SMART PEDESTRIAN CROSSING FOR THE BLIND AND VISUALLY IMPAIRED

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***Abstract*— The aim of our research is to promote equal opportunities for the blind and visually impaired. It is indisputable that they can encounter challenges even in everyday traffic situations. An environment which is not unobstructed can make it impossible for a visually impaired person to approach it unaided. They are only able to use it independently when strict conditions are met in pedestrian crossing points without traffic control equipment. SafeXOne [1] is a smart pedestrian crossing system designed for roads without traffic control equipment. Our goal was to design an addition that supports the visually impaired in their orientation, mainly through a voice-based solution. It would allow for the proper recognition of the crossing point, i.e., the orientation of the individual. We want to help the visually impaired with supplemental light signals as well. In addition, we use the basic warning signals of the SafeXOne system to enhance security.**

Keywords— ***smart crossing, visually impaired, blind person, sound signal.***

I. Introduction

A. The goals of the project

As stated in the abstract, the main goal is to promote the safe inclusion of blind and visually impaired people in our public spaces. The project focuses on pedestrian crossings. Visually impaired people usually avoid places and routes that they consider unsafe. This may mean that a specific crossing point simply does not have any traffic control system established. In these situations, they can only rely on auditory cues. The system explained in this study offers a solution that enhances the safety of crossings and intersections that lack traffic lights.

B. Overview of the SafeXOne system

The SafeXOne smart pedestrian crossing system is a newly created traffic safety tool. It was designed with easy installation in mind, so the road and sidewalk surfaces do not need to be broken up. This allows the application to be used widely and to be set up quickly. The system is comprised of four 1m tall rectangular poles, two at each side of the crossing. The poles that are on the same side make up an optical gate that uses infrared light to detect movement. This connection allows the system to notice a pedestrian crossing the road. The two types warning signals to oncoming vehicles are the bright yellow blinkers and the laser plane projected over the crossing at ankle height. Raspberry Pi modules realize controlling of the system. This includes network communications, data collection, and remote control.

Fig. 1. Demonstration of the SafeXOne system

Figure 1. is a still image of the functional simulation of SafeXOne. Here we can observe the design and the light signals that define the base system.

II. Background Research

A. The number of visually impaired people in the population

Based on the data of the World Health Organization [2], the number of visually impaired people worldwide was estimated to be around 285 million (in 2010). This includes 39 million blind people and 246 million with less severe visual impairment. 82% of blind and 65% of visually impaired people were over the age of 50.

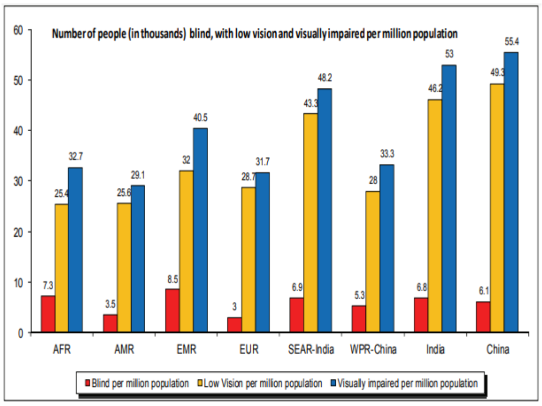

Fig. 2. Statistics of the number of visually impaired people (2010) [2]

Figure 2. visualizes the number of blind and visually impaired people according to geographical regions. It is clear that in the European region the proportion of these people is under the global average. Nevertheless, there were more than 26 million people living with visual impairment in the area at the time of the statistic.

According to the Hungarian Central Bureau of Statistics [3], [4], the population of Hungary in 2011 was 9,985,722. This included 82,484 visually impaired individuals, of which 9054 were blind. Around 61% of visually impaired and 53% of blind people are women. Furthermore, approximately 76% of visually impaired and 74% of blind individuals are over the age of 50. This illustrates that older persons are more likely to suffer from visual impairment. 15.6% of visually impaired and 18.9% of blind people live in the capital. In towns and municipalities, the proportion of visually impaired people is 64.3% whilst for blind people it is 61% [4].
Based on these statistics we can conclude that the vibrant capital city is not the most preferred choice of habitation for these individuals. The reasons for this phenomenon include the hard adaptation to the high local traffic that pose challenges for the mentioned groups.

B. *Special circumstances related to the target group's daily traffic situations*

1) *Types of visual impairment*

Several studies have been conducted to help improve the lives of visually impaired people. These studies unfold the way they sense their surroundings and their daily experiences [5]. Researching the topic can help us understand that even actions that seem mundane to us can be a challenge to a visually impaired individual. Their habits related to traversing traffic are greatly affected by the type of visual impairment that they have. The general cases are the following:

- Reduced sharpness: Most people are familiar with this concept. The main sufferers are the older generations.
- Limited field of vision (central): People with this sort of impairment can benefit from signals that they can detect with their peripheral vision.
- Limited field of vision (peripheral): Due to the loss of their peripheral vision, the individual cannot react to the other participants of traffic properly.
- Combination of reduced sharpness and limited field of vision
- Light sensitivity only: Individuals who can sense some light, for example identify the location of a strong light source.
- Complete blindness: This category includes people that cannot sense any light.

2) *Daily traffic related challenges*

In the following section we explain the challenges a visually impaired person may face that seem simple for an able individual [5].
In an unknown intersection the most important information we need is which street we are in. This is rarely displayed in a format that an impaired person can make sense of. They often need to develop a mental map of their common routes that helps them track their location. They usually achieve this by counting housing blocks or intersections. In other cases, they may ask fellow pedestrians of their current whereabouts.
A blind person has to process much information while crossing an intersection. They must figure out if their destination is straight ahead, or if they should make a turn. They need to be aware of the number of streets merging in the intersection and the width of the road. They need to know whether the curb they reached is the other side or just a safety island. These parameters are readily available to an able person. Contrary to this, blind people cannot attain the same information as they can only use their hearing. Improper or missing information might even cause dangerous situations.
Regarding the traffic control systems of the intersection, the blind person must be aware of the following:

- Type of the system
- Whether there is an integrated sound signal
- Whether the lamp is initiated by a button, and the location of that button
- Whether there is enough time available to properly analyze the orientation of the crossing before the lamp switches and they have to cross.
- Whether the specific equipment stops traffic completely or just partially.
- If a safety island is present, whether there is a second button to be pressed at the island.
- Whether there is any parallel traffic during their crossing of the road.

Attainment of all this information may be accomplished through listening to patterns across multiple signal cycles or searching for poles with buttons along the sidewalk.
Before a blind pedestrian crosses the road, they must be aware of their orientation to the crossing. Tactile ground surface indicators (if present) and auditory cues about the parallel traffic might aid the person.
In conclusion, any signal that may seem insignificant to people with normal vision can help a visually impaired individual tremendously, as they use any information that they possibly encounter.

C. *Current solutions aiding the target group*

In this section, we take an overview of the already used assistance methods for visually impaired people. This helps us identify the most dangerous situations for the individuals and the existing solutions. Furthermore, knowledge of the current technology allows us to assess whether we can integrate some of it into our system.

1) *General methods*

As an introduction, we shall list the simplest and oldest aiding techniques [5]. These are the following:

- Travel companion
- White cane
- Service dog

2) *Remote control*

A more advanced method is the use of a four-button remote control that initiates various aiding equipment in Budapest, Hungary. This remote control helps visually impaired people find traffic control lamps, start speakers at public transport stops that tell them about the upcoming buses and trams, and the ATS systems. This is used for example at Metro line 4, where it helps them find the proper escalator [6].

3) *Crosswatch*

Crosswatch [7] is a mobile phone application that helps blind people navigate at intersections using the camera of their phone. It uses machine vision to provide information to the user about the location and orientation of the intersection. The program takes several pictures in a minute, which then the phone's processor analyzes, and notifies the user via a sound signal. Tests show that the application can provide useful information to the users. Therefore, it may become a viable solution in the future.

4) *ZebraRecognizer*

ZebraRecognizer [8] is another application that uses the camera of a mobile phone. It helps the user locate the crossings by analyzing the painted road signs. It can calculate the distance to the crossing in meters and its relative position using real-time data. This information can help the person travel more safely.

III. HEARING AND ENVIRONMENTAL NOISE

In order to produce an auditory signal that aids the target group well, we must consider the nature of hearing as a signal processing method. The signal must be clear and easy to identify. To achieve this, we also need to account for the noise composition and levels that are present at the application environment. In this section, we analyze traffic noise, the detection of auditory signals, and the characteristics of the signal to be used in our system, based on the previous information.

A. *Traffic noise*

The Environmental Noise Directive [9] of the European Union mandates the creation of noise maps and noise protection action plans every 5 years for specified areas. These areas are towns of more than 100,000 inhabitants, roads, railways, and airports above certain levels of annual traffic in each member state. This measurement program in Hungary was last conducted in 2017 [10].
We can learn important information from the noise maps comprised of the data [11]. The size of the specific town and the traffic levels of the particular road pose radically different expectations for the sound signaling system of the application.

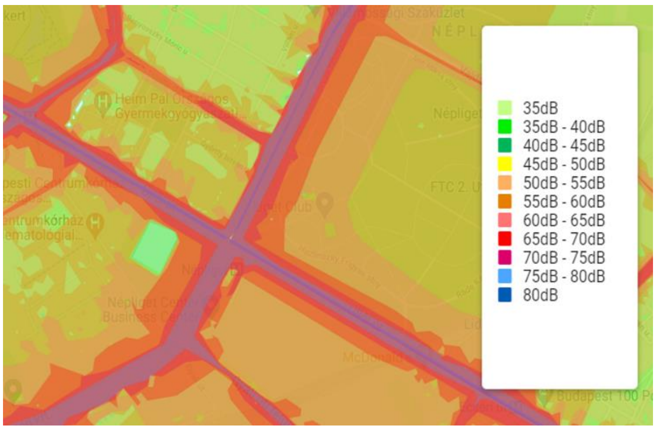

Fig. 3. The noise map of Budapest, Népliget area [11]

As it is clearly visible on Fig. 3, noise levels near a busy town road can exceed 75-80dB. In comparison, the same noise map for a less frequented small-town road (Fig. 4.):

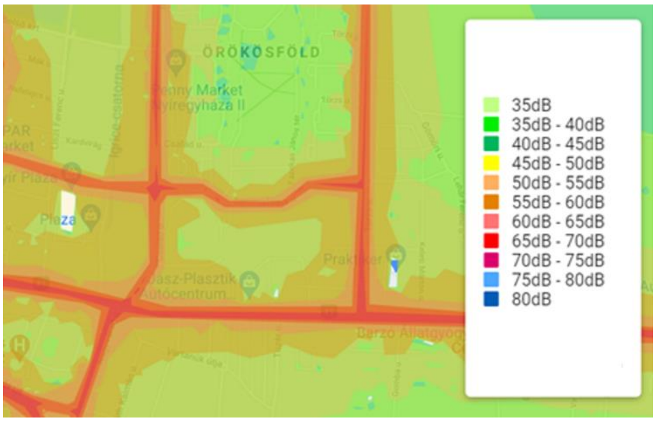

Fig. 4. Noise map of Nyíregyháza, are near Route 41 [11]

In a smaller town such as Nyíregyháza, noise levels rarely go above 70dB at the busiest roads.
It is clear, that the sound signaling system must be built in a way that it can be set up according to the noise levels of the specific application environment. This allows us to produce a signal that is loud enough to be identified, but not excessively loud, so that the system does not become irritating to the people living nearby.
Finding the lowest acceptable signal level is also important for low power consumption. Because of the logarithmic dB scale, raising the signal even just a few dBs require significantly more power (Table 1.).

TABLE I. RELATION OF SIGNAL LEVEL AND POWER REQUIRED
REFERENCE: [12]

dB	Voltage	Power	Perceived loudness
+3	1.4X	2X	1.23X
+6	2.0X	4.0X	1.52X
+10	3.16X	10X	2X
+20	10X	100X	4X
+40	100X	10,000X	16X

The quadratic relation of the voltage and power is also obvious based on (1).

$$P = I^2 \cdot R = \frac{U^2}{R} \tag{1}$$

This must be considered when picking the suitable speaker.

B. *Auditory signal processing*

In this section, we look at the parameters of sound, mainly the ones assisting localization [14].
Based on three data, we can define the position of a sound source relative to the listener in a polar coordinate system. First one is the azimuth angle, second is the elevation angle, and third is the distance of the source.

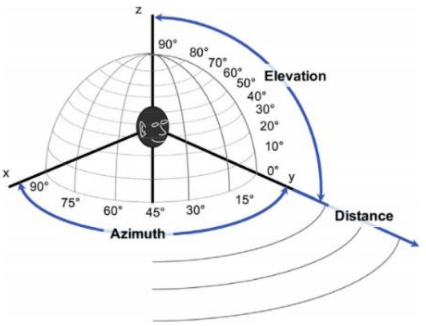

Fig. 5. Parameters of sound source localization [14]

One of the binaural cues used to determine the azimuth angle of a sound source is the Interaural Time Difference (ITD). We can observe this phenomenon on sound waves that have a wavelength greater than the diameter of the head (~17.5cm). In this range, the head causes the diffraction of the waves, and in turn, the two ears hear the sound at different times. This time difference can be expressed with Woodworth's equation (2):

$$\Delta t = \frac{r \cdot (\alpha + \sin\alpha)}{v} \tag{2}$$

Where r is the radius of the head in meters, α is the azimuth angle in degrees (-90° < α < 90°), and v is the speed of sound in meters per second. ITD is the biggest at 90° incidence angle, as this is the case where the sound waves need to travel the most distance between the two ears. Using Woodworth's equation, we can calculate that this distance is 2.57r. Taking r to be 0.0875 meters, we can use the basic equation for frequencies to see the maximal frequency in (3):

$$f_{max} = \frac{v}{\lambda_{\min}} = \frac{343}{2.57 \cdot 0.0875} \approx 1525 \quad Hz \tag{3}$$

Where f_{max} is the maximal frequency where ITD is still relevant, and l_{min} is the corresponding minimal wavelength. Thereby, 1525 Hz is approximately the biggest frequency where the phase-shift of the wave carries useful information for the brain regarding the location of the sound source.

The binaural cue that helps localization in the higher frequency range is the Interaural Intensity Difference, or Interaural Level Difference (IID/ILD). We can observe this phenomenon with sound waves that have a shorter wavelength than the diameter of the head. In this frequency range, the head blocks and reflects some of the acoustic energy (masking). This causes the two ears to perceive the sound with different intensities. Using the same approach as before, we can calculate the lowest frequency where the phenomenon is relevant (f_{min}) in (4):

$$f_{\min} = \frac{v}{\lambda_{\max}} = \frac{343}{0.175} \approx 1960 \quad Hz \tag{4}$$

In frequencies that are higher, the sound pressure level difference is the main information that helps localization of the sound source.

The distance of the sound source can be estimated using a variety of cues. For example, higher frequencies decay more over distance, and the ratio of direct and reverberant sound also carries information. Localization is easier for wide band sounds and sounds with a known frequency spectrum, such as speech (for which we also have a larger basis of comparison). The binaural cues mentioned before can also help in some cases [14].

Localization in the direction of elevation is less important for our application, so we are not going to elaborate on that topic.

It is also important to examine the perceived loudness of sounds. Sound pressure levels in decibels do not define the detectability of a sound completely. At different frequencies, we sense different sound pressure levels to be "equally loud". We can illustrate this using the equal loudness curves.

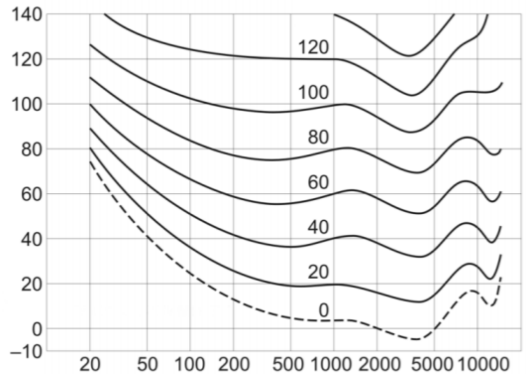

Fig. 6. Equal loudness curves (x=frequency in Hz, y=sound pressure level in dB) [15]

The perceived loudness in phons is equal to the measured sound pressure level in dBs at 1 kHz. 0 phons is the threshold of hearing. It is clear that different frequencies have a different threshold. We can also see that for example a 20 dB signal at 1 kHz and an 80 dB signal at 20 Hz are perceived to be equally loud [15].

We can see that the human hearing is quite sensitive below 1000 Hz, while localization is also adequate in this range [14]. Correlating with this assumption, other studies have shown that for traffic signal speakers 880 Hz is an ideal frequency, as it can be detected well in traffic noise, while walls and windows block it decently. This makes the signaling system more tolerable for the locals [16].

Still, we do not need to use only this single frequency. The properties of sound discussed in this section (frequency, sound pressure level) can be measured with proper instruments. Thereby, if we can integrate a suitable measuring device in our system (a certain microphone), then we can measure the aforementioned properties, and create a signal that is the most suitable for the given situation. It would allow us to dynamically alter our signal's traits, accounting for the level and composition of ambient noise in the given moment. This would make sure that the signal is loud enough, but only as loud as needed, and is not masked by the present frequencies of traffic noise. Human voice would also be a suitable signal, as our hearing is pronouncedly sensitive to it. This dynamic application method would make our system well suited to be implemented in a smart city concept.

Based on the knowledge gathered in this section, we can conclude the following requirements for the sound signaling system to be implemented into our application:

- The system needs to monitor ambient noise dynamically.
- The selected speaker must be able to operate in a wide frequency band (for example the bandwidth of speech).

We need to select devices that meet these criteria.

IV. Selecting the Devices

A. The structure of the system

The sound signaling system needs five basic components. To measure the frequency composition and sound pressure level of the ambient noise, we need a microphone. To produce the suitable signal based on the measured data, we need a wideband speaker. The subsystems also need to communicate with one another, as there are four individual poles in the SafeXOne system. Furthermore, we want to utilize the remote control mentioned in the *Current solutions* section. A signal detection device is required to facilitate the communication with this tool. Last, but most importantly, we need to integrate programmable electronics to control all the equipment that make up the system.

B. Programmable electronics

Because of the local data processing, choosing the suitable programmable electronics also defines the range of the other devices that we can use. Some equipment may not be compatible with certain electronics, and the amount of data to be sent and processed is also a major factor. Thereby, it is important to select control electronics that can accommodate most modules without significant redesign and changes. This property is especially important for the prototype stage. The most widely used such devices are the Raspberry PI [17] and the Arduino [18] products.

The Raspberry PI is basically a low power computer. Even the simplest version can run a terminal-based operating system. From a data processing standpoint, this makes the device really strong. The downside of this strength is higher power consumption. Whether such high data processing capabilities are needed is also worth consideration.

Arduino is one of the most common programmable microcontroller brands. This is partially due to the reasonable pricing, but also the open-source hardware and software. This means that with proper skills and knowledge the modules can be modified to suit a specific application (for example, there are many robotics-specific modules). The software can also be expanded with self-written extension modules, in a remarkably easy manner. This allows for a wide selection of equipment to be integrated, which makes Arduino the basis of many similar projects [19], [20].

Based on all this information, we selected Arduino (Nano 33 IoT) for this stage of the project. The choice of other devices shall be based around this decision.

C. Local communication

The system is made up of four subsystems. This necessitates communication of these devices. This communication is required at the initiation of the system (when the pedestrian uses the remote control), so that all the units receive the signal. It is also necessary during data collection. This connection is needed as it would not be efficient to equip all four units with network communication and signal detection capabilities. There are many widespread and proven wireless local communication solutions, the most common ones being WIFI and ZigBee [21], [22], [23].

The ZigBee technology is oriented towards low consumption and good security. It is suitable for applications with small data traffic.

WIFI is a well spread local communication technology. There are many modules based on this solution. Some of these applications are optimized for quick data transmission, others for low power consumption, so the options are abundant.

The use of wired communication is not viable, as roads that have been built with EU funding cannot be reworked within five years after their completion [24].

At this stage of the project, selecting the local communication tool is not appropriate. After some testing, we can have a closer idea about the amount of data to be transmitted, as well as the necessary network speed. We can select the proper device based on these pieces of information later.

D. Speaker

The basic operating principle of loudspeakers is that they convert electrical power to the kinetic energy of a diaphragm. This diaphragm in turn moves the surrounding air particles, which we perceive as sound. There are many types of transducers used today (magnetostatic, piezoelectric, electrodynamic, etc.). For our application, we plan on using an electrodynamic loudspeaker. One of the main reasons behind this choice is the close proximity of Harman-Becker Automotive Systems LLC., and VisibleCrossing LLC. The goal is the closer collaboration of the two Székesfehérvár-based companies in the future.

An electrodynamic loudspeaker is remarkably simple, consisting of just eight main components [25]:

- Pole plate: A component of the magnet system. It helps channel the magnetic flux lines through the desired path.
- Magnet: Provides a permanent magnetic field. Its material is usually either ferrite or neodymium.
- Front plate: The third piece of the magnet assembly. Like the pole plate, its purpose is to channel the magnetic flux lines to the airgap.
- Voice coil: The current passing through the coil produces a magnetic field according to Lenz's law. The coil is placed in the permanent magnetic field of the magnet assembly, so the induced field of the coil will cause it to move. Altering the frequency of the current, we can produce sound.
- Spider: The main suspension part of the speaker. It makes sure that the coil returns to its original location after the current changes.
- Basket: It is the central frame of the speaker, to which all the subassemblies are connected.
- Cone: The diaphragm that radiates sound. It moves together with the voice coil, providing a larger surface to move enough air to produce adequate sound energy.
- Dust cap: It closes the center of the voice coil, protecting it from the outer elements. It is also part of the diaphragm sources and affects the speaker's sound reproduction capabilities.

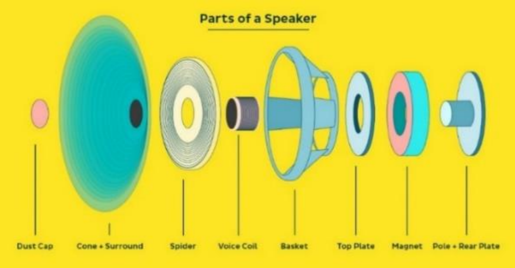

Fig. 7. Exploded view of an electrodynamic speaker [26]

This allows for an economical design with good power handling capabilities.

Certain supplemental elements may also be added to alter the sound pressure levels produced at different frequencies. Specific tonal imbalances in the frequency response can be corrected either actively (DSP software) or passively (with an RLC-circuit based filter). These solutions usually depend on the specific application. The device to be used in this certain project is not aimed to achieve the cleanest Hi-Fi sound, thereby, we might not need to resort to such extensions [25]. The directivity of the speaker might be of more interest. This can be affected using a grille or waveguide in front of the speaker [25]. The latter increases the directivity of the transducer, while it also raises the sound pressure level generated. This power increase is quite important for our far-field application. Using the industry standard measurement data of a speaker (sound pressure level at 1 meter, with 1 Watt input power) we can calculate the decrease of intensity over specific distances (5).

$$I = 20 \cdot log_{10}\left(\frac{d_1}{d_0}\right) \tag{5}$$

Where ‘I’ is the decrease of intensity, ‘d_0‘ is the referenced distance from the speaker, and ‘d_1‘ is the distance from the speaker at which we want to know the decrease. Taking a general speaker with ~85 dB_{SPL} sensitivity at d_1=15 meters, we can see that the decreased intensity is only 62 dB with 1 Watt input power. If we check Table I., we can see that regaining this loss of more than 23 dBs would require over 100 times the power. With this in mind, the 4-5 dB increase provided by a waveguide can be very useful.

Based on our requirements, the speaker should be similar to ones used in AVAS (Acoustic Vehicle Alerting System) roles, in electric and hybrid powered cars. These speakers usually have a sensitivity of 80-85 dBs. Even more importantly, they can handle whether conditions very well, due to their original application. This must be considered, as our system is continuously operated outdoors, in varying environmental conditions.

E. Microphone

One of the most important criteria of our project is to produce a sound that accounts for the dynamically changing ambient noise, so that the transferred information is always adequate to the pedestrian. To accomplish this, we need to measure the properties of the surrounding traffic noise. It is clear that perfect real-time measurement cannot be achieved, as the system’s own sound generation and the measurement of ambient noise happens close by. The solution to this is that the sound to be produced would be defined based on data collected before the specific time of initiation of the aiding signal (pressing the button on the remote control). To achieve this, we need to constantly store noise data for predefined stretches of time [27].

A microphone to be connected to programmable electronics is composed of two main parts. One is the microphone unit itself, the other is an amplifier circuit on a PCB board. The most often used microphone technology is that of an electret microphone. This is a capacitor-based transducer with a pre-polarized membrane, so there is no pretensioning needed. Due to its special makeup, its size can be particularly small. This is the reason why these microphones are the predominant choice for mobile phones. Setting the amplification correctly is key for this microphone type.

There are two main types of amplifier circuits used for this application. The first one is automatically set, where the circuit sets the gain dynamically, based on the sounds of its surroundings (mainly used for sound recordings). The second type can be manually adjusted, which allows for sound pressure level measurements, and comparison of the measured data. This second type would be suitable for our solution. The most adequate gain setup would be set based on future tests.

Fig. 8. MAX4466-based electret microphone with adjustable gain

With the reasons mentioned above in mind, we selected the MAX4466-based electret microphone with adjustable gain (Fig. 8.) [28].

F. Logical composition

Figure 9. illustrates the proposed logical connections of the components in the system. There is a one-way data transfer towards SafeXOne. The early prototype would be designed to be simple, where SafeXOne takes part in the transfer of data through internet, and supplies power to the devices.

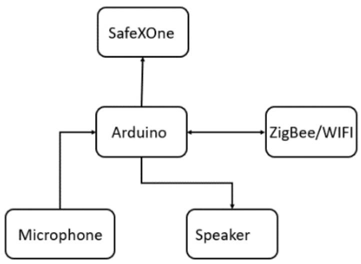

Fig. 9. Illustration of the system’s logical composition

The local communication module would either be ZigBee or WIFI. This is the unit that is responsible for the internal communication of the system, providing two-way communication between devices. The microphone sends the raw data to the Arduino module, which is responsible for the processing of this data. At the end of the sequence, the speaker produces the calculated signal.

V. Conclusion and Future Plans

To this point of our research, we collected the reasons and requirements that support the necessity of the proposed system and are needed for the creation of the prototype. The base idea is to upgrade the SafeXOne system with equipment that helps the orientation of visually impaired people at pedestrian crossing points and helps their navigation during the crossing.

To supply the necessity of the idea, we overviewed the types of visual impairment and the specific needs of aid for each type. We collected information on the existing aiding technologies, best practices in the area of traffic safety, some of which we may use to expand our system (supplemental light signal, tactile surface, etc.). We started designing the system after assessing the compiled knowledge.

In the following section of the project, we examined the question of hearing: the process of it, detection of auditory signals, sound source localization, and the information needed to select the proper aiding signal. These are all needed to select the right devices and optimize future tests and measurements.

After this research, we set up the requirements and defined the devices to be used. These are the programmable electronics, the local communication technology, the speaker, and the microphone. The devices were selected with the goal of creating a prototype and to conduct first round tests. For the programmable electronics, we selected Arduino, based on its flexible programming, as well as the open-source hardware and software. There are also some related existing solutions that further support this choice. The speaker would be a noise generator used in electric cars, based on its sensitivity, wide-band sound reproduction capabilities, and environmentally resistant structure. Last but not least, the microphone would be a MAX4466-based electret microphone with adjustable gain. This adjustment allows us to alter the amplifier circuit based on the conducted future measurements. The frequency range of the device is also suitable for our applications, while the simplicity and widespread use also makes acquiring the product easier.

The next step of the project is obtaining the parts for the prototype, composing the system, and conducting tests and measurements. The initial test would be conducted in controlled environments, while later the extension devices can be installed at currently operating SafeXOne pedestrian crossing sites.

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UAV based navigation system for forest fires monitoring

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***Abstract* — In recent years, large amount of forest has been destroyed by fires, bringing terrible consequences for the environment and society. It is important that firefighters possess an increased situational awareness about the fire spread, in order to act appropriately to prevent the fire to an uncontrollable size. Recent advances in UAV technology shows promising applications for UAVs to detecting and monitoring forest fires. Therefore, one of the most important issues is UAV's flight navigation system. In this study, we suggest a structural diagram of the UAV navigation system, which is based on radio control from a ground control panel using geolocation system. This approach provides effective application of UAV, both in automatic and manual modes by means of onboard navigation and control equipment. The results shows that the use of UAVs is an effective way of combating a fire situation in addition to existing methods and technologies for solving operational problems of fire detection.**

Keywords — aerial fire monitoring, forest fire, UAV, navigation system.

I. Introduction

In recent years there have been a significant number of wildfires that have devastated millions of hectares of forest. In addition to destroying local flora and fauna, these fires also destroy infrastructure and, unfortunately, sometimes result in human casualties among fire brigades and civilians who may be accidentally surrounded by fire. Thus, early detection and real-time fire surveillance are two key factors that allow firefighters to act appropriately to keep fires from reaching unmanageable proportions. There is a need for a less costly and more efficient way to accomplish the forestry tasks previously performed by aviation. In this regard, of particular interest are unmanned aerial vehicles of various technical equipment and flight ranges.

Unmanned aerial vehicles (UAVs) are becoming even more important for environmental monitoring, on the one hand, providing data from remote and inaccessible areas, and on the other, reducing the cost of conducting necessary research using traditional field methods, while increasing operational efficiency. Photo and video recordings obtained with the help of unmanned aerial vehicles, both with conventional and special cameras, give a complete picture of forest massifs and their condition, including information on the species and heights of trees and their exact location in accordance with the coordinates of the GPS and Glonass navigation systems, which, of course, is necessary for effective and sustainable forest management.

UAVs with computer-based remote sensing systems are an increasingly becoming an attractive and realistic option. The use of UAVs in the fire systems solves a number of problems associated with the lack of staff, the inaccessibility of areas, the need to minimize the impact of human presence, when carrying out forestry work to determine the operational and current data on the fire.

The use of UAVs at the moment is limited to special cases when solving production tasks, mainly in an experimental manner. Relevant is the development of theoretical foundations and practical techniques for organizing the effective use of UAVs for detecting forest fires with the definition of flight paths, parameters of information and command lines of communication. In addition, it is important to have spare power units or a device for recharging them in the field, as well as the required number of the most demanded spare elements of the UAV [1].

The modern level of technology has greatly expanded the capabilities of UAVs as an autonomous system of various structural forms of design and purpose. Thanks to the use of various cameras and prompt automated processing of the obtained information, such vehicles can be used to monitor the state of forests, roads, the effectiveness of forest management activities [4]. The use of computer vision technology in the remote monitoring system using UAVs will automatically detect fires in real time and warn about them. The processing of data received from the UAV makes it possible to determine the places of fire occurrence, as well as to quickly and correctly determine the coordinates of the place of fire occurrence and mark them on the terrain map. This article discusses the use of navigation control system of UAVs, which allow to perform flights for monitoring and detection of forest fires.

II. System design

A. System description

One of the most important issues in the use of UAVs for forest fire control and suppression of forest fires is the development of flight paths and flight control systems. At the same time, the built-in navigation equipment of the UAV and automatic course and vertical stabilization devices on the basis of direction gyroscope and position sensors allow to keep the body in a stable state and thus provide acceptable accuracy in determining the coordinates and direction of the forest fire on the terrain map [3]. Various methods are proposed for the precise georeferencing of UAV images, implemented by additional use of GPS navigators as part of the receiver, increasing the overlap of images [2].

Each forest fire must be monitored from the air from the moment of its detection until its complete elimination in order to take prompt action. In order to detect hidden fires, forest fires are circled 4-5 times a day. Range of fire location depends on height of observation, weather and smoke level. For the solution of this problem it is optimal to use UAVs with the flight range from 2 km to 10 km and with the flight time of 20...60 min, that corresponds to the ground patrolling.