Emergency App for People with Hearing and Speech Disabilities: Design, Implementation and Evaluation According to Legal Requirements in Germany

Jens Weppner
German Research Center for Artificial Intelligence and University of Kaiserslautern
67663 Kaiserslautern, Germany
{firstname.lastname}@dfki.de

Paul Lukowicz
German Research Center for Artificial Intelligence and University of Kaiserslautern
67663 Kaiserslautern, Germany
{firstname.lastname}@dfki.de

ABSTRACT
We describe the design, implementation and evaluation of an App that allows people with hearing and speech impairments to make emergency calls to standard emergency call centers. The application was evaluated in two user studies involving people with hearing disabilities and emergency center staff receiving emergency calls from the emergency application. The development had been contracted by a german governmental committee in charge of regulating the emergency call infrastructure and is in the process of being introduced as the official emergency App in Germany.

Categories and Subject Descriptors
H.4.3 [**Information Systems Applications**]: Communications Applications; H.5.2 [**Information Interfaces and Presentation**]: User Interfaces; J.3 [**Life and Medical Sciences**]

Keywords
Emergency Call App, Communication Application, DTMF Communication, Hearing and Speech Disabilities, Application Design, User Study Evaluation.

1. INTRODUCTION
Emergency numbers (like 911 in the US and 110/112 in Germany) are the key to saving lives in critical situations. As a consequence making them available to people with disabilities is a crucial concern. Since, per definition, the use of such numbers is based on audio communication people with hearing and speech related impairments cannot use them without assistance. Thus, Rubin et al. [3] published a case where a spouse of a deaf husband died because he could not be heard properly during the emergency call.

In the era of smartphones with complex mobile speech recognition it may at first seem surprising why the problem has not yet been solved. In this paper we describe the regulatory and technical issues that have so far prevented the implementation of such an App and describe the solution we have implemented on behalf of the responsible German government committee. We also present the results of the evaluation of our system with speech and hearing disabled users and the emergency call center personnel.

Related Work. Starner et al. [4] introduced emergency case communication of deaf people into the smartphone era. They also used tone encoded messages but relied on the existing tele-typing (TTY) standard disseminated in emergency call centers in the United States. Paredes et al. [2] recently proposed a mobile phone application prototype suited for people with hearing and speech disabilities. However, they use text messages for emergency communication which does not comply with German regulations. Secondly, they did not present or evaluate an integration into the emergency center. Buttussi et al. [1] demonstrated another class of mobile application for easier communication in emergency situations between emergency medical responders and deaf people by video-based sign language descriptions.

2. REQUIREMENTS AND DESIGN
The aim of our work has been to implement a smartphone App that allows people with hearing and speech disabilities to make distress calls to the standard European emergency numbers. Key requirements were (1) compliance with all relevant regulations, (2) full compatibility with existing hard and software solutions in the emergency call centers (consequently any solution had to function without any additional software being installed in the call centers), (3) the ability to run "out of the box" on standard smartphones and (4) a user interface that can be operated by people without special technical skills in a stress situation. The development had been contracted by a German governmental committee in charge of regulating and governing the emergency call infrastructure and which is in the process of being introduced as the official App approved by all the relevant organizations.

Regulatory and Technical Issues. While people take emergency numbers for granted, they often do not realize the complexity of the infrastructure and the amount of legislation behind them. This includes a network of local and regional call centers and provisions that ensure that any emergency call made to the corresponding number from any

PervasiveHealth 2014, May 20-23, Oldenburg, Germany

DOI 10.4108/icst.pervasivehealth.2014.255584

mobile phone (or landline) is routed to the appropriate center with rough position information. A valid SIM card or balance is not required. A congested cell will terminate low priority (non-emergency) calls to give priority to any voice based emergency call. All technical and operational aspects are lied down in the corresponding regulation which often involves multiple jurisdictions. In addition, given the large number of call centers that exist countrywide, even small technical changes to the call center infrastructure amount to large cumulative costs and need to be avoided. As a consequence of the above, making any changes or extensions to the emergency call procedure is a difficult process. The most important issue relevant for our work is the fact that the call needs to be routed through the *GSM voice network* refraining from any use of internet connectivity. This is both a legal (laid down in the German Telecommunication Law) and a technical concern (with respect of billing, localization and prioritization). Text messages (SMS) are also not acceptable since they have no guaranteed arrival delay and cannot be routed to a specific regional center. In summary, the only communication channel that can be used is the standard GSM voice channel with no direct possibility of sending text messages between the emergency center and the caller. The problem is aggravated by the fact that all commercial smartphones restrict direct access to the secured GSM core including direct access to the voice channel. Consequently, sound generated by a text to speech solution cannot be injected into the voice stream of a call. At the same time we cannot assume that the call center operator has the ability to read an incoming text. This would in general require modifications to the existing soft- and/or hardware in the center which was ruled out in the requirements. The need to refrain from any extensions to the existing call center hard- and software also impacts the return channel from the operator to the caller. Thus, we are not allowed to assume a keyboard to be available to transmit text messages back to the caller. At the same time using speech recognition to translate the emergency operator speech to text is also not feasible.

As described below the solution we came up with was the "air" interface for microphone to loudspeaker loop and loudspeaker to microphone loop together with the so called "Dual Tone Multiple Frequency" (DTMF) tones used for tone dialing.

Functional and Usability Requirements. The mobile application needs to enable the user to do three things: the initiation of an emergency call, transmission of additional predefined information, and optional, interactive, bi-directional communication with the emergency center. The emergency expert group requested that the call must start with an announcement (based on synthetic voice) that introduces the matter of the emergency call to the emergency center. This information includes the type of emergency, number of injured people, pre-configured personal disabilities, special diseases, current GPS based location, location accuracy and instructions to the emergency center on how to proceed. The system must repeat this announcement until a confirmation from the center confirms the call to ensure that the information has actually reached a human operator. After the announcement is fully understood and acknowledged additional real-time, bi-directional text-based communication must be possible. A key concern is the speed and accuracy of typing on the smartphone in an emergency situation. Thus, an additional requirement has been formulated for a user interface that allows quick, single click transmission of predefined text blocks addressing the most common messages while providing an extended mode for arbitrary two-way communication.

Definition of Text Blocks and Codes. Text blocks have to be pre-defined and deposited in the emergency centers as well as stored in the smartphone application. The police department of Kaiserslautern (Germany) committed a prototypical set of relevant question for the most common emergency situations. I.e. one of the 44 prototype text blocks is "Can you open the door?" which is resolved by the code *8# in the prototype application. The final definition of text blocks was initiated in the meeting of the emergency call expert group (EGN) in November 2013. The definition is based on a complex structural chain of responsibility decisions of the different authorities. Authorities are the police, fire department and medical emergency department.

3. IMPLEMENTATION

Communication: From User to Emergency Center. As described above a core technical issue is the fact that most phones do not allow application generated sound to be inserted into the audio stream of the call. In order to solve this problem the text input from the user is translated into synthetic speech on the smartphone and the output through the loudspeaker at full volume. This is generally possible while the call is active. Consequently, the sound is received by the microphone and heard at the emergency call center on the other side of the line. Tests with different devices and within different environments (ranging from silence to talking people in 1m distance) have shown that the sound volume and quality is adequate.

Communication: From Emergency Center to User. As explained before, key requirements were to rely on the GSM voice channel only and to avoid any changes in the existing emergency center software and hardware. This means that the trivial solution of the operator inputing messages using a keyboard and transmitting these messages to the phone via a data channel was not feasible. As a first approach we considered a speech recognition software translating the operator voice messages into text. However, reliable speech recognition in general runs on external servers not on smartphones. Thus, given the fact that the use of a data connection was not allowed, this solution was not practicable. As a consequence we have decided to use the phone key pad (also present in one form another in every call center) for text input and transmit the text using DTMF tones. The tones are used for a variety of applications are by default transmitted over the voice line. On the smartphone our App can pull them out of the audio stream and easily decode them.

We investigated DTMF-based character by character submission of questions (like writing a text message). Together with the emergency call center expert group members we decided that this method is too slow for general input. As a default modality we agreed on short codes representing predetermined questions (see previous section). Codes are short sequences of DTMF digits, * and #. They are entered via the keypad and injected directly into the voice channel (no loudspeaker/microphone loop is necessary in the emergency center). We implemented a frequency detection algorithm on the smartphone recognizing the sequences which are then looked up in a text block code table. If the look-up is successful the text is shown to the user and a voice-based acknowledgment is sent to the emergency center. Full text input using the number pad (like test message entry) has been retained as a fall back option in case the pre-defined messages are not applicable.

App Functionality. The applications logic flow consists of four elements (see figure 1) as described in the next paragraphs in sequential order. The first step is setting the user attributes during the first launch of the application. In any further launch the user could change personal attributes on demand. The user can select the following attributes (from top to bottom in figure 1a): speech-impaired, deaf, hampered, diabetic, bleeder and anaphylaxis. This information is made available to the call center during an emergency call. In case of an emergency the user launches the App with the default screen (see figure 1b) with emergency specific information. There are two simple item categories displayed on the initial screen: The selection (checkbox) of the type of emergency (from top to bottom: criminal act, fire, medical emergency) and the selection (−/+ buttons) of the number of injured people. Selection of previous emergency information is optional. The user could also quickly directly proceed by selecting between the two buttons (dial *110* for German police or dial *112* for German ambulance, fire and rescue, police) which immediately initiated the emergency call.

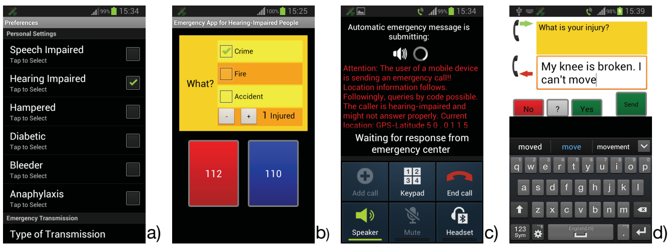

Figure 1: Emergency smartphone application screenshots. a) user attributes settings *(speech-impaired, deaf, hampered, diabetic, bleeder and anaphylaxis)* b) application start *(criminal act, fire, medical emergency, number of injured people)* c) Dynamic emergency call announcement prior to emergency call acknowledgement d) Bi-directional communication

A spoken message is automatically generated (see figure 1c) by the system after initiating the emergency call. The message contains the GPS position (if available), user attributes, type of emergency, number of injured people and instruction for the emergency center how to acknowledge this announcement[1]. The announcement will be updated if the GPS position becomes available later on or changes. The announcement will be played back repeatedly until the emergency center acknowledges. Repeating the message solves the issue of wait loops which might occur before emergency staff handles the call. Since a hearing impaired user cannot hear the message being played of the phone loudspeaker we give a textual feedback of synthetic speech transfer and give an indication (moving status circle) for waiting for acknowledgement by the emergency center. At this stage, the user has the possibility to end the emergency call for whatever reason. As soon as the emergency call is acknowledged by the emergency center the application flow is shifted to the next screen (see figure 1d) where visual feedback for acknowledgement is given and incoming questions are displayed in the upper text field. The user is able to input textual responses or supplements to the emergency with the on-screen keyboard (the send button is part of the keyboard) with common Android user experience (i.e. text message input). Outgoing responses are displayed in the scrollable upper text field (i.e. text message history). Quick answer buttons (yes; I do not understand/I do not know; no) allow fast responses without typing. In this stage ending a call is only possible by the emergency center to avoid inadvertent call ending by the user.

[1]The announcement is acknowledged with ∗1# which is described in the audible announcement itself.

4. EVALUATION AND ADAPTATION

To evaluate and improve the system we set up two user studies. User study A) intended evaluating people with hearing disabilities (deaf or strong hearing impairment). User study B) evaluates the interaction with the emergency center staff with the incoming synthetic voice and outgoing text block interaction. Both user evaluations consisted of a hands-on experience with video-based monitoring for offline evaluation and multiple-choice statements (fully applies - does not apply at all) after two runs of fictive emergency scenarios.

Participants with Hearing Disabilities. Ten people with hearing and speech disabilities with age ranging from 18 to 65+ (1 participant in range 18-25 years, 2 in range 26-35 years, 4 in range 46-55 years, 1 in range 56-65 years and 2 were over 65 years), eight males and two females participated (see figure 2). Three of them did not own and did not use a smartphone before, five characterized themselves as experienced and two as casual smartphone users (see figure 2(k)). For the study we developed two fictitious emergency situation scenarios which were communicated to the participants as written short stories. In one scenario a fire broke out in the test person's kitchen in an apartment building which put additional danger to third persons. The test person had to use the App for help and give additional information about the situation. The other scenario was about a robbery in the park the test person witnessed. The appearance of the robber and the robbery act itself had to be transmitted to the emergency center.

The technical realization was over a real cell phone to landline telephone connection (no mock-up communication). The application was configured for a local phone number. The smartphones Android home screen showed the emergency app icon. All participants were able to read the scenarios in the preparation room. One participant was tested at a time. A trained emergency center staff was receiving the call at a real emergency call center. The participants were instructed to start the emergency call and received no further assistance during the study.

Participant	Statement (a)	Statement (b)	Statement (c)	Statement (d)	Statement (e)	Statement (f)	Statement (g)	Statement (h)	Statement (i)	Statement (j)	Statement (k)	Smartphone Owner	Age Range	Gender
[1]	2	2	3	2	3	3	3	3	1	3	4	no	46-55	male
[2]	1	1	1	1	1	1	1	1	4	3	1	yes	26-35	male
[3]	2	1	1	2	3	1	2	1	4	3	1	yes	18-25	male
[4]	4	4	4	1	2	1	2	1	1	2	4	no	46-55	female
[5]	3	2	1	1	2	2	2	2	2	2	2	yes	65+	female
[6]	1	1	3	2	2	2	1	1	2	2	3	yes	26-35	male
[7]	4	1	1	3	3	4	1	1	2	2	3	yes	56-65	male
[8]	1	1	1	1	1	1	1	1	3	3	1	yes	46-55	male
[9]	1	1	1	2	1	2	1	1	2	3	2	yes	46-55	male
[10]	1	3	1	1	2	1	1	1	2	1	4	no	65+	male
Average	*2*	*1,7*	*1,7*	*1,6*	*2*	*1,8*	*1,5*	*1,3*	*2,3*	*2,4*	*2,5*			

Figure 2: User study (participants with hearing disabilities) multiple choice results. Statements (a)-(k) are rated in the range from 1 (fully applies) to 4 (does not apply at all). See section 4 for detailed question description.

As a result of our observation 10 (all) participants managed to launch the app and initiate the emergency connection. 3 participants did not correctly set the type of emergency (criminal act, fire, medical emergency) on the start screen (forgot scenario details or overlooked the check boxes). 4 participants did not correctly set the number of injured people ($-/+$ buttons). 10 participants selected the red button (112) and never the blue button (110) for initiating the emergency call. 1 participant switched off the automatically enabled loud-speaker (a new screen overlay is needed to prevent this). 9 participants quickly familiarized themselves with the use of the quick-response buttons (yes; I do not understand/I do not know; no). 1 participant was not able to correctly type text with the default Android on-screen keyboard (never used a smartphone keyboard before and had a permanent finger/key offset) but was able to initiate the connection at least. 4 participants repeatedly chose the wrong button (yes button instead of keyboard send button) for submitting the message (an extra "send" button is needed).

We defined rating 1-2 as *applies* 3-4 as *does not apply* (see figure 2). As a result of our survey (see figure 2) in figure 2(a) 7 of 10 participants understood the partitioning of start screen. Figure 2(b): 8 out of 10 participants expected that the emergency call is instantaneously initiated after pressing the police or fire department button. Figure 2(c): 7 of 10 expected that an emergency connection is not created by just opening the app. Figure 2(d): 9 of 10 understood that they have to wait for an acknowledgement before communication is possible. Figure 2(e): 7 of 10 immediately saw when action was required (by answering questions). Figure 2(f): 8 of 10 found communication (text display and text input) intuitive. Figure 2(g): 9 of 10 found the quick-response option comprehensible. Figure 2(h): 9 of 10 understood the message history layout. Figure 2(i): 7 of 10 rated the visual layout as comprehensible. Figure 2(j): 5 of 10 thought the font size is too small. Based on the results we are currently enhancing the application in multiple ways. For directing the user to the correct emergency center (112 or 110) icons will be displayed additionally on the colored buttons. A 'send message' button will be placed directly below the text field instead of being just part of the keyboard. The contrast of the whole layout as well as the type size will be increased.

Emergency Call Center Employees. Three full-time emergency center employees participated. We executed evaluation in a real emergency center environment. We explained the general principle of the App and the usage of codes. A trainee was seated spatially separated and was introduced to the fictitious emergency scenarios A1 and A2, and then instructed to place fictive phone calls to the real emergency center (authorized by local authorities). During our observation we registered that the employees were not used to synthetic speech with the current parameters (speed and pitch). The loudspeaker/microphone loop at the smartphone made understanding the message even more difficult. Active noise cancellation clipped the beginning of an announcement coming from the smartphone (a repetition of the message is needed). Feedback loops were not an issue. Nonetheless, while the participants complained about the feature, in the end they were able to understand the message. However, we conclude that if possible it is advisable to, at the smartphone side, use a headset with a microphone held to the loudspeaker or use a special jack to short-circuit audio-out to audio-in whenever possible. This leads to a much better quality as a transmission from the phone loudspeaker to the phone microphone. Another interesting effect was how the staff dealt with longer breaks during the communication (typing text needs longer than speaking). It was not always obvious for them if the user is typing or doing nothing. We therefore enhance the smartphone application by repeating the asked question acoustically as an acknowledgement by the smartphone and acoustically inform the staff member that the user is currently typing his answer.

5. REFERENCES

[1] F. Buttussi, L. Chittaro, E. Carchietti, and M. Coppo. Using mobile devices to support communication between emergency medical responders and deaf people. In *Proceedings of the 12th international conference on Human computer interaction with mobile devices and services*, pages 7–16. ACM, 2010.

[2] H. Paredes, B. Fonseca, M. Cabo, T. Pereira, and F. Fernandes. Sosphone: a mobile application for emergency calls. *Universal Access in the Information Society*, pages 1–14, 2013.

[3] P. N. Rubin and T. Dunne. *The Americans with Disabilities Act: Emergency Response Systems and Telecommunication Devices for the Deaf*, volume 2. US Department of Justice, Office of Justice Programs, National Institute of Justice, 1995.

[4] Z. Zafrulla, J. Etherton, and T. Starner. Tty phone: Direct, equal emergency access for the deaf. In *Proceedings of the 10th International ACM SIGACCESS Conference on Computers and Accessibility*, Assets '08, pages 277–278, New York, NY, USA, 2008. ACM.