HOST UNIVERSITY: Lund University

FACULTY: Faculty of Engineering and Architecture

DEPARTMENT: Department of structural Engineering and Building Materials

Academic Year 2022-2023

# The design of evacuation alarms for people who are deaf or hard of hearing

Anastasia Afanasova

Supervisor: Dr. Enrico Ronchi

Master thesis submitted in the Erasmus+ Study Programme

**International Master of Science in Fire Safety Engineering**

**DISCLAIMER**

This thesis is submitted in partial fulfilment of the requirements for the degree of *The International Master of Science in Fire Safety Engineering (IMFSE)*. This thesis has never been submitted for any degree or examination to any other University/programme. The author(s) declare(s) that this thesis is original work except where stated. This declaration constitutes an assertion that full and accurate references and citations have been included for all material, directly included and indirectly contributing to the thesis. The author(s) gives (give) permission to make this master thesis available for consultation and to copy parts of this master thesis for personal use. In the case of any other use, the limitations of the copyright have to be respected, in particular with regard to the obligation to state expressly the source when quoting results from this master thesis. The thesis supervisor must be informed when data or results are used.

Read and approved,

Anastasia Afanasova

11 May

# The design of evacuation alarm for people who are deaf or hard of hearing

*Anastasia Afanasova*

**Fire Safety Engineering**
**Lund University**
**Sweden**

**Report 5694, Lund 2023**

**Master Thesis in Fire Safety Engineering**

The design of evacuation alarm for people who are deaf or hard of hearing
Anastasia Afanasova

Report 5694
ISRN: LUTVDG/TVBB—5694--SE

Number of pages: 39
Illustrations:

Keywords
Alarm system, Deaf people, Hard-of-hearing people, Fire safety.

Abstract
The ability to hear is essential for receiving auditory signals, which serve as warnings and alerts in many situations, including fire evacuation. However, people with hearing impairments may miss out such signals and can be exposed to dangerous situations. This is particularly relevant in scenarios where audible alarms are the primary form of alert, such as in fire scenarios, natural hazards, or home security systems. The development of an effective alarm system for people with hearing impairments is crucial to ensure their safety and protection. The use of tactile cues can provide an alternative form of alert, which can be just as effective as audible signals. Therefore, it is important to investigate the design and implementation of alarms that can cater to the needs of people with hearing impairments and ensure that no one is left behind in fire emergency situations. This thesis introduces a prototype of a tactile alarm in which a set of key features of the vibrations can be customized. It is developed using Arduino program and is presented in two prototypes, based on either a motor or magnet system. This device is designed to facilitate testing of the effectiveness of tactile alarms for people with hearing impairments.

Fire Safety Engineering

Lund University

P.O. Box 118

SE-221 00 Lund

Sweden



Lund 2023.

**Table of contents**

## Abbreviations

**AC**: Alternating Current
**dB**: Decibels
**DC**: Direct Current
**Hz**: Hertz
**IDE**: Integrated development environment
**LVDT**: Linear variable differential transformer
**V**: Volt
**WHO**: World Health Organization

# 1. Introduction

Building fires are a significant issue around the world. In particular, according to the information of European fire safety alliance, more than 5000 individuals annually die in residential settings. Moreover, there is a strong statistic showing that the significant number of fires (around 50%) happens during nighttime, when people are typically asleep and unaware of the danger (Bruck & Ball, 2007). Therefore, it becomes clear why most of the occupants (more than 80%), who died in 114 reported fires, happened during their sleeping time (Bruck & Ball, 2007). Additionally, while some people may quickly react on the alarm signal and leave the building, it may be much more difficult for people with hearing impairments (Storesund & Glansberg, 2018).

Hearing disabilities are related to the problems with communication and exchange of information, creating an obstructive and potentially hazardous external environment (Dalton et al., 2003) and making it particularly relevant to emergency alarms. Typically, alarm systems are comprised of motorized bells, wall-mounted sounders or horns, and speaker strobes (Fagbohun & Oni, 2016). Speaker strobes are capable of emitting an alarm, which may be followed by a voice evacuation message providing information to evacuees (e.g., cautioning individuals within the building against utilizing elevators) (Crimmins, 2019). There are various frequencies and tones that can be presented, but the majority of smoke detectors utilized in residential settings emit a series of beeps with a singular high frequency of 3000 - 5000 Hz (Bruck & Ball, 2007). Unfortunately, as these traditional alarm systems rely on sound, they are ineffective for people with hearing impairments, making it difficult for them to respond quickly and safely to emergency situations (Smedberg & Ronchi, 2022).

According to the World Health Organization (WHO), there are approximately 466 million people with hearing impairments worldwide and this number is expected to rise to over 900 million by 2050. This means that around 6% of the world's population is currently experiencing some form of hearing loss. However, it is important to note that not all individuals with hearing loss identify as Deaf or hard of hearing, and there is a wide range of experiences and degrees of hearing loss within this population. As an example, in the WHO statistics the degree of hearing loss is defined as a one greater than 40 decibels (dB) in the better hearing ear in adults and a hearing loss greater than 30 dB in the better hearing ear in children. The number of people with hearing loss also changes with region (Table 1).

*Table 1 – the prevalence of people with hearing loss in different regions*

| Country | US | UK | Australia | India | Sub-Saharan Africa | China |
|---|---|---|---|---|---|---|
| Millions of people | 37.5 | >11 | 3.6 | 63 | >34 (children) | >70 |

The highest percentage of people with hearing loss in developed counties is presented in the United States - approximately 15% of adults aged 18 and over have some issues with hearing (NIDCD, 2021). Moreover, among adults aged 75 and older, about 50% have disabling hearing loss (NIDCD, 2021). In the United Kingdom this number of people is lower, but still significant - it is estimated that around 1 in 6 people have some form of hearing loss, which is more than 11 million people (links are provided in the references). Additionally, in Australia, it is estimated that approximately 3.6 million people have some form of hearing loss (link is provided in the references).

As it was mentioned before, the issues related to some degree of hearing loss affect primarily elderly people (over 65), for whom there is a high possibility of hearing loss due to the aging process (U.S. Fire Administration, 1999). Additionally, as there is high probability that elderly people have movement difficulties due to their age, meaning that they are likely to need much longer time for evacuation or even a person to help with it. Therefore, despite there is not enough data about the percentage of fatalities within the group of people with hearing impairments, it is considered representative to infer some information through elderly people statistics (Ladou, 1997). As an example, in Sweden, according to Jonsson et al. (2022), more than 50% of all fatalities during the period from 1999 to 2018 are people over 65. Moreover, the authors also stated that almost 20% of the residential fires happened during night time, from 10pm to 6am. It proves the fact that it is necessary to create an alternative alarm system, which is capable of waking up people with hearing disabilities.

Nevertheless, it is not only the aging process, which causes the hearing impairments. For example, in low- and middle-income countries, the prevalence of hearing loss is often higher due to a number of other factors. According to PAHO, one of the main reasons for hearing loss in younger age groups, especially in low- and middle-income nations, is ear infections that are left untreated, which often lead to ear discharge. Out of 76 countries that responded to the survey, less than a half - only 32 - have created strategies and initiatives to prevent and manage ear diseases and hearing loss. The report states that several countries lack trained healthcare workers, educational resources, data, and national plans to support individuals who have ear and hearing impairments.

Another mentioned issue - the lack of professionals in medical field of service - is also clearly visible in developing countries, where many doctors choose to migrate to more developed areas, causing the significant decrease of professionals in their homeland (Eastwood et al., 2005). This is especially noticed in sub-Saharan Africa, where the majority of doctors (more than a half) does not come back to this region after migration, while just nearly more than 10 percent choose the opposite (Eastwood et al., 2005).

Apart from migration trends, the significantly low number of doctors can be explained by the lack of medical schools in most of the countries. While in half of them there is only one related institution, in 11 out of 47 countries there are no medical institutions at all.

Overall, the so-called ‘barriers’ for proper medical service in the developing world include (Malkin, 2007):

a) High cost of the private healthcare services
b) Limited access to clean water and basic sanitation, and a lack of education the majority of developing countries population
c) Most medical equipment is not produced in the developing countries, but is imported from developed nations
d) Almost 40% of exported equipment cannot work due to the absence of trained personnel or necessary accessories, and almost all the equipment stops working after 5 years.

As a result, in India, it is estimated that there are approximately 63 million people with hearing loss (Ministry of Health & Family Welfare Government of India), making it one of the countries with the highest prevalence of hearing loss in the world. In sub-Saharan Africa, it is estimated that approximately 34 million children have hearing loss (Desalew et al., 2020). In China, it is estimated that there are more than 70 million people with hearing loss (Wiley Online Library).

Overall, the prevalence of hearing loss can vary widely within a country and such factors as age (Xuewen & Jianbo, 2021), gender (Michikawa et al., 2009; Corazzi et al., 2020), and socioeconomic status (He et al., 2018; Emmett et al., 2015; Nakahori et al., 2020). Nonetheless, these estimates show that hearing loss is a significant public health issue that affects millions of people worldwide, and highlights the importance of developing effective solutions to address this issue. However, it is important to know that the estimates presented in the Table 1 are often based on self-reported data and may not accurately capture the full extent of hearing loss in these populations.

There are various technologies that have been developed to assist people with hearing impairments in being alerted in case of emergency. Smedberg & Ronchi (2021) provide an overview of various technologies that have been developed to assist people with hearing impairments. They discuss a variety of technologies, and overall suggest that tactile alarms may be the best option for alarming people with hearing impairments. As a result, this project is focused on the design of a tactile alarm prototype, in which vibrations can be systematically modified in order to evaluate their effectiveness.

According to Smedberg & Ronchi (2021), tactile alarms work by converting sounds into vibrations that can be felt by the receiver, and these alarms have several advantages over other types of technologies. First, tactile alarms can be used in a wide range of environments, including noisy environments where sound-based alarms may not be audible. Secondly, tactile alarms can be used during sleep, ensuring that the user is alerted by alarms even while sleeping. This applies to both regular alarms to wake up in the morning and fire alarms. Third, tactile alarms can be customized to the specific needs of the user, including the intensity and pattern of vibrations. Additionally, tactile alarms can be used both by people with or without hearing impairments.

Additionally, it was noted that tactile alarms have been found to be more effective than other types of alarms in a variety of settings. As an example, according to Bruck et al. (2007), tactile alarms were more effective than visual alarms in waking up people with hearing impairments. As a result, it was decided to focus on tactile alarms in this report and, especially, on bed shakers in order to provide a solution for alarming people with hearing impairments.

## 2. Background

Vibrating alarm systems can not only be used in emergency situations, but also in everyday life, to wake up people in the morning (Desselle & Proctor, 2000), (Kelly, 2017). These systems typically include the bed shaker, which is based on the vibrating motor and is connected to the alarm clock. Therefore, when the desired time comes, the alarm system starts working, creating the vibration, which wakes person up. Nowadays, these vibrating mechanisms are also used in other systems, including fire alarm. The working principle remains the same, but now the person is awakened due to emergency situation – fire presence.

Fire alarm bed shaker systems can be either hardwired or wireless. Hardwired systems are typically more reliable, as they are also equipped with the backup battery. Wireless systems can be more flexible in terms of placement, but they may be less reliable.

There are several examples of fire alarm bed shaker systems that are currently available on the market. This section presents a set of examples of such system, but it is not deemed to endorse any particular system, but rather to facilitate the understanding of what is commercially available on the market and examples of their functionalities. One such system is the Bellman & Symfon Visit Smoke Alarm Transmitter combination (presented by Figure 1), which is manufactured by Bellman & Symfon (Bellman & Symfon website).

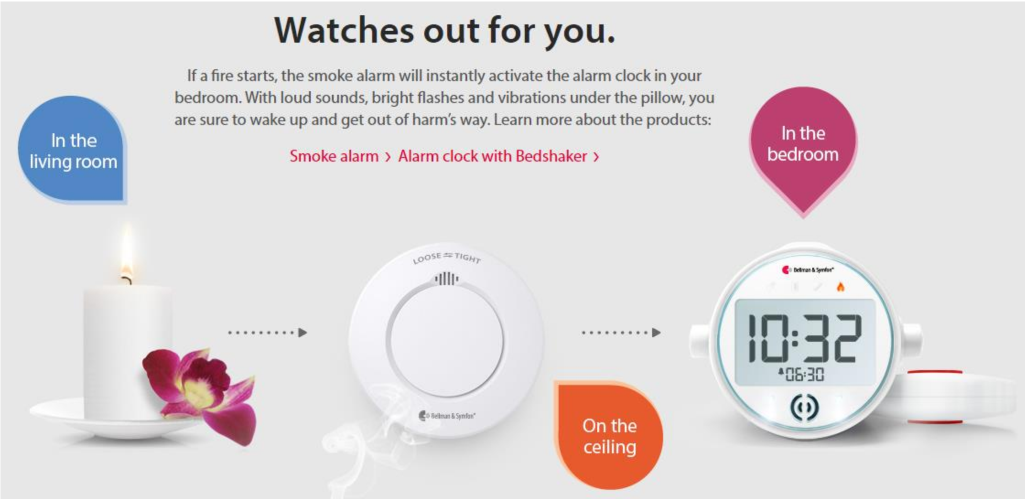



*Figure 1* – Example of fire alarm of Bellman & Symfon company. (The image is taken from: https://bellman.com/en/our-solutions/visit-smart-home/)

Another example is the SafeAwake Fire Alarm Aid (presented by Figure 2), which is manufactured by SafeAwake (SafeAwake Smoke Alarm Aid website). This device includes a bed shaker, as well as a built-in microphone that listens for the sound of the smoke alarm. When the smoke alarm is detected, the device activates the bed shaker and a voice alarm that says "fire, get out." Other companies that manufacture bed shaker alarm systems include Silent Call Communications, DEAFGARD and Lifetones Technology (DEAFGARD and Lifetones Technology websites).


*Figure 2* – SafeAwake Fire Alarm Aid (The image is taken from: https://www.safeawake.com/)

Some experimental work has been conducted on the effectiveness of bed shakers in the awaking process of people with hearing impairments. Smedberg & Ronchi (2021) provided a full review on the existing research, where the bed shakers were used during different sleeping stages of these people. Overall, most of the participants woke up in some time from just some seconds to 4 minutes after the vibration started working, proving that the vibration is an effective solution for waking up people with hearing impairments. The authors also highlighted the fact that, although there are existing standards, which can be applied for vibrating devices, they are more often focused on its vibration itself, rather than on how they are received by people or how these devices should be installed. For example, UL 1971 standard provides the requirements regarding the frequency of vibration and cross section of vibrating device, but gives no information about how and where this device should be installed. Therefore, protocols for the testing of vibrating alarms in relation to installation settings are recommended to be provided in future.

## 3. Aim and objectives

The purpose of this thesis is to design a vibrating alarm in order to have the opportunity to warn people who are unable to hear the alarm sound about a fire. In addition, the scope is to be able to deliver vibrations that can be customized so that a testing protocol considering the installation setup of the alarm can be developed in the future. While the most common and used type of fire alarm is accompanied by a loud sound, it is not the option for people with hearing impairments. This is why there is a need of new alarm system development. It is also important to mention that some devices using this working principle already exist in the market, but there is no information regarding their testing on sleeping people or any opportunity to systematically change the vibration parameters.

The objectives of the thesis are therefore:

1) To analyze the existing market of vibrating alarms for people with hearing impairments, including different types and installation setups.

2) To identify key variables affecting the design of vibrating alarms and the delivered tactile stimuli.

3) To develop a prototype of vibrating alarm (either by customizing an existing commercial alarm or developing a brand-new system), which allows modifying vibration parameters to be able to test their effectiveness in a systematic way.

4) To describe how a vibrating mechanism is meant to work with a detection system (presented in a form of smoke sensor in this thesis) in two prototypes.

## 4. Delimitations

This work is mostly focused on the construction and development of the prototypes of a vibrating alarm communicating with a smoke sensor in which the key variables affecting their effectiveness in waking up people with hearing impairments can be manipulated. The tests of the device on people are expected to be the next stage of the work and, therefore, are not considered here.

It is also important to mention that these prototypes are not presented as the final product version, but as a proof-of-concept of customizable vibrating alarm systems for people with hearing impairments. Therefore, they are expected to be improved in future research, meaning the possibility of being connected not only with a fire alarm (as it is presented in this thesis), but also to any other alarm systems.

There were different technological solutions for creating a vibrating device, including the use of the vibrating motor, an amplified signal to the magnet or speaker system, and vibration generator. Nevertheless, due to the scope of thesis, time limits and the proof that the bed shakers and low frequency sound are the most effective in waking people up (Ashley, 2007), it was decided to limit these options to the first two, which were affordable and with components easily available on the market.

The alarm system under consideration (including both prototypes) is expected to be used in hotels and, potentially in the future, in residential buildings so the main installation of the device will be chosen systematically in a way to ensure an effective waking of sleeping people in beds. Thus, the design of this alarm is developed in connection to its future use in a bed setup.

Finally, it should be noted that in this thesis no vibration measurements were made in relation to both created and actually delivered vibrations. The reliability assessment is also not provided and recommended for the future research.

# 5. Theoretical background

In this section, an introductory description of the vibration concept is discussed. The section starts with the short history of the vibration exploring process – how people of different centuries were trying to understand its mechanism and how it could be used in their everyday lives. Afterwards, there are several subsections, describing the vibration from the different points, including the explanation of its working principle, parameters, types, the methods of creating and measurement. All this theory was necessary in order to understand how the intended vibrating alarm system was expected to work and what were the options of creating both prototypes.

## 5.1 What are vibrations? Historical background

Vibration is a phenomenon that affects many aspects of our lives. From the small-scale vibrations of the mobile phones to the large-scale ones - in bridges, buildings (Shabana, 2019), and vehicles (some of these examples are shown in Figure 3). Understanding the nature of vibrations and their effects is quite important for different fields – from geology to architecture.

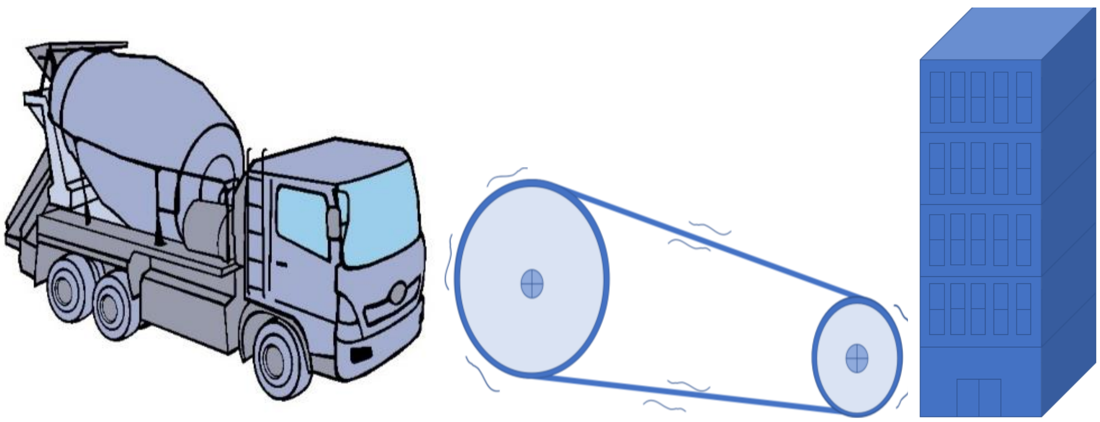


Figure 3 – from left to the right: vehicle systems (transport mean), mechanism system (industrial belting), multistory building

Vibrations can be both harmful and useful. On one hand, they can cause damage and failure to structures, machines, and other systems, leading to significant safety and economic consequences (Klinger, 2014). On the other hand, vibrations can be harnessed for various applications, such as in musical instruments, medical devices, and industrial equipment (Binti Abdul Manaf & Bt Sulaiman, 2015). This report includes exploring both the history, nature, and applications of vibrations, as well as the methods and tools used to measure and analyze them.

The history of vibration research started in the 5th century of BC with the Pythagorean school in Croton – the high education institution in Italy (back then Magna Graecia), which worked primarily on the numbers and music theory (Dimarogonas, 1990). Although most of his knowledge was lost due to the absence of written records, some pieces were found later in the Greek literature and translated, which allowed to analyze the vibration path to its actual concept.

The first mention of the 'vibration' term was at the time of Platon (around a century after Pythagoras) (Stahl et al., 1949), but this phenomenon was noticed long before. Pythagoras' school observed a strong connection between the sound and vibration and, therefore, was trying to study it. Pythagoras himself produced some experiments and proved that the resulted vibration of the taut spring depends on its length. Later, the study of vibration continued with Galileo (the beginning of XVII century), who noticed the difference in frequencies of a pendulum depending on its length (Shabana, 2019). Continuing his work, I. Newton created the second law of motion in 1687, which provided a way to describe in vector form the motion of the vibrating systems. That was an important part in understanding their working principle and formed the basis for the expressions of J. L. Lagrange (XVIII century), which were used for description of vibration systems with more than one degree of freedom.

Meanwhile, another significant contribution was made by R. Hooke, who created the law of the elasticity (1660) to show the connection between the stress and strain of any deformable body. It showed that these two units are fully proportional to each other. Following this law, D. Bernoulli and L. Euler examined the beam vibration, which led to a joint development of the beam theory of bending in 1750.

Finally, after more than a century, in 1877 professor J. W. Strutt (also known as Lord Rayleigh) created the modern theory of mechanical vibration and developed an approach to find the vibration frequency using the energy conservation law.

**5.2 Vibration basics**

As was discussed before, the designed alarm system is based on vibration technology, and, therefore, it is necessary to start with the basics of the vibration process. According to Mobley (1999), a vibration can be defined as ‘a periodic motion or one that repeats itself after a certain interval of time’. It occurs when a system is disturbed from its equilibrium position and the resulting force causes the system to oscillate. The motion of the object is back and forth or up and down, and the speed, displacement, and acceleration determine the vibration characteristics (Mobley, 1999), (Chaurasiya, 2012). The time after which the vibration repeats its cycle again is called the period of vibration (T), and the inversed form of this unit is denoted as frequency. The first is measured in seconds, and the second – most often in Hertz (Hz). The maximum displacement of a wave from its equilibrium position is called the amplitude ($X_o$), as shown in Figure 4.

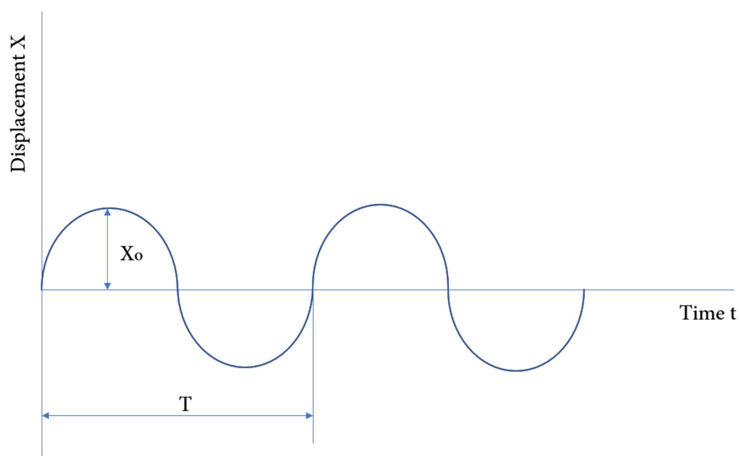



Figure 4 – Example of small oscillations of a pendulum where Xo is the amplitude and T is the period of the vibration.

### 5.3 Vibration types

There are various types of vibrations. One of the most common classifications are *linear* or *non-linear* or *angular* vibrations, where in the first type the vibrating object is moving in a straight line, while in the second it is rotating (Shabana, 2019; Rayleigh, 1969)**.** Another way of classifying vibrations is based on its frequencies. Low-frequency vibrations are within the 20 Hz limit, while high-frequency vibrations are those which exceed this number (Galchev et al., 2011). Vibrations can also be categorized as either *random* or *periodic*. Random vibrations are those that occur in a seemingly unpredictable pattern, such as the vibrations caused by rough road surfaces when driving (Galchev et al., 2011). In contrast, periodic vibrations occur in a repeating pattern and are often caused by regular cycles of motion, such as the vibrations produced by a tuning fork or a guitar string.

According to Ashley (2007), it was noticed that the intermittent vibration (repeating the three-pulse pattern) is 100% effective in waking up people with hearing impairments. The continuous vibration, on the contrary, was less effective, awaking from 82 (hard of hearing) to 93% (fully deaf) of the participants. one possible reason for this, according to the replies of participants, was the fact, that this kind of vibration is used regularly, on the everyday basis. Therefore, the users were not identifying it with the emergency situation.

### 5.4 How to create vibrations

The method of creating vibration strongly depends on which kind of vibration is needed. Overall, there are four main categories of vibration:

1. *Mechanical vibration*. It can be created by shaking or oscillating an object. This can be done manually, with a tool or machine, or with an electric motor. (Schmitz & Smith, 2021)
2. *Electromagnetic vibration*. It can be created using an electric current that passes through a coil or magnet, which causes the coil or magnet to vibrate. (Xu et al., 2018)
3. *Piezoelectric vibration*: Piezoelectric materials produce a voltage under mechanical stress and vibrate after connection to the electric current. This effect is used in piezoelectric transducers to create vibrations (Fakhzan & Muthalif, 2013).
4. *Sonic vibration*: Sound waves can also be used to create vibrations. It can be done by using a speaker or other audio device to generate sound waves that create vibrations (Evens, 2002).

For the designed alarm system, the mechanical type of vibration is produced by the first prototype and electromagnetic vibration – by the second prototype.

### 5.5 How to deliver vibrations

Another important point to consider in this thesis project was to understand how vibrations can be transmitted in different materials. As the main object where the device could be installed is the bed, wood and foam materials were checked, as they are expected to be the main components of a typical bed.

Zhang et al. (2015) made a test for checking how the vibration transmission changes with the foam thickness. In order to do this the authors involved 12 people from 24 to 56 years with 50/50 gender distribution. These people were sitting on the foam seat, which was put under the random vibration from 0.5 to 20 Hz. Overall, the results showed that the resonance vibration frequency was decreasing with the increase in foam thickness, for the case of vertical vibration, from the bottom the seat pan. The coherency between the acceleration of the foam surface and the seat pan was calculated through the division equation of these two values and the result was 0.9.

According to Dünisch (2017), the ability of wood to transmit vibrations depends on two physical properties: the density and elastic modulus, and on some characteristics – grain of the fiber or structure. The author chose 91 different wood samples and tested them using the pendulum to create impulse for vibration. Afterwards, the resulted vibration was measured by the laser sensor (3 times minimum), and, for the case when the vibration was provided from the bottom side of the horizontal wood surface, the conclusion was that:

1) With an increase of the wood thickness there was a negligible decrease in vibration frequency, but the vibration amplitude and its duration decreased much more;
2) Vibration waves are quite clear and strong for softwood in the vertical direction (from bottom to upper layer of horizontal wood sample).

Overall, the author divided all the wood species in four groups, based on the type of the wood, its growth rings and rays' characteristics (more information about it can be found in Dünisch (2017)). For the first group of the samples, a low frequency, but longer duration was noticed. For the second group – low vibration frequency also was noticed. In the third group, quite high vibration frequency and short duration was mostly detected. For the fourth group, the differences in all the vibration parameters were too high to be comparable.

### 5.6 How to measure vibrations

Since the early 1900s, there has been gradual development of the technology for testing vibration sensors – devices converting vibration into electrical signals. Scientists have been exploring and researching, leading to the evolution and maturation of test methods and types of sensors (Cao et al., 2012).

Vibration measurements typically involve measuring displacement, velocity, acceleration, and other parameters and in recent years these measurements have become an important tool for researching, designing, and maintaining mechanical structural products. As a result, the creation of various types of sensors followed.

Goyal and Pabla (2016) provide a comprehensive overview of the various devices used for measuring vibration and his findings are here summarized. All the devices can be classified into three categories and are presented in Table 2 with examples.

*Table 2 – Devices for vibration measuring*

| Contact-based devices | Non-contact-based devices | Hybrid devices |
|---|---|---|
| Accelerometers, velocity sensors, displacement sensors | Laser vibrometers, fiber-optic sensors, acoustic emission sensors | Combine features of both contact-based and non-contact-based devices |

For each of these devices the details, advantages, and limitations are discussed below.

a) ***Accelerometers*** are contact-based devices used to measure vibration, and they are among the most commonly used vibration sensors (Mobley, 1999), (Goyal & Pabla, 2016).

In order to measure the vibration this device is needed to be installed on the sample and connected to a portable vibration analyzer (or monitor) (Mobley, 1999). The basic principle of accelerometers is that they measure acceleration, which is proportional to the vibration level (Faisal et al., 2019), (Goyal & Pabla, 2016). Accelerometers consist of a mass-spring system that moves in response to the vibration. The movement of the mass generates an electrical signal that is proportional to the acceleration. The electrical signal is then processed to obtain the vibration level.

Accelerometers are preferred over other vibration sensors because they provide a direct measurement, have a wide effective range (from 1 to 10000 Hz) (Mobley, 1999), and are relatively easy in terms of installation. However, their main limitation is that they are sensitive to temperature changes and may require temperature compensation to maintain accuracy.

b) ***Velocity sensors*** are contact-based devices used to measure vibration, and they are among the most commonly used sensors for measuring low-frequency vibrations.

These sensors measure the velocity of the vibrating surface by using a magnet-coil. The sensor consists of two main components: 1) a permanent magnet, which is attached to the vibrating surface and 2) a coil, which is fixed to the frame. As the magnet moves, it produces a voltage in the coil, and this voltage is proportional to the velocity of the vibrating surface. After processing this voltage' signal, the level of vibration can be detected.

Velocity sensors could be preferred over accelerometers (in case of low-frequency vibrations) because they provide a direct measurement of velocity and do not require any temperature compensation, unlike accelerometers. However, they are not suitable for high-frequency vibrations, as the mass of the magnet can affect the vibration measures.

c) ***Displacement sensors*** are contact-based devices used to measure vibration by directly measuring the displacement of the vibrating surface.

Displacement sensors measure the change in distance between the vibrating surface and a fixed reference point. The sensor consists of a probe attached to the vibrating surface and a displacement transducer. The second one is there to measure the distance from the probe to the reference point. It can be presented in a form of a linear variable differential transformer (LVDT) or a capacitive sensor. The voltage signal generated by the displacement transducer is proportional to the displacement and is processed to obtain the vibration level.

Displacement sensors are preferred over accelerometers and velocity sensors for low-frequency vibrations because they provide a direct measurement of displacement, which is proportional to the vibration level. However, displacement sensors also have some limitations. First, they are more expensive than the other types of vibration sensors. Secondly, they require careful installation in order to avoid errors in the measurement. Additionally, displacement sensors may not be suitable for high-frequency vibrations, as the measurement accuracy may be affected by the mass of the probe.

d) ***Laser vibrometers*** are non-contact devices used to measure vibration by detecting the Doppler shift of laser light reflected from the vibrating surface.

These sensors measure the velocity of the vibrating surface using a laser beam. The laser beam is directed to the surface, and the reflected light is detected by a photodetector. There appears the frequency shift of the light (due to the Doppler effect), and this shift is proportional to the vibration velocity.

The laser vibrometers could also be preferred as there is no contact with the vibrating surface. However, laser vibrometers are more expensive require careful alignment for accurate measuring. Additionally, laser vibrometers may not be suitable for rough or curved surfaces, as the laser beam needs a smooth surface in order to allow reflecting from it.

e) ***Fiber-optic sensors*** are non-contact devices that use optical fibers to measure vibration by detecting changes in the intensity, phase, or polarization of light transmitted through the fiber.

Fiber-optic sensors measure the changes in the properties of light, which is transmitted through the fiber caused by its vibration. The optical fiber is typically a single-mode fiber that transmits light, which is then either reflected back to the source or transmitted to a detector – this depends on the type of used sensor. The changes in the fiber optical properties are then measured in order to obtain the vibration level.

Fiber-optic sensors could be preferred over other types of vibration sensors for their non-electrical measurement and high vibration sensitivity. However, fiber-optic sensors are also very expensive and require careful installation. Additionally, they may not be suitable for high-frequency vibrations.

## 6. Method

Several methods were used to search for information for this thesis research. First of all, as my supervisor had already conducted research on alarm systems for people with hearing impairments, he provided an initial list of sources and standards for review. Another approach was to perform a search of literature using keywords related to the scope of the thesis, such as: "vibration principle", "vibration types", "theory of vibration", "means of vibration measurements", "deaf and vibration", "alarm for deaf". The search was done both in scientific databases (including Web of Science, ScienceDirect, Scopus) and by using search engines (such as Google Scholar and LUBsearch) and screening was performed by the author to identify the most relevant literature to the scope of the thesis.

Overall, approximately 50 papers were read, including mostly articles published in scientific journals and books.

### 6.1 Idea

The main idea of this thesis research was to create a vibrating alarm system allowing to manually or via a program regulate its vibration parameters for future testing with people with hearing impairments. In order to do this, first of all, it was important to choose the vibrating component for the future alarm system. During the first meeting with the supervisor regarding the options for the developing this alarm, two types of vibrating device were discussed: 1) to use a motor-based device, ordered from those available on the market; and 2) to use a magnetic device in order to create vibration. After checking different alternatives, these two devices were chosen and ordered for several reasons:

1. The size should be compact, meaning that the final alarm system would also be of a manageable size;
2. The price of the device was affordable;
3. The device allowed for customization of its vibration;
4. Based on existing examples of use the chosen devices, the probability to create working prototypes was high.

Regarding the advantages and disadvantages of these two devices, the following are considered: first, the magnet-based device is more reliable due to having a longer life span than the motor-based device. As the first has a magnet inside, which works constantly without any issues, the motor, instead, can be broken due to wear out, for example. Secondly, as its work based on the alternating current (AC) supply, magnet-based device can be used in connection with the amplifier, where its vibration parameters can be regulated. It is also possible to control the magnet-based device through a software, meaning that chosen vibration parameters can be more precise. Motor vibration, instead, depends on its speed, which can be regulated by the applied voltage. It is, therefore, easier to change the voltage than use an amplifier or specific software, as it is needed for magnet-based device, but the intensity will not be as precise as the one, done in program.

Therefore, after a discussion concerning the available options on the market, the chosen items were ordered. It should be noted that those were not the only devices providing the required characteristics for the prototype and they should be considered only exemplary for the scope of the thesis.

### 6.2. Getting started

The next stage was to explore the knowledge concerning how to connect a vibrating device to a smoke sensor (a standard MQ2 smoke sensor[1] was used in this research) in order to demonstrate a fully functional alarm system, which becomes activated by smoke reaching this sensor. For this purpose, the Arduino hardware and software components were expected to be used, in addition to the vibrating devices and a relay module.

### 6.3 Conceptual design

The desired alarm system is predicted to be presented in two ways – with the use of the motor-based (mechanical vibration) and magnet-based (electromagnetic vibration) vibrating mechanisms. The suggested prototype solution is presented in Figures 5 and 6.

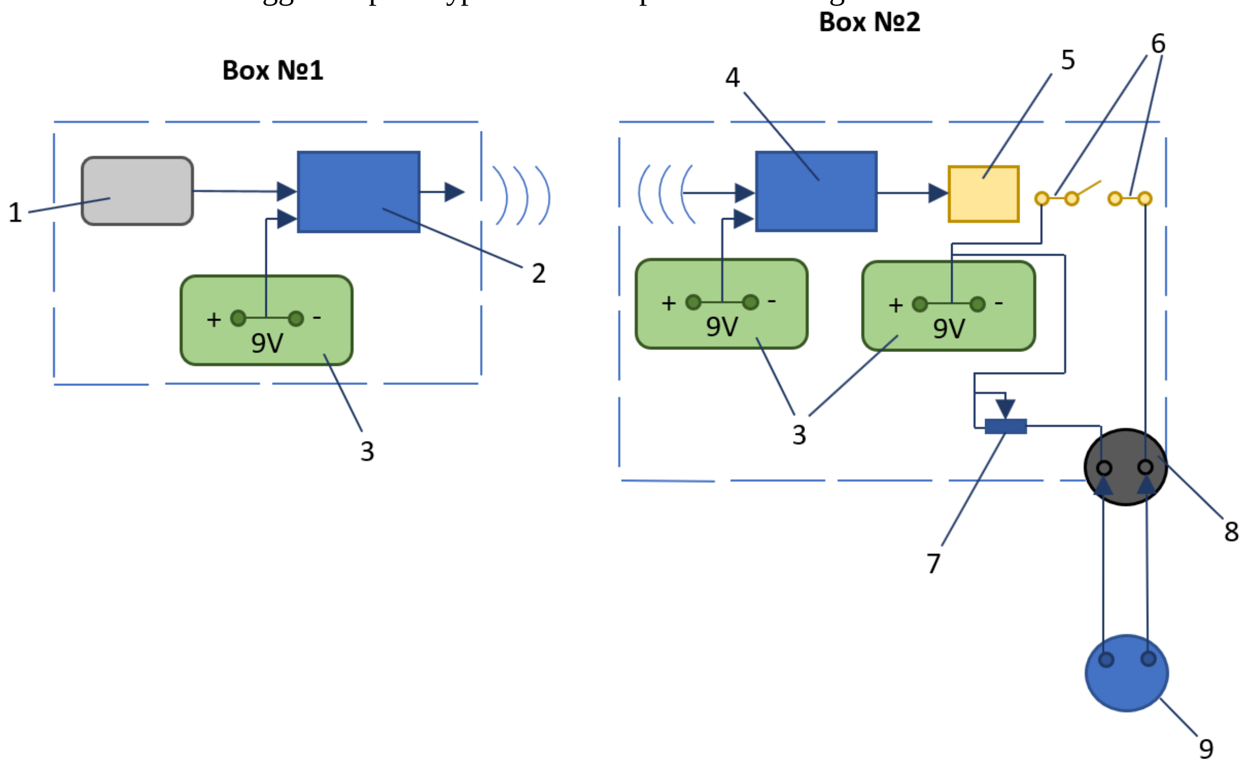



*Figure 5* – The drawing scheme of the prototype №1 in which a motor-based vibrating mechanism is adopted.

Where:

1 – MQ2 smoke sensor
2 – Converter (transmitter of the signal)
3 – DC power supply
4 – Converter (receiver of the signal)
5 - Relay
6 – Relay contacts
7 – Amplitude and frequency control
8 – Detachable connection
9 – Motor-based vibrating device

[1] https://www.amazon.se/AZDelivery-luftkvalitetsmodul-kompatibel-Arduino-inklusive/dp/B07CYYB82F/ref=asc_df_B07CYYB82F/?tag=shpngadsglede-21&linkCode=df0&hvadid=476618280365&hvpos=&hvnetw=g&hvrand=8208915166995899371&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=1012442&hvtargid=pla-752138925519&psc=1

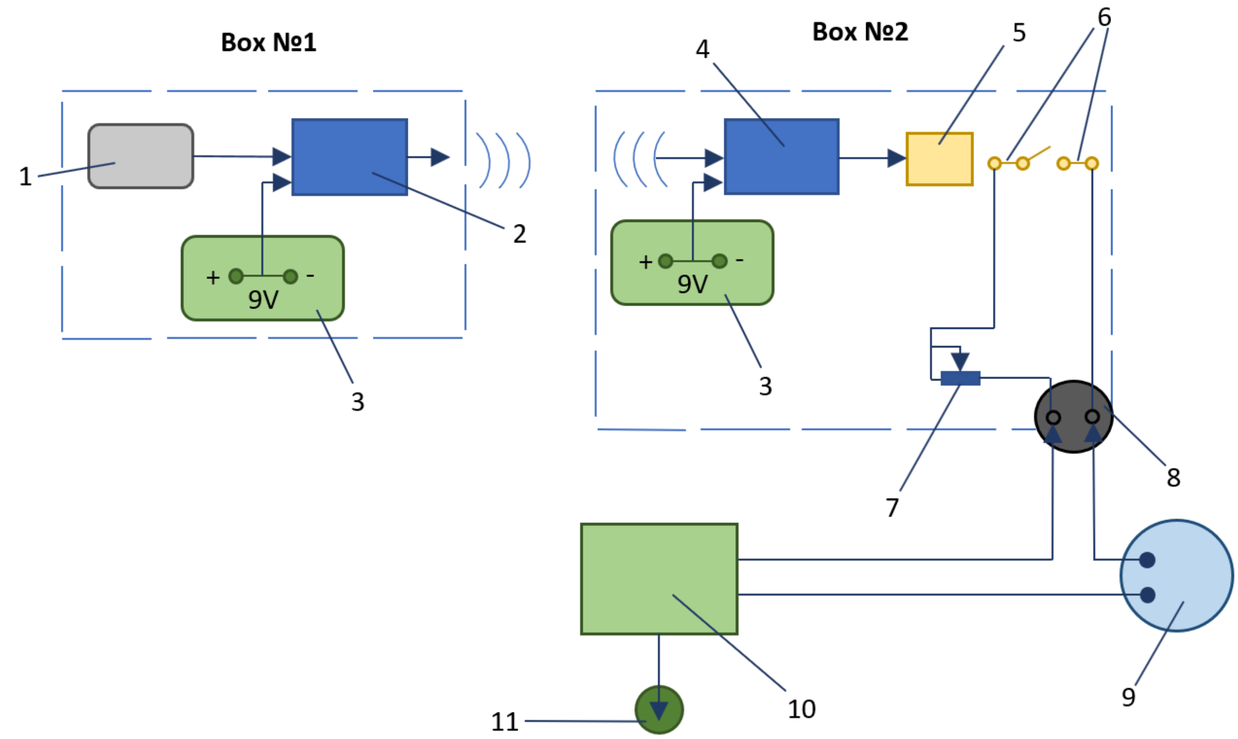



*Figure 6* – The drawing scheme of the prototype №2 in which a magnet-based vibrating mechanism is adopted.

Where:

1 – MQ2 smoke sensor
2 – Converter (transmitter of the signal)
3 – DC power supply
4 – Converter (receiver of the signal)
5 - Relay
6 – Relay contacts
7 – Amplitude and frequency controller
8 – Detachable connection
9 – Magnet-based vibrating device
10 – AC power supply
11 – AC network ~220V

Both systems are expected to work in the following order:

1) In the presence of smoke, the signal of the specific frequency is created
2) This signal is converted and transmitted from the Box №1 to the Box №2
3) In the Box №2 this signal is again converted and proceeded to the relay
4) After the fourth step, the relay contacts become closed so the current can follow to the next parts

Depending on the type of vibrating mechanism, either the motor-based or magnet-based device starts working and creating vibrations of different intensity, regulated by the controller.

**6.4 Development**

In this section, the development of the two prototypes of the alarm system for people with hearing impairments. It includes the official name presentation, the working principle of both prototypes and the development from the original idea, presented in the sketches, to the actual working devices.

### 6.4.1 Presentation

According to the thesis project task, the alarm system for people with hearing impairments was constructed in two prototypes. It was decided to name it as “Three ‘A’ alarms”, meaning the following: “Attention-Alarm-Action”. Therefore, the final short names of the devices are: AAA_1 (for the first prototype) and AAA_2 (for the second prototype).

### 6.4.2 Prototype working principle

The prototype mechanisms were developed in accordance with the Figures 5 and 6 presented in section 6.3. There are two vibrating devices, which were used in the prototype models: the first prototype is motor-based and the second one is magnet-based. There were two boxes: 1) 10*10 cm box presented in the form of a standard smoke detector (see Figure 7), and 2) a box of 15*7 cm size (see Figure 8).

The Box №1 is used with the same construction for both prototypes and consists of the standard smoke sensor MQ2, a converter (transmitter of signal) and DC power supply in a form of 9V battery (PAIRDEER 2PCS as a used example). The Box №2 consists of a relay, a converter (receiver of signal), a controller of the amplitude and frequency of vibration and DC power supply in a form of batteries.

The components of Box №2 are similar for both prototypes with the only difference in the number of batteries used. So, while in the first prototype model (with the use of a motor-based device) two batteries are needed, in the second one (with the magnet) – only one battery is used.

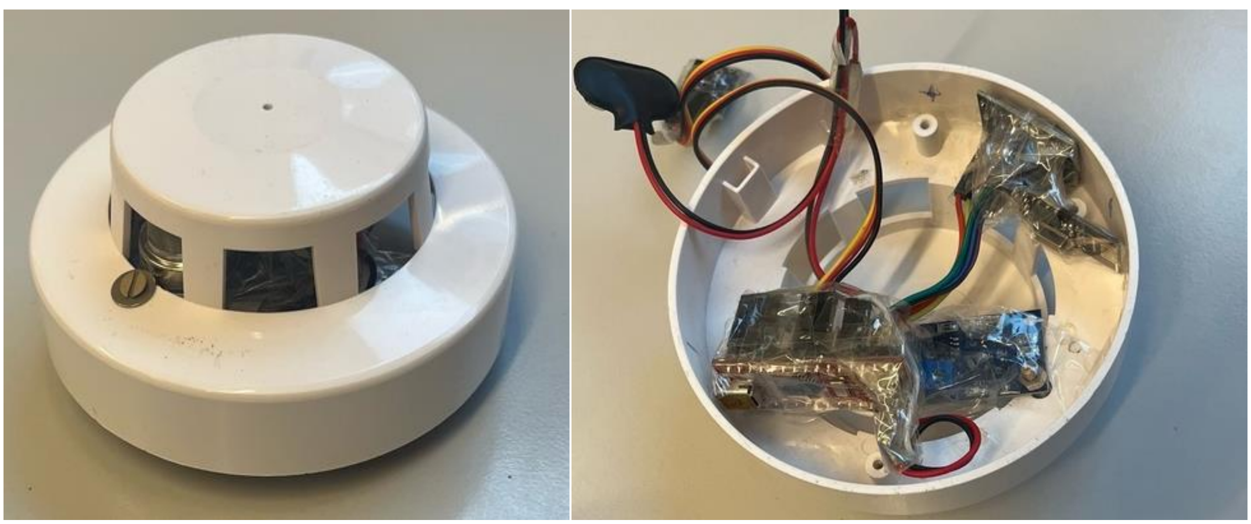


*Figure 7* – The closed and open view of Box №1 including the smoke sensor, converter and DC power supply.

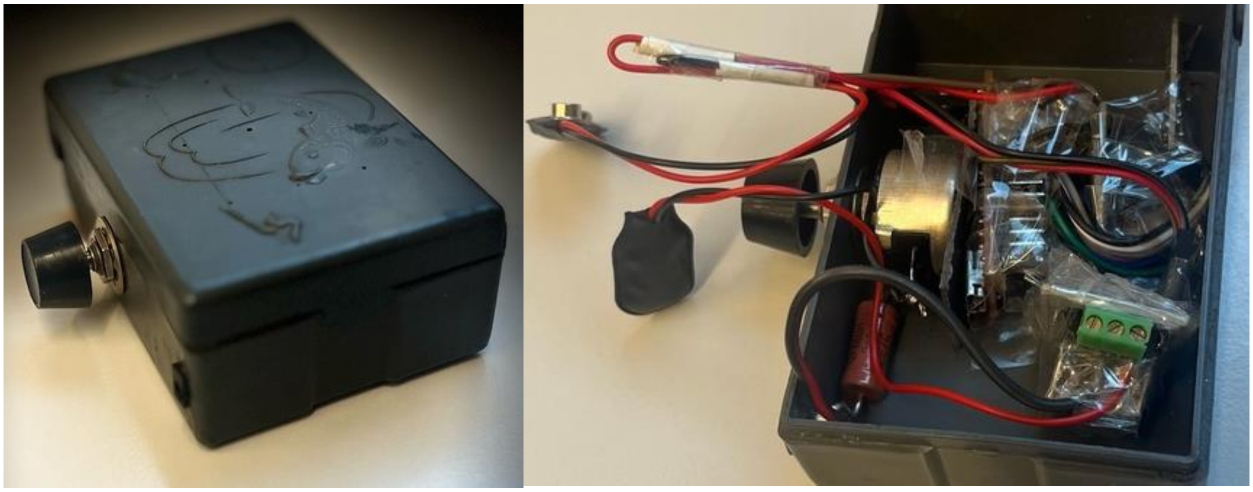


*Figure 8* – The closed and open view of Box №2 including a relay, a converter (receiver of signal), a controller of the amplitude and frequency of vibration and DC power supply.

The working process starts with the detection of the smoke by MQ2 smoke sensor and signal generation. This signal comes to the converter-transmitter, where it is processed and transmitted to the converter-receiver of Box №2. It is important to mention that the smoke sensor and converter-transmitter are supplied by the standard 9V battery mentioned above.

After the signal was received by the converter in Box №2, it goes to the relay, which contacts are normally open, but become closed in the moment the signal reaches them. Here the converter-receiver – similarly with the converter-transmitter of the Box №1 – is supplied by 9V DC power supply. The relay contacts are used in order to turn on the motor-based vibrating device 5 x 9 cm (which uses DC power to work), which is connected to relay's electrical circuit. Additionally, this circuit includes a DC power supply, powering both the motor-based vibrating mechanism (Figure 9) and its amplitude/frequency controller.


*Figure 9* – Motor-based vibration device[2].

The second prototype uses the magnet-based vibration device of 12 cm depth (D) x 12 cm width (W) x 3 cm height (H), which, in contrast with the first one, uses AC power supply. As a result, in order to use this device, a separated power supply is needed, using 220V AC network power. Therefore, AC voltage is applied to the magnet-based vibration device (Figure 10), which is also connected to relay contacts. In this case, same as in first prototype, in the presence of smoke relay contacts become closed and turn on the second vibrating mechanism. Additionally, in both prototypes it is possible to change the amplitude and frequency of vibration in the device by twisting the controller based on the outside of the Box №2.

*Figure 10* – Magnet-based vibration device[3].

[2] https://www.amazon.com/vibrating-Shaker-Sleepers-Hearing-Seniors/dp/B0814VCL7T/ref=psdc_1063278_t3_B000OOWZUK?th=1
[3] https://www.amazon.de/-/en/203162-Bodyshaker-Loudspeaker-100-Watt/dp/B002LQAHPE/ref=psdc_571760_t1_B009RGJ47S

The ready-to-use prototype systems are presented in Figures 11 and 12, with the detailed explanation of their components (in accordance with Figures 5 and 6).

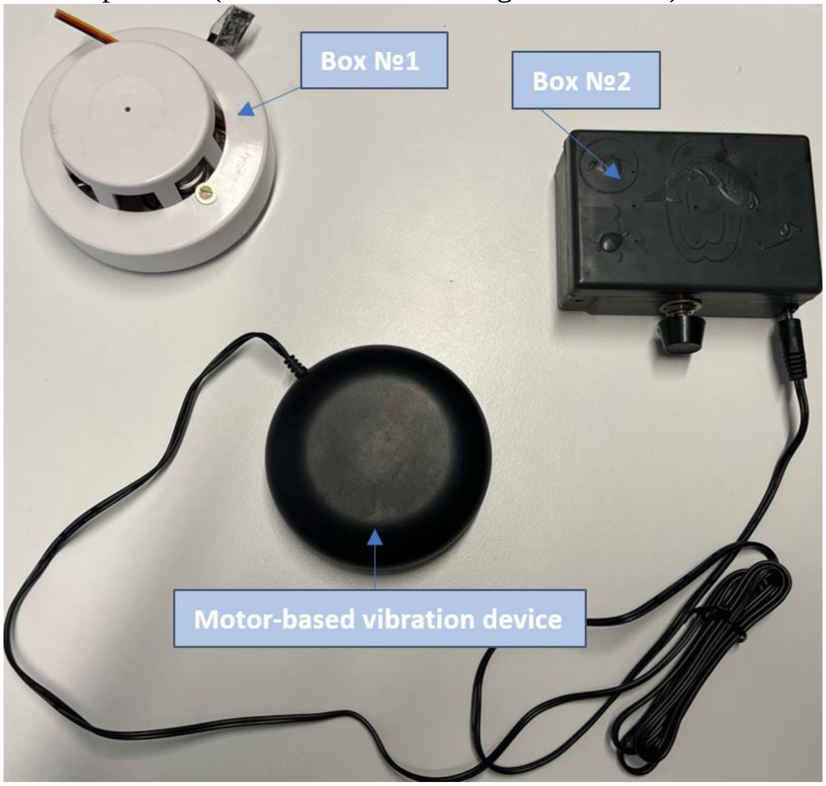



*Figure 11* – AAA_1 prototype.

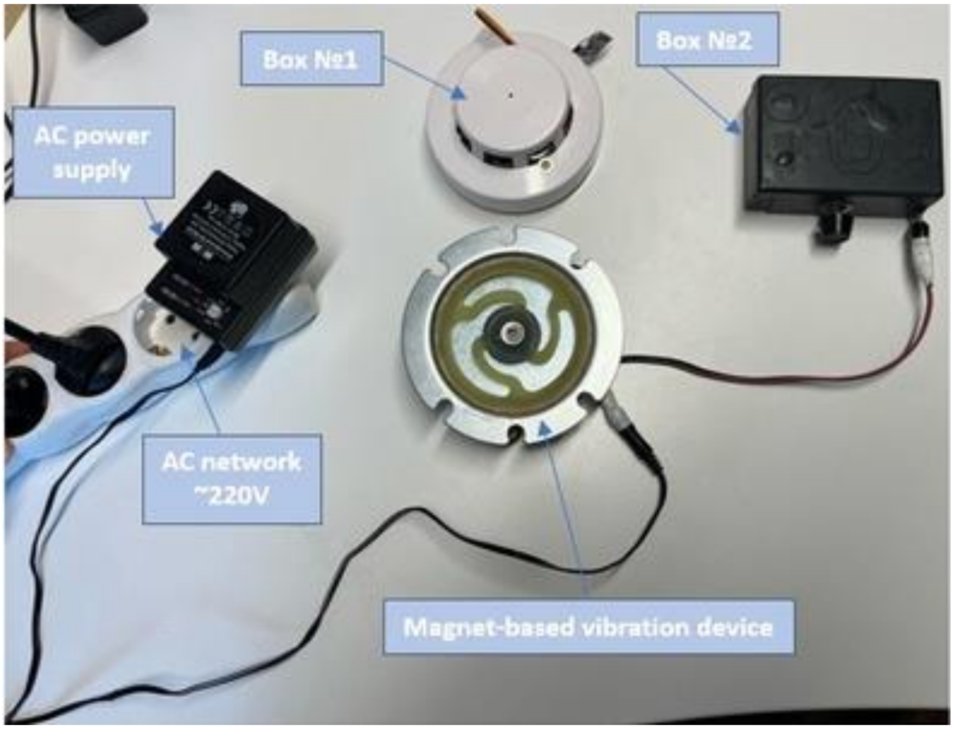



*Figure 12* – AAA_2 prototype.

The used converters are based on microelectronics using Arduino software (https://www.arduino.cc/en/software). They are powered by standard DC power supply - 2PCS 9V battery. In both boxes the same model of converter was used, where one of them was creating the signal and another – receiving it. The small size of these converters allowed having compact alarm system components both for the first and second prototype solutions.

In addition to the discussed prototypes, an amplifier of sinusoidal signals[4] was bought, which can be powered by a separate 12V DC power supply, connected to the ~220V AC network. The amplifier has three controllers. Controller a) is regulating the vibration amplitude, controller b) – low frequency and controller c) – high frequency. This system with an amplifier (Figure 13) allows the tests of second vibrating mechanism in order to get its necessary vibration parameters related to a specific amplitude and frequency of vibration. For this purpose, a sine wave generator[5] should be used, which sends the signal of the specific frequency (standard is from 20 to 20000 Hz) to the amplifier.

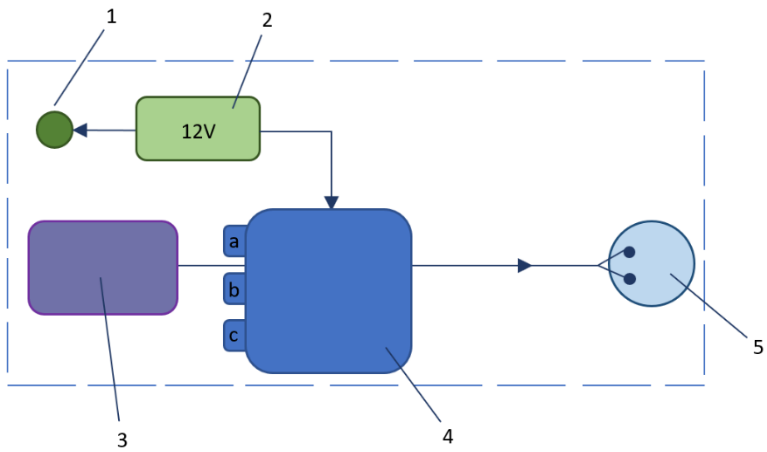



*Figure 13*– The scheme for the future tests of the magnet-based vibrating device.

Where:

1 – AC network ~220V
2 – 12V DC power supply
3 – Sine signal generator
4 – Sine signal amplifier
5 – Magnet-based vibrating device

a – Vibration amplitude controller
b – Low frequency controller
c - High frequency controller

One of the main parts of the development stage was the use of an Arduino platform[6]. Its concept consists of using both hardware and software, so the Arduino boards can transmit the signal (for example, the light from the sensor) from one to another and activate the output mechanism (for example, the vibrating device). These boards should be programmed with the in an integrated

[4] https://www.amazon.de/-/en/WANGCL-ZK-1002MT-Bluetooth-Subwoofer-Amplifier/dp/B09SL5PSM7/ref=sr_1_11?crid=ERBKBF6NFV7N&keywords=100w+verst%C3%A4rker&qid=1675775530&sprefix=100w+amplifier%2Caps%2C115&sr=8-11

[5] An example of such device can be found in https://www.arborsci.com/products/sine-wave-generator

[6] https://docs.arduino.cc/ and https://www.circuitschools.com/what-is-arduino-how-it-works-and-what-you-can-do-with-arduino/

development environment program (IDE), that is also a part of Arduino project, and where its programming language can be implemented.

Regarding the method to write the code – there are several examples, which are provided in open access by the developers, so they were used to create the specific code for the desired system. Therefore, after putting the written code (given in the Appendix of this thesis) IDE program, the Arduino boards were ready to work. The last step was to connect the first Arduino board to the vibrating device and the second – to the smoke sensor (MQ2). It was made using the standard wires and allowed having the complete system for both prototypes.

Overall, these prototypes are presented as a starting point for future implementations and improvements. It was constructed using the existent devices from the market as an example, but with the main improvement of having ability to change vibration intensity. The inner components of prototypes are also considered being different from ones presented on the market, however, there was no information in the open access about them and, therefore, these components were chosen by experimental way. Finally, while there are some examples of motor-based vibrating devices as a part of vibrating alarms on the market, there were no magnet-based vibrating components used in such systems.

The next stage would be to measure the range of vibration intensity, but this was outside the scope of the current thesis. Therefore, they are expected to be done in future, by any of the methods described in subsection 5.6.

# 7. Prototype testing

The prototype was tested in order to verify that the programming code worked as intended and ensure that the communication between the boxes and vibrating mechanisms worked. In order to achieve this goal, the full activation process was done in line with the procedure presented in subsection 6.4.2. First, an aroma stick was used to create the smoke and activate the smoke sensor. It was placed close to the Box №1 (as shown in Figure 14) in order to decrease the time needed for activation. After approximately 20 seconds from the ignition, the relay contacts became closed, and the motor-based vibration system started working. The process was repeated for both prototypes in order to prove they both worked as intended. The vibration intensity could be regulated from being barely felt to a strong vibration. The full process of the alarm activation is recorded by video, which is available in Zenodo[7].

As a result, a motor-based vibrating device in prototype AAA_1 worked as intended. In AAA_2 prototype, the signal from the smoke sensor did not activate the magnet-based vibrating alarm. However, in case of the manual connection of the relay contacts, the magnet-based vibrating mechanism did work as intended. It is also important to point that for both prototypes the vibration was possible to be regulated manually, by controller on the Box №2.

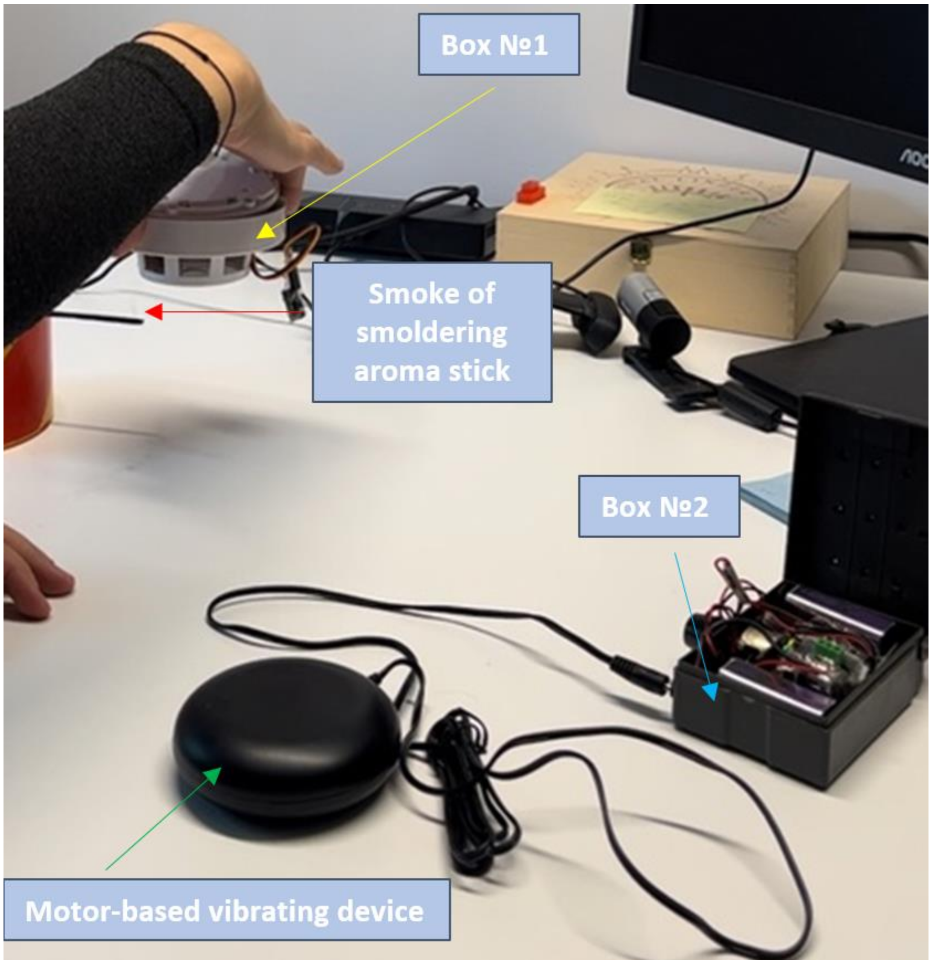



*Figure 14* – The testing procedure of the vibrating alarm systems.

[7] https://doi.org/10.5281/zenodo.7922518

## 8. Discussion

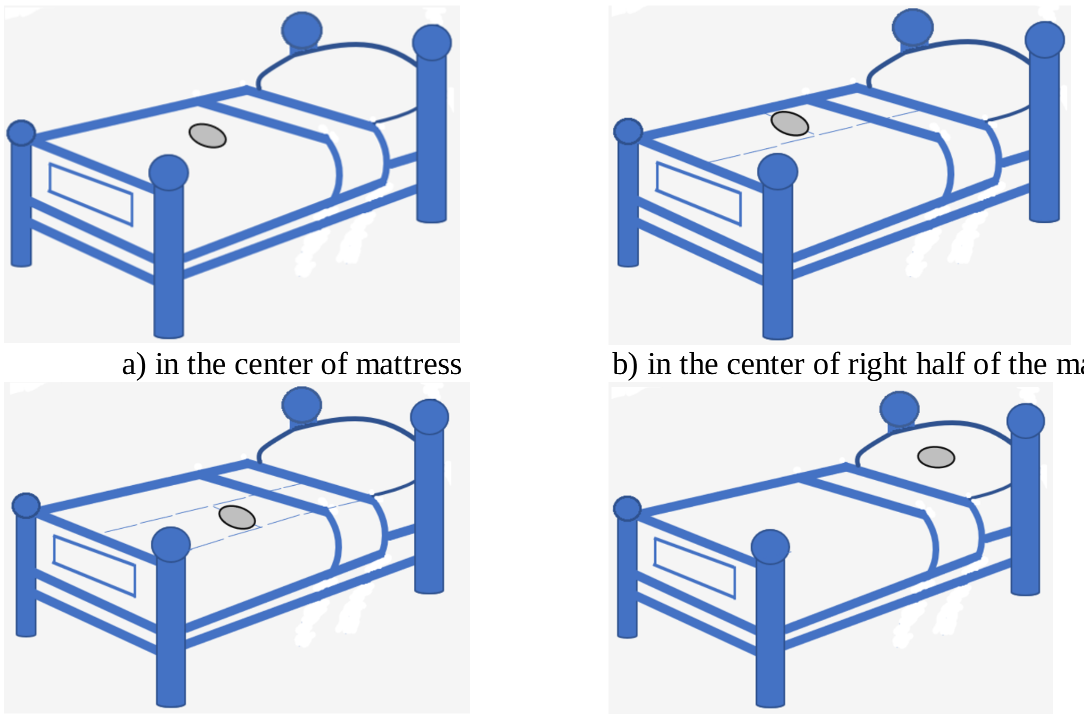
Overall, the market of existing alarms for people with hearing impairments was explored and analyzed. Among all the presented options, the two types of vibrating devices were chosen to be used in designed prototypes of alarm system – first, the motor-based type and second - magnet-based. The main criteria for these solutions were: the cost, compact size and the opportunity to change vibration parameters. As a result, two prototypes (AAA_1 and AAA_2) of customizable vibrating alarm for people with hearing impairments were developed. They were designed using the actual vibrating devices from the market, which were then connected to the smoke sensor in order to present its future use.

After detection of the smoke presence by MQ2 sensor, a signal is created, amplified and transmitted to the vibrating component - either motor-based or magnet-based, - which starts creating vibration. It is important to mention that there is a controller, allowing to regulate the vibration intensity from low to high. It can be done by twisting the circular controller on the outside of the Box №2. Therefore, the future tests can be done, using the different modes and checking, which one is the most effective in waking up a person with hearing impairments.

The vibrating devices are in working conditions and are ready to be used for testing different vibration parameters on people with hearing impairments. Therefore, this work represents a starting point for the development of a testing procedure to investigate if and how quick people with or without hearing impairments will be awakened from these devices.

These tests can include modifying different vibration parameters – frequency, amplitude – or the type of vibration (using either the magnet or motor-based devices). It is also possible to improve the existing prototypes and to add the opportunity to change the patterns of vibration, making it intermittent or continuous. Possible solution is: to install a switcher, which will constantly turn it on and off.

The testing can be done in a sleeping laboratory, which will allow measuring how much time the person with different degrees of hearing impairments needs to wake up during a specific sleep stage. It is also important to investigate how the installation of the device in the bed affects the effectiveness of the vibrating alarms. First, it is important to note that the vibrating device should be tested in presence on or under/inside the mattress, which will allow to see if this device will fall down or move, significantly decreasing its effectiveness. However, as it is considered to be uncomfortable for a user in case of having the device in the bed center, above the mattress, it is suggested to change this position to the left or right corner of the bed (in the head side) in the experimental sets. Secondly, one of the possible solutions could be to fix the device on the bed frame, in order to also avoid the device falling down. Finally, as some people may sleep on a side, while others, for example, - on the back, there are several options of the placement suggested in Figure 15.



a) in the center of mattress b) in the center of right half of the mattress

c) in the center of left half of the mattress d) under the pillow

*Figure 15* – Possible locations of the vibrating devices.

Therefore, the final set of the experiments, including the change of vibration intensity, are presented in the Table 3:

*Table 3 – Final set of suggested experiments*

| | | *In the left corner of the mattress (head side)* | *In the right corner of the mattress (head side)* | *In the center of mattress* | *In the center of right half of the mattress* | *In the center of left half of the mattress* |
|---|---|---|---|---|---|---|
| Above mattress + low intensity | | Experiment №1 | Experiment №2 | | | |
| Above mattress + medium intensity | | Experiment №3 | Experiment №4 | | | |
| Above mattress + high intensity | | Experiment №5 | Experiment №6 | | | |
| Below mattress + low intensity | | Experiment №7 | Experiment №8 | Experiment №9 | Experiment №10 | Experiment №11 |
| Below mattress + medium intensity | | Experiment №12 | Experiment №13 | Experiment №14 | Experiment №15 | Experiment №16 |
| Below mattress + high intensity | | Experiment №17 | Experiment №18 | Experiment №19 | Experiment №20 | Experiment №21 |
| Attached to the frame + low intensity | Experiment №22 | | | | | |
| Attached to the frame + medium intensity | Experiment №23 | | | | | |
| Attached to the frame + high intensity | Experiment №24 | | | | | |
| Under the pillow | Experiment №21 | | | | | |

In addition to the experiments from Table 3, in case of adding to the prototypes the option of changing the patterns and after measuring the exact values for vibration parameters, which can be created by these prototypes, this set of experiments can be expanded and more precise in terms of values.

According to Asley, (2007), the intermittent vibrating pattern seems to be in some degree more effective than the continuous one. Therefore, one of the potential improvements for the designed prototypes is to implement this pattern into the Arduino code to get the desirable features. It is also possible to use the amplifier (which is presented in Figure 13) to see the range of change in vibration intensity of the magnet (Figure 10).

It is expected that the main parameter to be monitored in these tests will be time to awaken the person in every sleep stage. Therefore, it will allow understanding which device position, vibration pattern and intensity are the most effective in waking up a sleeping person with or without hearing impairments.

These tests, however, could be not 100% representative in terms of results. First reason is that it can be stressful for some people to sleep in a different room or bed. The fact that they will be monitored while sleeping or that they need to fall asleep in order to be tested can cause discomfort or inability to fall asleep at all. Moreover, in case they will manage to fall asleep, the sleeping condition may be easier for interrupting, which is not the case of usual everyday life conditions. However, it is considered to be difficult to organize the same testing condition in the participants' houses and will allow to exclude only one stressful factor – infamous room or bed.

After these basic tests, one of the future implementations could be to move away from the concept of the limited use of this system. It is suggested to try any kind of wearable device (for example, the smart-watches) in order to expand the area of action, opportunity to take it away from home or use in different emergency situations, not only during fire scenarios.

As it was mentioned in introduction section, tactile alarms could be a solution for alarming people in noisy environment, making the technology effective both for people with or without hearing impairments. Therefore, after the creation and testing of the new prototype - for example, smart watch system – one of possible solutions (in addition to implementation of this new alarm system to the market) could be to supplement the existent smart watches with vibration in case of emergency. The analysis of the most popular brands of smart watches among users should be done, after which the modifications could be suggested to these famous companies and implemented to new models. However, it will take much longer amount of time to do the tests and develop the new solution for the final alarm system for the deaf or hard of hearing people.

## 9. Conclusion

The purpose of this thesis was to create working prototypes of a vibration alarm system for people with hearing impairments. The two prototypes – AAA_1 and AAA_2 – were developed, where either a magnet or motor-based device is connected to a smoke sensor and creates vibration in the moment it is reached by smoke. Although these prototypes do not necessarily represent a final version of a system for systematic testing of vibrating alarm, they are expected to be used as a proof-of-concept working example. This allows future testing on real people to understand which vibration configuration (involving parameters such intensity, amplitude, vibrating patterns, etc.) is the most effective in awaking people with hearing impairments during fire scenarios in relation to the device installation on the bed. This will allow the systematic testing of the effectiveness of vibrating alarms with people and eventually contribute to an equal fire safety for people with hearing impairments.

## References


1. EU-wide data on residential fires. European Fire Safety Alliance. https://vk.com/away.php?utf=1&to=https%3A%2F%2Fwww.europeanfiresafetyalliance.org%2Four-focus%2Fstatistics%2F
2. Storesund, K. & Glansberg, K. (2018). Smoke alarm efficiency – Waking sleeping occupants. RISE Fire Research AS.
3. Crimmins, D. (n.d.). WHAT IS A FIRE ALARM SYSTEM? Realpars. https://realpars.com/fire-alarm-system/
4. Bruck, D. & Ball, M. (2007). Optimizing Emergency Awakening to Audible Smoke Alarms: An Update. Human Factors: The Journal of the Human Factors and Ergonomics Society, 49(4), 585–601. https://doi.org/10.1518/001872007X215674
5. Dalton, D. S. et al. (2003). The Impact of Hearing Loss on Quality of Life in Older Adults. The Gerontologist, 43(5), 661–668. https://doi.org/10.1093/geront/43.5.661
6. Fagbohun, O. O. & Oni, O. A. (2016). Security Devices Application Studies in Crime Prevention and Policing in Nigeria. American Journal of Engineering Research (AJER), 5(12), 58–69.
7. U.S. Fire Administration. Fire Risks for the Deaf or Hard of Hearing. Publication FA-202, December 1999
8. J. Ladou, (1997). Occupational and Environmental Medicine. Second Edition. Stamford.
9. Jonsson, A., Runefors, M., Gustavsson, J., & Nilson, F. (2022). Residential fire fatality typologies in Sweden: Results after 20 years of high-quality data. Journal of Safety Research, 82, 68–84. https://doi.org/10.1016/j.jsr.2022.04.007
10. Smedberg, E. & Ronchi, E. (2021, August). Review of Alarm Technologies for Deaf and Hard of Hearing Populations. Fire Protection Research Foundation.
11. Bruck, Dorothy & Thomas, Ian. (2007). Waking effectiveness of alarm (auditory, visual and tactile) for adults who are hard of hearing.
12. Sminkey, L. (2019). New WHO-ITU standard aims to prevent hearing loss among 1.1 billion young people. World Health Organization. https://www.who.int/news/item/12-02-2019-new-who-itu-standard-aims-to-prevent-hearing-loss-among-1.1-billion-young-people#:~:text=Over%205%25%20of%20the%20world%27s,%2D%20and%20middle%2Dincome%20countries
13. (2021). Quick Statistics About Hearing. National Institute on Deafness and Other Communication Disorders. https://www.nidcd.nih.gov/health/statistics/quick-statistics-hearing#:~:text=Approximately%2015%25%20of%20American%20adults,over%20report%20some%20trouble%20hearing.&text=Among%20adults%20aged%2020%2D69,in%20the%202011%E2%80%932012%20period.
14. Hearing loss and deafness. British Academy of Audiology. https://www.baaudiology.org/about/media-centre/facts-about-hearing-loss-and-deafness/
15. (2018). Addressing the rising prevalence of hearing loss. World Health Organization.
16. About ear health. Australian Government. Department of Health and Aged Care. https://www.health.gov.au/topics/ear-health/about
17. (2023) NATIONAL PROGRAMME FOR THE PREVENTION & CONTROL OF DEAFNESS (NPPCD). Ministry of Health & Family Welfare Government of India. https://nhm.gov.in/index1.php?lang=1&level=2&sublinkid=1051&lid=606#:~:text=Hearing%20loss%20is%20the%20most,at%206.3%25%20in%20Indian%20population.

18. Desalew, A., Feto Gelano, T., Semahegn, A., Geda, B., & Ali, T. (2020). Childhood hearing impairment and its associated factors in sub-Saharan Africa in the 21st century: A systematic review and meta-analysis. SAGE Open Medicine, 8. https://doi.org/10.1177/2050312120919240
19. Zhou, Y., et al. (2019). Mutation analysis of common deafness genes among 1,201 patients with non-syndromic hearing loss in Shanxi Province. Mol Genet Genomic Med., 7 (3). https://doi.org/10.1002/mgg3.537
20. Malkin, R. A. (2007). Barriers for medical devices for the developing world. Expert Review of Medical Devices, 4(6), 759–763. https://doi.org/10.1586/17434440.4.6.759
21. PAHO & WHO. (2014). Many countries lack capacity to prevent and treat hearing loss. https://www3.paho.org/hq/index.php?option=com_content&view=article&id=9345:2014-many-countries-lack-capacity-prevent-treat-hearing-loss&Itemid=0&lang=en#gsc.tab=0
22. Eastwood, J., Conroy, R., Naicker, S., West, P., Tutt, R., & Plange-Rhule, J. (2005). Loss of health professionals from sub-Saharan Africa: The pivotal role of the UK. The Lancet, 365(9474), 1893–1900. https://doi.org/10.1016/S0140-6736(05)66623-8
23. Xuewen, Y. & Jianbo, G. (2021). The prevalence of hearing loss in different age groups, gender and Hearing threshold: A systemic review. International Journal of Medical Research & Health Sciences, 10(1), 30-37.
24. Michikawa, T., Nishiwaki, Y., Kikuchi, Y., Nakano, M., Iwasawa, S., Asakura, K., Milojevic, A., Mizutari, K., Saito, H., Ishida, S., Okamura, T., & Takebayashi, T. (2009). Gender-specific associations of vision and hearing impairments with adverse health outcomes in older Japanese: A population-based cohort study. BMC Geriatrics, 9(1), 50. https://doi.org/10.1186/1471-2318-9-50
25. Corazzi, V., Ciorba, A., Skarżyński, P. H., Skarżyńska, M. B., Bianchini, C., Stomeo, F., Bellini, T., Pelucchi, S., & Hatzopoulos, S. (2020). Gender differences in audio-vestibular disorders. International Journal of Immunopathology and Pharmacology, 34. https://doi.org/10.1177/2058738420929174
26. He, P., Luo, Y., Hu, X., Gong, R., Wen, X., & Zheng, X. (2018). Association of socioeconomic status with hearing loss in Chinese working-aged adults: A population-based study. PLOS ONE, 13(3). https://doi.org/10.1371/journal.pone.0195227
27. Emmett, S. D., & Francis, H. W. (2015). The Socioeconomic Impact of Hearing Loss in U.S. Adults. Otology & Neurotology, 36(3), 545–550. https://doi.org/10.1097/MAO.0000000000000562
28. Nakahori, N., Sekine, M., Yamada, M., Tatsuse, T., Kido, H., & Suzuki, M. (2020). Association between self-reported hearing loss and low socioeconomic status in Japan: Findings from the Toyama dementia survey. BMC Geriatrics, 20(1), 275. https://doi.org/10.1186/s12877-020-01680-y
29. Desselle, D. D., & Proctor, T. K. (2000). Advocating for the Elderly Hard-of-Hearing Population: The Deaf People We Ignore. Social Work, 45(3), 277–281. https://doi.org/10.1093/sw/45.3.277
30. Kelly, L. (2017) Suffering in Silence: The unmet needs of d/Deaf prisoners. Prison Service Journal, 234. pp. 3-15.
31. Shabana, A. A. (2019). Theory of Vibration: An Introduction. Springer International Publishing. https://doi.org/10.1007/978-3-319-94271-1
32. Home smart home. Bellman & Symfon. https://bellman.com/en/our-solutions/visit-smart-home/

33. The SafeAwake Fire Safety Device. SafeAwake; An InnovativeDevice for Alerting Sleeping Individuals to an Emergency. https://www.safeawake.com/
34. DeafGard Vibrating & Flash Fire Alarm. Audio. https://www.audilo.se/442-deafgard-vibrating-flash-fire-alarm.html?gclid=EAIaIQobChMIh4vJuerH_QIVmQWiAx3nmgn0EAQYAiABEgLXmfD_BwE
35. Peace of Mind at Your Bedside. Lifetone Technology. https://www.lifetonesafety.com/
36. Klinger, C. (2014). Failures of cranes due to wind induced vibrations. Engineering Failure Analysis, 43, 198–220. https://doi.org/10.1016/j.engfailanal.2013.12.007
37. Binti Abdul Manaf, M., & Bt Sulaiman, S. (2015). Integrating vibration sensing and non-speech visualization to notify hearing impaired students on fire in a controlled situation. 2015 International Symposium on Mathematical Sciences and Computing Research (ISMSC), 36–42. https://doi.org/10.1109/ISMSC.2015.7594024
38. Dimarogonas, A. D. (1990). The origins of vibration theory. Journal of Sound and Vibration, 140(2), 181–189. https://doi.org/10.1016/0022-460X(90)90523-3
39. Stahl, W. H., Cohen, M. R., & Drabkin, I. E. (1949). A Source Book in Greek Science. The Classical Weekly, 43(3), 41. https://doi.org/10.2307/4342616
40. Mobley, R. K. (1999). Vibration fundamentals. Newnes. Chaurasiya, H. (2012). Recent Trends of Measurement and Development of Vibration Sensors.
41. Rayleigh, J. W. S. (1969). The theory of sound. Vol. 1 (Repr. of 2. ed. rev. and enl.1894, Vol. 1). Dover Publ.
42. Galchev, T., Kim, H., & Najafi, K. (2011). Micro Power Generator for Harvesting Low-Frequency and Nonperiodic Vibrations. Journal of Microelectromechanical Systems, 5961600. https://doi.org/10.1109/JMEMS.2011.2160045
43. Ashley, E. (2007). Waking Effectiveness of Emergency Alerting Devices for the Hearing Able, Hard of Hearing, and Deaf Populations.
44. Schmitz, T. L., & Smith, K. S. (2021). Mechanical Vibrations: Modeling and Measurement. Springer International Publishing. https://doi.org/10.1007/978-3-030-52344-2.https://doi.org/10.1007/978-3-030-52344-2
45. Xu, X. et al. (2018). Review of Electromagnetic Vibration in Electrical Machines. Energies, 11(7), 1779. https://doi.org/10.3390/en11071779
46. Fakhzan, M. N., & Muthalif, A. G. A. (2013). Harvesting vibration energy using piezoelectric material: Modeling, simulation and experimental verifications. Mechatronics, 23(1), 61–66. https://doi.org/10.1016/j.mechatronics.2012.10.009
47. Evens, A. (2002). A Shock to Thought. Sound ideas, 1-17.
48. Zhang, X. et al. (2015). Transmission of vertical vibration through a seat: Effect of thickness of foam cushions at the seat pan and the backrest. International Journal of Industrial Ergonomics, 48, 36–45. https://doi.org/10.1016/j.ergon.2015.03.006
49. Dünisch, O. (2017). Relationship between anatomy and vibration behaviour of softwoods and hardwoods. IAWA Journal, 38(1), 81–98. https://doi.org/10.1163/22941932-20170158
50. Arun Faisal, I., Waluyo Purboyo, T., & Siswo Raharjo Ansori, A. (2019). A Review of Accelerometer Sensor and Gyroscope Sensor in IMU Sensors on Motion Capture. Journal of Engineering and Applied Sciences, 15(3), 826–829. https://doi.org/10.36478/jeasci.2020.826.829

51. Cao, Y., Rong, X. L., Shao, S. J., & He, K. P. (2012). Present Situation and Prospects of Vibration Sensors. 2012 International Conference on Computer Distributed Control and Intelligent Environmental Monitoring, 515–518. https://doi.org/10.1109/CDCIEM.2012.128
52. Goyal, D., & Pabla, B. S. (2016). The Vibration Monitoring Methods and Signal Processing Techniques for Structural Health Monitoring: A Review. Archives of Computational Methods in Engineering, 23(4), 585–594. https://doi.org/10.1007/s11831-015-9145-0

**Appendix**

Here the used Arduino code is presented:

```
#include <SPI.h> //
#include <nRF24L01.h> //
#include <RF24.h> //
#define PIN_D 3 //
#define PIN_CE 9 //
#define PIN_CSN 10 //
RF24 radio(PIN_CE, PIN_CSN); //

int potValue[1]; //

void setup() {
Serial.begin(9600); //
pinMode(PIN_D, OUTPUT); //
radio.begin(); //
radio.setChannel(5); //
radio.setDataRate (RF24_1MBPS); //
radio.setPALevel(RF24_PA_HIGH); //
radio.openReadingPipe (1, 0x7878787878LL); //
radio.startListening(); //
}

void loop() {
if(radio.available()){ //
radio.read(&potValue, sizeof(potValue)); //

digitalWrite(PIN_D, potValue[0]); //
Serial.println(potValue[0]);//
}
}
```