an image of the face which is to replace that of the signer's is required to produce the final result. Moreover, Face Swapping produces the highest quality results out of all the approaches. Depending on the tool, the results can also be quite realistic. The strongest disadvantage of this solution is its processing time, taking up to 30s for an 8-10s GIF, which critically affects the user's experience. Additionally, there is the issue of distortion- i.e. the signer's face in the final result being considerably deformed. This happens when the facial characteristics of the faces in use are not compatible enough (e.g. a very small mouth swapped with a very wide one). A solution for this could be to offer only compatible available-for-swapping faces for each GIF; something that does solve the problem, but adds pre-processing overhead/cost (finding and testing possibly compatible images). Overall, though, this approach appears to be the most sustainable of the three. The three approaches are based on the ASL videos/GIFs that are recorded by professional signers from the U.S recruited in the ASM4Deaf project.

4.4 Lo-Fi Prototype

Prototyping is a widely used method in the user-centered design process and Lo-Fi prototypes are utilised in early design stages to test the functionalities and layouts of a user interface before development starts [21]. It is an easy method for end-users to understand the functionalities and provide valuable feedback, insights and point out issues with regards to usability [22]. This is done by presenting the prototype and encouraging end-users to provide feedback, which was done in the form of a workshop utilising focus group discussions and an end-user survey (see Table 2).

Once the app is installed on the smartphone, the end-user journey can be summarised in the following steps: 1) user initiates the MSMAs of preference, 2) user selects the specifically ASM4Deaf designed keyboard 3) user searches for keywords for the signed message to be posted, 4) based on results returned, user constructs the signed message and 5) user is satisfied with the result and posts it or returns to edit the result. Next, a couple of screens from the end-user's journey is presented.

The end-user launches the MSMA, e.g. WhatsApp and selects the ASM4Deaf keyboard by clicking the keyboard icon at the bottom right-hand corner of the screen. Once selected, the end-user types in sign language alphabet the term to search for relevant GIFs and receives results.

From the results, the end-user can select the preferred torso option (from the related options returned based on the term searched) and then select the facial expression to combine. It could be a happy, sad, angry etc. facial expression. Two options of this prototype screen where designed and evaluated.

The differences are the focus on the middle facial expression and torso in Option B so as to not distract the end-user's attention and the size and placement of the "Preview" button.

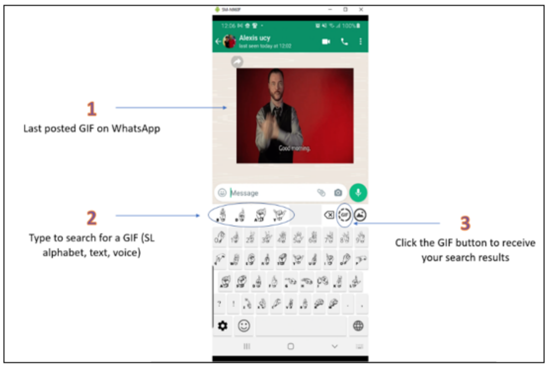

Figure 3: Screen 1 of Lo-Fi prototype

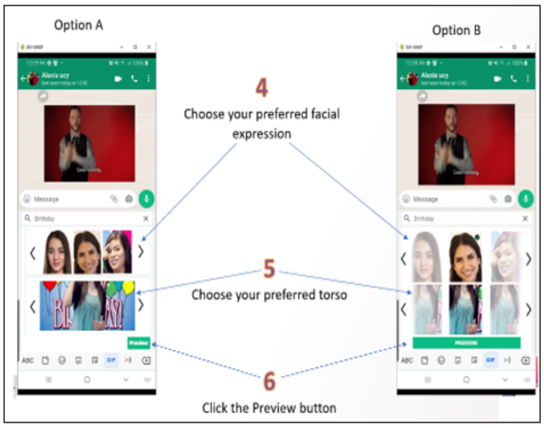

Figure 4: Screen 2 (Options A and B) of Lo-Fi prototype

The combined result can be previewed and the end-user decides whether the result is satisfying and can thus be posted or whether it needs to be edited. If editing is needed, the respective button is clicked and the end-user is directed to the previous screen to re-construct the signed message. The final posted result is posted on the relevant social media app.

5 RESULTS

Results from the first workshop with primary and secondary end-user groups are presented in this section. The workshop was organised in collaboration with the School for the Deaf in Nicosia, Cyprus (http://eid-scholi-kofon-lef.schools.ac.cy/.. The workshop was planned to be delivered in presential mode, as it would have led to higher participation. However, due to the COVID-19 pandemic, the workshop was postponed several times until it was eventually decided to use a remote delivery method with zoom as the videoconferencing tool. A total of 20 participants had registered for the workshop with 11 participating on the day. From the 11, five represented the primary end-user group and six the secondary end-user group. Five participants also completed the adapted SUS questionnaire.

5.1 Focus Group

Following an extensive presentation of the prototype, the focus group discussion was based on several questions for each screen of the prototype. For screen 1 (see Figure 3), discussions centred on the input methods to search for a GIF (i.e. sign language alphabet, text, voice). Was the use of sign language alphabet a good choice as an input method and whether there are other input methods that could be considered. For screen 2 (see Figure 4), discussions were aimed at understanding whether it was clear to end-users that once the search results were returned, they needed to combine head and torso results to create their own GIF. There was also discussion on the use of focus in the results, thus a comparison of the two different options regarding the design of this specific screen. Looking at screen 3 (see Figure 5), it was important to determine whether the screen was overwhelming and whether there was a clear understanding of what needed to be done in the screen. Lastly, whether there were any recommendations about improving the current screen designs.

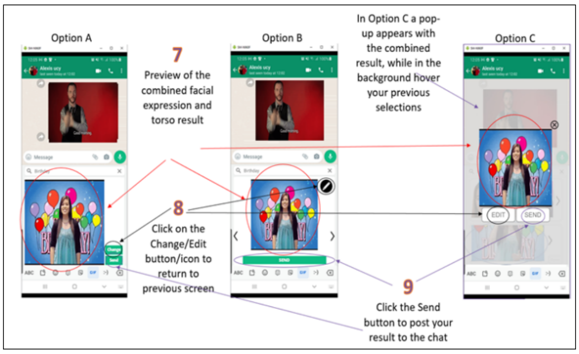

Figure 5: Screen 3 (Options A, B and C) of Lo-Fi prototype

More general questions, i.e. not screen specific ones, focused on the overall experience (e.g. fun, difficult etc.), whether the app supports socialising, in a fun and exciting way, whether the app could be used as an educational tool to help interested persons learn ASL and how this learning experience can be further enhanced (e.g. having subtitles in the final combined video). A very important discussion point was on their preference towards the app in terms of fun and entertaining vs. quality and efficiency for the signed messages. This has significant design implications, affects the user experience and expectations and in turn acceptance and credibility of the app. Participants preferred the fun and entertaining nature over quality and efficiency in terms of ASL, providing freedom and flexibility that also matched the technical limitations that such a solution requires. The results from the focus group discussion, coupled with results from the adapted SUS questionnaire (see Section 5.2) are summarised as recommendations in Section 5.3.

5.2 Questionnaire

In the workshop 11 people had participated. Nevertheless, in terms of the questionnaire there were only 5 responses. The demographic data of the people that answered the questionnaire are shown in Figure 6. The responses are 80% from people who are Deaf or Hearing Impaired (i.e. primary end-user group) and 20% from Hearing people (i.e. secondary end-user group). It is also important that we have coverage on all age groups, as well as the fact that all participants have a good and very good use of mobile applications and smartphones, i.e., the main target group.

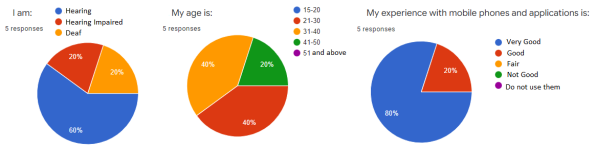

Figure 6: Demographics.

Despite the small number of responses, participants are confident that they would like to use the application as exhibited in Figure 7. In fact, 80% of the participants replied that they would like to use the application often and very often. This showcases a real need for such an application that enables Deaf, hearing impaired and hearing end-users to communicate socially in their preferred sign language through MSMAs.

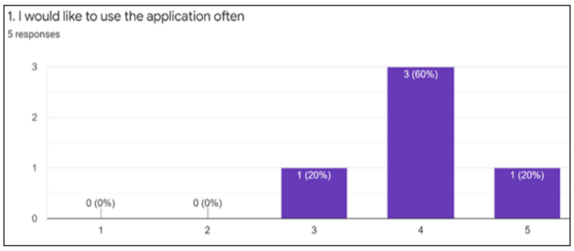

Figure 7: Application use responses

Two more important results from the questionnaire are that the Lo-Fi prototypes were assessed as well thought and well connected, as well as the fact that the users will have no problems in using the mobile application (see Figure 8). This revealed that the design of the Lo-Fi prototypes was intuitive and well understood in terms of the functionality to be offered by the mobile application, by all participants.

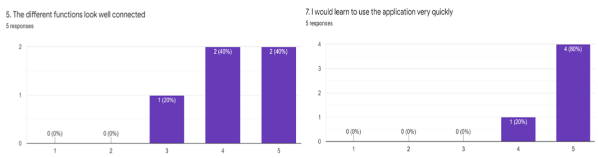

Figure 8: Usability and Ease of Use

Despite the fact that the responses were received from a small number of participants (N=5), still the above results in conjunction with the recommendations and considerations received from the live interactive discussion with all participants (N=11) and presented in the following subsection showcase a strong interest for the ASM4Deaf mobile application. This is evident based on the fact that the discussion was highly engaging with > 30 minutes spent on receiving recommendations on the mobile application functionality and usability. These are presented in Section 5.3.

5.3 Recommendations and Considerations

Table 3 summarises the main recommendations and considerations from the end-user feedback collected during the evaluation of the Lo-Fi prototype. Based on these, a priority list has been defined that will drive the design of the Hi-Fi prototype, to be evaluated in the second iteration phase. The priority list is based on the rating scale that defines the severity of the problem and technical limitations. The scale is as follows: 1 = problems to be addressed (priority is high); 2 = problems that may be addressed based on remaining time and budget available in the project (priority is medium); 3 = problems that are out of scope or out of project budget (priority is low).

6 CONCLUSION/FUTURE WORK

Deaf persons have a serious and unfair disadvantage regarding different social aspects of everyday life. One very important aspect is access to technological products since they are stereotypically designed for hearing people with key parameters such as usability,

Table 3: Improvements suggested with priority based on the qualitative and quantitative results collected

Feedback/Recommendations	Priority	Consideration	Technical comments	Product sustainability
Subtitles and/or sound functionality.	1	Manually added for each GIF.	Examine external API for dynamic sound to text.	API for dynamic sound to text.
Select the subtitles and/or GIF's language.	1	Manual subtitles translation.	Examine external API for dynamic translation.	API for dynamic translation.
Input method 1) sign language alphabet, 2) text.	1	Already considered and to be supported.	None.	Functionality is sustainable.
Input method 3) speech to text (voice).	2	Use external Speech to text API.	Google Voice can be a viable external API.	External API – payment model must be examined.
Voice recording should be transformed to 1) sign language alphabet, 2) text.	2-3	Complicates functionality and design - cluttered UI.	Complicated => feedback that available keyword was recognised.	Complications also on product sustainability.
List of words and phrases available that can be used from the database (auto-completion).	1	Provided for 1) finger-spelling, 2) text. Complicated for 3) speech to text (voice).	Call to ASM4Deaf API to retrieve keywords.	Functionality is sustainable.
For voice spelling/search the context of a word and how it needs to be used in a sentence.	3	Natural Language Processing (NLP) required.	This needs NLP, outside of the scope of this project.	Complications also on product sustainability.
For older Deaf end-users it might be more difficult to use and training may be needed.	1	Create a video tutorial.	Augmented Reality guidance – future work.	Functionality is sustainable.
Save videos/GIFs to be sent later when Internet/data connectivity is available.	1	Screen 2 - a tab to display saved GIFs. Screen 3 there will be a button to "save" a GIF.	"Save" button in addition to "edit" and "send" buttons and functionality.	Functionality is sustainable.
Desktop version of the application, due to memory limitations with saving GIFs.	3	First focus on mobile app before considering desktop version.	Focus is to ensure mobile app usability and functionality.	Complications also on product sustainability.
CY SL to ASL translation (or from one SL to another), in terms of text, SL alphabet, SL country specific GIF.	3	User an external API. Not primary focus of this work.	E.g. Google Translate API based on characters.	Complications also on product sustainability.
Consider the location of the receiver and map it to that SL GIF video.	3	User an external API. Not primary focus of this work.	E.g. Google Translate API based on characters.	Complications also on product sustainability.
Using avatars.	3	Not primary focus of this work.	No comment.	Complications also on product sustainability.
Ensure that the original video with the original signer face is also available for selection.	1	Already considered and to be supported.	None.	Functionality is sustainable.

accessibility and inclusiveness being largely neglected. This has a major impact for Deaf or with hearing impairment end-users. Therefore, it is important to promote initiatives that make Deaf persons first class citizens. Research studies and declarations from the European and International bodies such as the EUD and the UN (see Section 1) are used as a compass in this work, which contributes through a mobile application and system that supports integration and use of sign language in MSMAs. This enables more natural and intuitive use of MSMAs from Deaf and/or with hearing impairments end-users, as well as enables communication between the Deaf and hearing communities. Foremost, the Connect Deaf mobile application was developed offering use of fingerspelling keyboards in 13 sign languages in MSMAs. Then, a Lo-Fi prototype was designed, which aims to validate the design of the Connect Deaf mobile application and at the same time include extra features, i.e., the ability to browse, search and edit GIFs in ASL, offering the full experience that MSMAs offer to the hearing community.

This work presents the ASM4Deaf system architecture, i.e., the cloud-based backend and mobile application, the technical approaches and the Lo-Fi prototypes defined and evaluated in the workshop conducted with end-users who are Deaf and their family and friends. Results from the study were important and key outcomes are: (i) the Lo-Fi prototypes were assessed as well thought and well connected in terms of the design of the UIs and the functionality and (ii) end-users indicated that they will have no issues in using the mobile application. This revealed that the Lo-Fi prototypes were intuitive and well understood in terms of the functionality and the UIs to be offered by the mobile application, by all participants. In addition, the workshop participants showed a genuine interest to discuss and contributed with a list of recommendations for consideration by the project team, in a lively and very interactive discussion, which revealed a strong interest for the ASM4Deaf mobile application.

Limitations of this study includes the small number of participants (N=5) that have answered the adapted SUS questionnaire, as well as a total of 20 participants had registered for the workshop with 11 participating on the day, impacted by the COVID-19 pandemic. Nevertheless, the participants were actively engaged and contributed with insightful comments that provide valuable input in the co-creation process. In the next phase of the project the Hi-Fi interactive prototype will be developed and assessed in focus groups with experts and in a second workshop, where the aim is to increase participation and have a more statistically significant sample for the evaluation study.

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