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An Assistive Technology for Hearing-Impaired Persons: Analysis, Requirements and Architecture

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Abstract—**In this contribution, a concept of an assistive technology for hearing-impaired and deaf persons is presented. The concept applies pattern recognition algorithms and makes use of modern communication technology to analyze the acoustic environment around a user, identify critical acoustic signatures and give an alert to the user when an event of interest happened. A detailed analysis of the needs of deaf and hearing-impaired people has been performed. Requirements for an adequate assisting device have been derived from the results of the analysis, and have been turned into an architecture for its implementation that will be presented in this article. The presented concept is the basis for an assistive system which is now under development at the Institute of Microsystem Engineering at the University of Siegen.**

I. INTRODUCTION

Many events in our environment generate noise that transports information about the particular event. The noise can be interpreted by the human being and gives him important information about the current situational context of his immediate surroundings. But this source of information is closed for people experiencing hearing-impairment. Hearing-impairment is one of the most widespread handicaps worldwide. The World Health Organization estimates that in 2004 about 275 million people have moderate to profound hearing loss. Hearing-impairment is the second most cause for years lived with disabilities (YLD) [1]. People experiencing hearing-loss cannot perceive acoustic information from the environment without an assistive device. Most of the people experiencing hearing-impairment can benefit from a hearing aid, which records the sounds of the surrounding, adapts the signal to compensate for the characteristics of the user's hearing-impairment and replays the adapted sounds into the user's ear. But people experiencing severe hearing-impairment may not be able to take advantage of a hearing aid, e.g. deaf people. To improve assistive devices for people experiencing severe hearing-impairment the authors propose the use of environmental sound recognition algorithms to detect audio events. In this contribution, a concept for an assistive technology for hearing-impaired people is presented. The approach applies pattern recognition techniques and modern communication technology to implement a system that analyzes the acoustic environment and signals events classified as critical to the user. A short summary of previous approaches is presented in the next section, followed by a literature analysis and requirements, which are the basis for the proposed architecture.

II. PREVIOUS RESEARCH

In the past, different approaches of assistive systems for people experiencing hearing-impairment were presented. The approaches can be roughly divided into two categories: Approaches for use in the home environment and approaches for use outside of the home environment. Whereas different assistive systems for the home environment are commercially available, a system for outdoor use is not known to the authors. In the following, some systems presented in the past will be introduced shortly.

References [2], [3] and [4] introduced electronic devices, designed as driver assistance systems. All three systems monitor the acoustic surroundings around a vehicle and inform the driver when the siren of an emergency-vehicle is detected. The device presented in [2] uses a bank of filters and phase-locked loops to detect signals in different frequency ranges. A digital logic checks if the signals form a siren and notifies the driver. An application specific integrated circuit is introduced by the authors in [3]. The analog signal from a microphone is digitized by an 8-bit analog to digital converter, processed by an autocorrelation algorithm, whose results are analyzed by a classifier. The classifier is tailored to acoustic emergency signals in Germany, the characteristics of which are defined by a national standard [5]. An artificial neural network-based recognition system for sirens, implemented on a standard PC, is presented in [4]. The input for the network is a vector consisting of twelve Mel Frequency Cepstral Coefficients (MFCC). Simulations with synthetically generated sounds – siren mixed with background noise – showed that the system can achieve an accuracy of more than 99% in the best case.

Portable systems for outdoor use are presented in [6] and [7]. The system introduced in [6] is able to detect five classes of sounds which can be defined by the user. A detected sound is reported to the user using an electro-tactile interface connected to the wrist. A system based on a smartphone is presented, in [7]. The smartphone runs an application that monitors the activity of the acoustic surroundings and informs the user if the acoustic activity changes. An assumption for the developed software is that a change in the acoustic activity is connected with an event which can be of interest for the user.

Each of the approaches has drawbacks: [2], [3] and [4] are designed for the use in a vehicle and can only detect one specific class of sounds. The implementation of [6] is not suitable for daily use, because the complete system weights 1.5 kg and runs only for 3 to 4 hours with one charge of the battery. The software presented in [7] doesn't recognize specific sounds.

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III. ANALYSIS AND REQUIREMENTS

An analysis of the needs of people experiencing hearing-impairment presented in the following section provides the basis for requirements for an assistive technology.

A. Analysis

Although hearing-impairment is a wide-spread disability, not much empirical research that focuses on the problems of hearing-impaired and deaf persons have been presented.

The authors of [8] present a study that focuses on the problems of deaf people in different situations in road traffic. They developed a questionnaire that contains questions about the participation in road traffic as a pedestrian, questions about the individuals' experiences when they learned to drive, and questions about experiences and hurdles when travelling by bus or train. It consists mainly of closed questions, with open sections to give further explanations. The questionnaire was distributed online and in paper form. 45 individuals returned the questionnaire. The following explanation focuses on the replies and comments of deaf persons as pedestrians.

The answers show that about 60% of the respondents cannot hear nearby vehicles, even heavy vehicles like trucks. More than 60% feel a bit or a lot less safe when they cross a street at a pedestrian crossing. About 60% feel a bit or a lot less safe when they move away from a crossing. At streets where no pavement is available, more than 80% of the respondents feel a bit or a lot less safe; ~6% feel a bit less safe at streets without a pavement. Further explanations that elaborate on problems experienced as pedestrians were given by 35.6% of the respondents. Answers included that the person concerned feels uncomfortable because he does not notice the sirens of emergency vehicles and approaching vehicles. Additionally, road works, other traffic when cycling and level crossings affect the feeling of safety negatively. Beside the feelings when participating in road traffic as pedestrians, the questionnaire elaborates on problems when orientating in public. The answers showed that nearly two-third of the respondents always or generally prepare themselves before travelling with the aim to avoid asking for directions. The preparations include looking at maps, printing out maps and directions, and using navigation systems. Preparations are done because most respondents (31 of 43 answers) sometimes have problems when communicating with hearing persons, because they are not understood.

Two major areas for assistive support for pedestrians experiencing deafness can be derived from the findings:

1. The described feeling of discomfort in road traffic can be tackled by the development of a system that monitors the acoustic surrounding of the individual and that informs the user about events and warns against threads, e.g. cars approaching from behind.
2. A supporting device assisting in navigating in an unknown setting and that helps to communicate with hearing persons would be helpful for those respondents who are not confident in communicating with hearing people.

Another approach to find out about the needs of people experiencing hearing-impairment for an assistive technology is presented in [9]. The authors interviewed eight persons with different characteristics of hearing-impairment and asked about their needs at home, at work, while driving and as pedestrians. When walking outside, the interviewees wanted to be informed about dogs barking, vehicles, bikes, and honking vehicles. In a second step, the authors presented to the interviewees characteristics and sketches for user interfaces for an assistive device. In summary, systems that can recognize sounds and show the relative direction of the source are preferred by the interviewees. A vital requirement was shown in the interviews in [9]: the user of an assistive device will not tolerate a high rate of false positives or false negatives.

A study motivated by audiology was conducted by the authors of [10]. To come up with a more realistic audiometric methodology, they assessed different situations and events in which audible perception is of great importance to hard of hearing people by a questionnaire survey. 52 situations had to be rated by the participants according to the importance. Results show that different situations in road traffic and alarms are of great importance to the participants. Among the 20 most important sounds are acoustic alarm signals of vehicles and noises of busy streets.

B. Requirements

Even when focusing on the needs for an acoustic assistive technology in road traffic, the spectrum of sounds is very wide. To cope with the diversity of sounds, the authors propose the use of pattern recognition techniques to implement an assistive device that is able to recognize the different sounds.

The recognition and classification of audio events consists of different steps and is illustrated in Fig. 1. Signals from the environment are recorded using a sensor or a set of sensors. To record environmental sounds, a microphone(-array) is used. The electric signal from the sensor is preprocessed and features which describe the characteristics of the sound are extracted by a feature-extraction step. A classifier is used to process the extracted features and recognize specific patterns in the recorded signal. The classifier is trained by a learning algorithm using a database containing patterns the classifier shall recognize. The requirements for the different steps in the classification are:

a.) Sensor & Preprocessing

The frequency spectrum of relevant sounds in road traffic is rather small. Moving vehicles generate noise in the frequency range roughly between 60 Hz and 8 kHz, with a rapid decrease of sound pressure over 2 kHz [11]. Sirens of emergency vehicles and horns are designed to

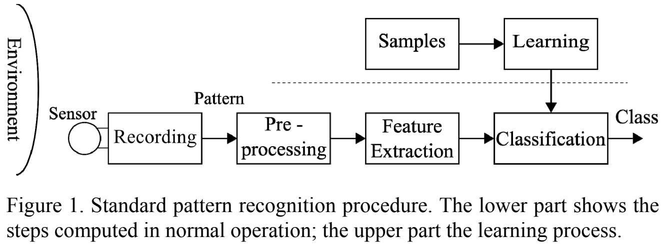

Figure 1. Standard pattern recognition procedure. The lower part shows the steps computed in normal operation; the upper part the learning process.

be easily perceivable by the human. So the major sound level is in the frequency range between 2 kHz and 4 kHz, because of the high sensitivity of the human ear in this frequency range. Since the device shall be used outdoor, the sensor must suppress wind noise. Another requirement for the sensor is the capability to monitor the surrounding around the user and enabling localization and tracking of a sound source. Three basic setups are possible (see Fig. 2): the minimum setup only monitors the acoustic surrounding behind the user, a complementing setup monitors the surrounding of the user which is not in the field of view (~160° - 175°), and the third setup monitors the complete surrounding of the user, i.e. a 360° acoustic observation.

b.) Feature extraction & Classification
The interviews showed that the sounds in road traffic which are of interest for a person experiencing hearing-impairment are mainly generated artificially, e.g. the noise generated by an approaching car. But also sounds made by humans or animals can be of interest. To be able to cope with the complete spectrum of sounds, the feature extraction as well as the classifier must be versatile. For different sounds, a different combination of features and classification method could be needed, so different feature extraction and pattern recognition algorithms must be implementable easily on the classification device. A vital requirement for use in road traffic is a very high recognition speed and high accuracy. E.g. if a vehicle approaches at 70 km/h, it moves ~ 20 m per second, giving the user of the device only short time to react. To train the classifiers, a database containing a comprehensive number of training examples must be available.

c.) User interface
The user interface must be comfortable and easy to use. Ideally it is possible to indicate the relative direction of the sound source with the user interface. Feedback given by the user interface may not be ambiguous and must be easy to interpret, because – dependant on the type of sound – the user must react in a short time. E.g. when a vehicle approaches with high speed.

An assistive device is not used in an isolated context, but in a social environment, so requirements exist, which are necessary to guarantee that the system will be accepted by the end user. Shinohara interviewed people experiencing impairments and concludes that assistive devices shall look like mainstream devices to not expose or even underline the impairment [12]. Devices shall be small and sleek. The device must have low power consumption so that the system is usable for at least a complete day. The device must be small in size and robust to ease integration in the daily life of the user.

IV. ARCHITECTURE

The requirements are the basis for the proposed architecture, which is shown in Fig. 3. The center of the architecture is a smartphone. In recent years smartphones have been equipped with powerful processors and gained a significant market share.

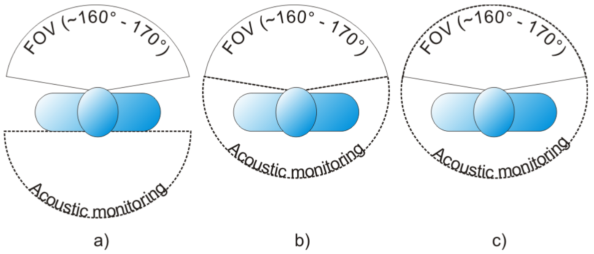

Figure 2. Acoustic Observation: a) minimum observation. b) complementing observation. c) full observation. (FOV = Field of view)

The classifier must be very flexible and versatile, because of the different sounds which shall be recognized by the assistive device. To implement different pattern recognition algorithms which can be executed in real-time, a processing device with considerable processing power is needed, which is today available in a smartphone. Another feature of a smartphone which is advantageous for the system is the direct internet access. This can be used to connect to an online service which stores training data for the classifiers. When the system recognizes a sound or if the user thinks that an event occurred which should have been recognized, the features of that sound can be uploaded to the database – either automatically or manually – and used by other users of the system to train their devices to achieve better recognition results. Such a training example can be tagged to identify its content and the region in which it was recorded. With such a community-driven approach, it is easily possible to accumulate a significant number of trainings data, needed by most pattern recognition algorithms. Special attention must be paid to the privacy of the uploaded data. Environmental sounds can contain sensitive information about the user of the system or people around him, so it is not sensible to upload sound files to the database. Further the data should only contain the feature set of the sound necessary to perform a successful classification. From the feature sets it may not be possible to reconstruct the original sound. The tools needed for a basic user interface are already available in a smartphone too. Each smartphone is equipped with a vibration alert, which can be triggered when a sound is recognized and the type of the sound can be shown on the screen of the smartphone.

Regarding the social requirements on an assistive device formulated in [12], a smartphone satisfies the demand for a device that is not exceptional. Due to the flexibility of the technology, a smartphone can run other assistant tools, e.g. a sign language to speech translator. Recent studies showed that mobile phones are not only used extensively by normal hearing people, but are also used by around 96 % of people experiencing deafness [13]. It can be assumed that the usage is increasing since the introduction of smartphone, because it allows the direct communication by sign language using video call.

For implementation of the system, a smartphone running the open source Android operating system (OS) is chosen, because of the availability of development tools, the programming in Java, allowing to port and use different already available software packages, and the market share of the OS.

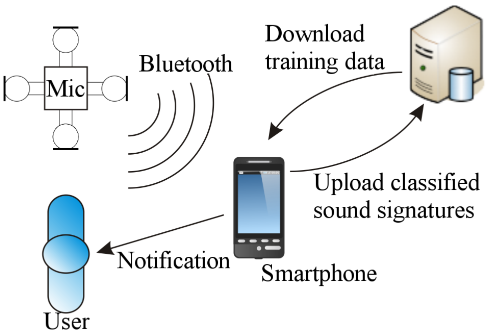

Figure 3. Diagram of the architecture. Sound is recorded using a microphone or microphone-array and processed by the smartphone. If a sound of interest is detected, the user is notified and the sound signature can be uploaded to a server.

As pointed out in the last section the system has to be designed to enable an acoustic observation of the user's environment and to inform the user about a critical sound event and the position of its source. This task cannot be performed by a smartphone alone. Although the smartphone contains all necessary functionality to implement a basic assistive device, it lacks two needed functions: first, a smartphone cannot be used to localize a sound source, since it is not equipped with an appropriate microphone and, second, the vibration alert can only inform the user that a sound was recognized, but not the direction the sound comes from. To deal with the first problem and to enable the smartphone to locate a sound source, it is complemented by an external microphone. The microphone can be designed using monaural or binaural techniques and is connected via Bluetooth to the smartphone. Even though, a monaural approach, in which an artificial pinna is used to distort a sound dependant on its direction, would lead to a smaller and less noticeable sensor, the use of such a microphone imposes a new problem: extensive knowledge about the incoming sound and how it is distorted by the artificial pinna is needed for direction estimation [14]. Machine learning algorithms are used to train the characteristics in a complicated process, which is not suitable for the end user. A microphone array is chosen for implementation of the sensor, although a microphone array has a bigger physical size. For simplification, the localization will only show in which of four quadrants the sound source is located.

Using the display of a smartphone for directional information leads to a kind of two-step use: in the first step the vibration alert marks an event. In the second step the user must take his phone, to identify the event and its source. In a critical event this could cost valuable time. To minimize the time, an external user interface is connected via Bluetooth. Different options exist for the interface, like vibro-tactile interfaces hidden in a bracelet or watch, or a more sophisticated haptic belt.

V. CONCLUSION

In this paper, the authors presented the concept for an assistive technology basing on pattern recognition methods in combination with modern communication technology. Requirements for an implementation and an architecture were derived from user needs reported in literature. Center of the implementation is a smartphone, which is complemented by external devices and emphasizes a community-driven approach to enhance the performance of the used pattern recognition techniques. The presented architecture is the basis for a system that is now in development at the University of Siegen. A first software prototype was implemented on a Google Galaxy Nexus smartphone and is now in evaluation. As a first result it was shown that this phone is capable of analyzing the acoustic surrounding in real time. One cycle consisting of recording, feature generation and classification is done in 32 ms. The average power consumption is ca. 45mW, without use of the display. Power consumption of the application was assessed using the PowerTutor-App developed by the University of Michigan [15].

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