LUT UNIVERSITY
LUT School of Energy Systems
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Selection of a Haptic Feedback enabled technology for use in the User interface devices of Elevators

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M. Sc. (Tech.) Jonas Nordfors

ABSTRACT

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Selection of a Haptic Feedback enabled technology for use in the User interface devices of Elevators

Master's thesis

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Haptic feedback is an important element in the successful and safe operation of user interfaces of an elevator. A haptic feedback can be obtained from a number of technologies and mechanisms. European Standard EN 81-70:2018 defines the minimum criteria that a user interface device should meet in order to be used in an elevator. Haptic feedback is a vital requirement that a user interface should have, according to the EN 81-70:2018. This thesis is focused on the investigation of various technologies that can be used to obtain a haptic feedback in UI devices of an elevator. The objective was to identify a new haptic feedback enabled technology that can meet the requirements defined by EN 81-70:2018.

The research work started with the identification of the available new technologies through online resources. With the help of experts, those technologies were selected for further investigation, that were expected to meet the elevator industry standards. A triangulation technique was utilized with European standard EN 81-70:2018, literature and information from expert opinions, as the vertices of the triangle. The information on various technologies was obtained through literature study and expert opinions. The literature study yielded in an understanding of the features and capabilities of each technology. The expert opinion provided an industry-based view of the technologies under investigation. The thoughts of the experts were collected in semi structured interviews. These interviews led to the evaluation of the capability of each technology to meet the industry standards.

Various parameters were defined as the benchmarks for comparison of the selected technologies. These parameters were obtained from EN 81-70:2018 and from experts. The outcome of the research was that piezo electric devices are the most suitable modern mechanisms that can be used in the user interface devices of an elevator.

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Atif Malik
Hyvinkää 26.11.2019

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LIST OF ABBREVIATIONS

AC	*Alternating Current*
CEI	*Capacitive Electrosensory Interface*
DC	*Direct Current*
EN	*European*
ERM	*Eccentric Rotating Mass*
LRA	*Linear Resonant Actuator*
UI	User Interface

1 INTRODUCTION

Changing social trends towards user interface devices has derived organizations in creating unique and innovative solutions for maintaining dominance in business. This has led to a changing corporate environment that pushes the industry leaders to introduce new technologies in their offerings. Rapidly evolving modern technologies bring the challenge of integration with existing products being offered by the companies. These challenges are eliminated with the researched solutions that meet the requirements of the product unification interface and the product standards defined by the local or international organizations. The successful completion of research evolves the technical offerings of the company thus providing a competitive edge in the market.

The ambition to introduce modern technologies into the products could be compelled by any of the following parameters:

i. To achieve better quality
ii. To increase the operational capabilities
iii. To enhance the performance
iv. To improve the usability
v. To prolong the operational life spam
vi. To introduce a fresh outlook
vii. To economize the production
viii. To boost the profits

These criteria are met with the help of research and development within the organizations. The organizational research explores the possibilities of channeling scientific knowledge into an engineered product. This thesis serves the same function.

1.1 Introduction to the thesis

This master's thesis has been completed in co-operation with KONE corporation. The focus of this thesis is to explore the technologies that can produce such a quality of haptic feedback, that they could be used in the user interface devices produced by KONE corporation. The investigation of the modern technologies for the thesis was executed at the premises of KONE corporation research and development center in Finland.

1.2 Introduction to the Company

KONE corporation is an elevator manufacturer. The offerings include a variety of elevator platforms. These platforms utilize a range of UI (user interface) devices. These user interface devices provide the media of interaction between the user and the elevator. This happens when a user gives a call through a UI device and receives a feedback. The most common user interface devices used by KONE corporation include buttons and information screens. Now KONE is exploring the possibilities to install haptic feedback technologies to be used in the user interface that could improve the user experience and quality of the products.

1.3 UI devices

User interface devices provide a media to accomplish interaction between humans and the computers. A user interface is the component of the computer that can be seen, heard and touched by the users. User interface devices usually operate with two components i.e. input and output. Input includes the media that imparts the requirements of the user to the computer. Some examples of input include the keyboards of a computer, the finger in case of a touch screen devices and voice in case of an audio enabled device. The output is the response by the computer to the input. The output is usually visible on a screen, which could be followed by an audio output as well. A decent interface design provides a good balance of mechanisms that facilitate input and provide an output which is conveniently perceived by the user. (Galitz 2007.)

User interface input devices that are used in the operation of elevators include buttons and touch screens. Output devices consist of information screens, illuminating symbols and audio announcement widgets. These devices are made code compliant that are defined by European standards within the European Union. The integration of the new technologies into the user interface devices becomes complex because of the requirements set by the International Standards. A traditional UI has been shown in figure 1.

Figure 1. Buttons on KONE car operating Panel (KONE, 2019).

1.4 Objectives and Boundaries of the thesis

The motivation of this thesis is to evaluate and analyze the factors that affect the use of haptic feedback in the user interface devices. This thesis will focus on the investigation of possible technologies that can be employed to achieve a good haptic feedback. The aspiration of the thesis is focused on replacing the traditional elevator activation devices used by KONE with a haptic feedback capable new technology. The scope of the thesis has been developed based on EN 81-70:2018 code. This code provides the requirements that must be met by the UI devices. The achievement of the objective is defined by the identification of a technology that results in the creation of a UI device that is EN 81-70:2018 code compliant.

The scope of this research has been limited to the development of a comparative study to identify the best technology that can be used to develop a haptic feedback device for UI.

1.5 Research Question

The objective was identified through the research question. This research is directed to seek the answer to the following research question:

What are the factors that influence the use of haptics in the user interface devices of an elevator?

What is the most suitable technology for obtaining haptic feedback in the UI devices in elevator?

The limitations to make the scope of the research visible, are defined based on the requirements outlined by the EN 81-70:2018 code. The focus of this research remains within the confines of accessibility to the user interface devices of an elevator. The research is expected to answer the above research questions based on the limitations derived from EN 81-70:2018.

1.6 Structure of the Research

This research has followed the common research pattern, popular among the scientific community. The research work was initiated with the identification of the research problem. The identification of the research problem was accomplished by carrying out discussions with the professionals from the UI category of KONE corporation. These discussions resulted in developing an understanding of the need of this research. The research objective was defined, and research question was developed. The thesis started with the familiarization of the technologies that are in use to serve the purpose of haptic feedback.

EN 81-70:2018 was adapted as the standard to be achieved with the results. For this purpose, an analytical tool was developed that facilitated the comparison of various present haptic feedback technologies. The parameters for comparison were obtained from the adapted standard EN 81-70:2018. The conformability of various technologies to the standard were assessed based on the opinions of the experts. Table 1 gives a short description of the structure of the thesis.

Table 1. Structure of thesis

Chapter	Title	Input	Outcome
1.	Introduction	An intro to thesis, literature	Understanding of this thesis and knowledge of technologies
2.	Methods	Parameters to collect information and questionnaire	Understanding of the requirements and available knowledge of technologies
3.	Results	Information obtained through the opinion of experts	Capabilities of the technologies under consideration.
4.	Analysis	Analysis of the expert opinion	Evaluation of technologies and selection of the most suitable one.
5.	Conclusion	Information from the results	Understanding of the outcome of the thesis

The working principles and limitations of each technology was studied. This information was extracted from the existing literature and research work of various organizations and researchers. This knowledge led to the understanding of the capabilities of the available technologies to meet the parameters outlines in the analytical tool.

The analytical tool was presented to a group of experts from UI category of KONE corporation and they gave their individual assessment on the ability of each technology to comply with the EN 81-70:2018 code and other industrial requirements. This evaluation was analyzed, and the research concluded with the recommendation of most suitable technology that can be used to achieve optimum haptics in UI devices.

2 LITERATURE REVIEW

2.1 Theoretical Paradigm

The theoretical paradigm is developed by using the existing literature about haptic feedback and various technologies that are in use to produce it. The theoretical paradigm provides the basis for familiarization with the concept of haptics and the available haptic technologies. The information for developing theoretical paradigm was extracted from various scientific databases including ScienceDirect and Jstor. The working principles of the technology were understood from various technical documents and electronic media developed by manufacturers of these technologies.

2.1.1 Haptic feedback

Haptic feedback is a physical element of mechanism design that enhances human computer interaction sensation. The presence of dissimilar surfaces, boundaries or markings help in perceiving the differentiation of objects, this discernment of objects is facilitated by haptic feedback by providing a pertinent tactile sensation which is recognized as a dynamic change or static impression. These commodities could be button like with passive haptic characteristics designed to provide a specific sensation. These objects can also have dynamic haptic response thus developing a physical sensation of execution of a task. The dynamic haptic response compensates the need to visualize the activation of the surface. A computer mouse with active haptic feedback responds to the edges of the operating windows through a smooth vibration, similarly with the menus it updates the user with feedback. Haptic feedback ranges are modest but recognizable by the user. An example of the haptic feedback from daily life can be the vibration of the wireless devices that divulge the incoming call or an alarm only to the user of the device and not to the people around. The information on the failure or success of execution of the operation by the device is communicated through a haptic response. The initiation of the haptic takes place with the touch by the user, which last for milliseconds. (Mclean, 2000.)

2.1.2 Purpose of Haptic feedback

In psychological and physiological terms Haptics is the capability of the user to sense the response from a device through sense of touch. Use of haptics enables the bidirectional flow of physical communication between humans and computers. This bidirectional communication is not trivial and is developed through complex mechanical designs facilitated by actuators. The activation of the mechanical systems is achieved through real time schemes that execute sophisticated algorithms. This activation of systems produces a response for the user, which is perceived as a communication by the human from the machines. This ensures the user that the input has been received and execution of the operation has started. Haptics are used as a language of instincts from machine to the user, to communicate that the command from the user has been received. The most demanding task in achieving a good haptic feedback is its ability to be sensed by the users. (Robles-De-La-Torre, 2006.)

Maturity of Haptic feedback

The use of haptic feedback in UI devices was intend to enhance the human machine interaction by creating a sense of touch from the machine (Hayward et al., 2004). The evolution of haptic feedback in the UI devices has resulted in sophisticated and reliable technologies that ensures the user of the acceptance of the command. The technologies have grown mature and new technologies are fast replacing the traditional solutions. There are set standards that define the requirements for the use of a haptic enable technology under different circumstances. (Blenkinsopp, 2019.)

In the light of the above cited work, it can be said that the haptic feedback in UI devices is a mature concept and has been practiced for a long time.

2.1.3 Piezoelectric Devices

Piezoelectric devices convert a change in pressure, force or acceleration in to an electrical signal. These are used in the metrology of various processes. Mostly, piezoelectric devices are used for quality assurance and control of various processes. Apart from that, these are being tested in new applications in various industries. The reliability of operation, the accuracy of feedback and operational life spam of piezoelectric devices make them a popular choice of research in new products. The piezoelectric effect was discovered in 1880 by Pierre Curie but it was adapted by the industry in 1950s for sensing applications. Over time the evolution of piezoelectric phenomenon resulted in the development of reliable measuring products. Due to the maturity of the technology, the piezoelectric devices have been used in modern medical instruments, nuclear equipment and aerospace devices. Further, the applications of piezoelectric devices in automotive industry, white products and commercial locations is gaining popularity. (Moubarak, Ben-Tzvi and Zaghloul, 2012.)

Uses of Piezoelectric devices

The use of piezoelectric devices gained wide acceptance owing to their high modulus of elasticity which is comparable to that of metals. The deflection in the sensing element is close to zero in spite that the piezoelectric devices respond to compression as an electromechanical structure. These characteristics of piezoelectric devices result in mechanical strength, fine linear behavior over a wide range of amplitude and very high natural frequency. Moreover, the radiations and electromagnetic field does not have any effect on magnetic field thus permitting the use of these devices under intense circumstances. (Partovi Shabestari et al., 2019.)

Working of Piezoelectric devices

The ability of the piezoelectric devices to measure different physical quantities depends upon the kind of technology that is used in it. Commonly metrological applications of piezoelectric devices include acceleration and pressure.

The piezoelectric device for the measurement of acceleration consists of a seismic mass connected to the crystal structure. When a motion occurs, the seismic mass creates a load on the crystal structure due to its momentum, in accordance with the second law of motion developed by Newton.

Figure 2 and Figure 3 show the working of a piezoelectric device as an accelerometer. The acceleration brings a change in the position of the mass with respect to the crystal thus hanging the electrical properties of the piezoelectric material which is displayed on an external indicator.

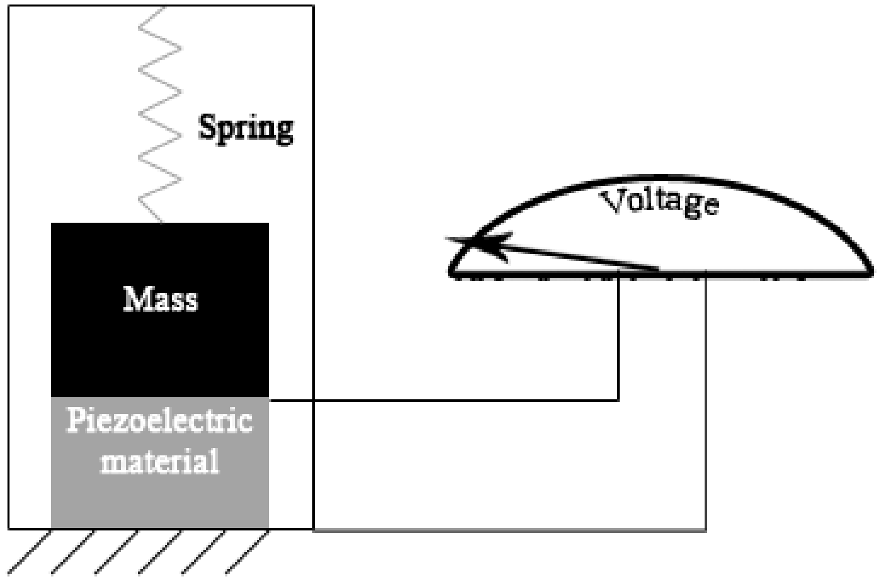


Figure 2. Piezoelectric device as acceleration sensor with no acceleration (En.wikipedia.org, 2019).

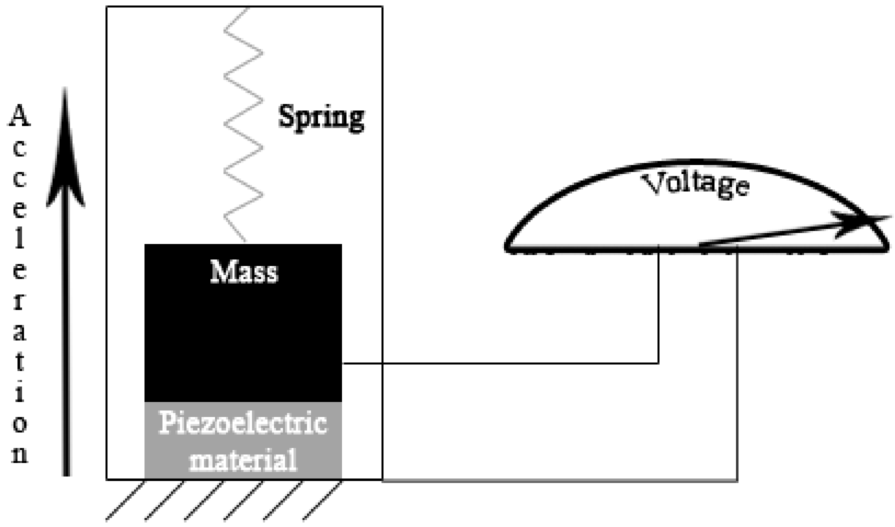


Figure 3. Piezoelectric device as acceleration sensor with acceleration (En.wikipedia.org, 2019).

The structure of piezoelectric device for the measurement of pressure, consists of a thin membrane attached to a heavier base. The massive base is installed to deflect the membrane in only one direction. Figure 4 shows the piezoelectric device used for pressure measurement.

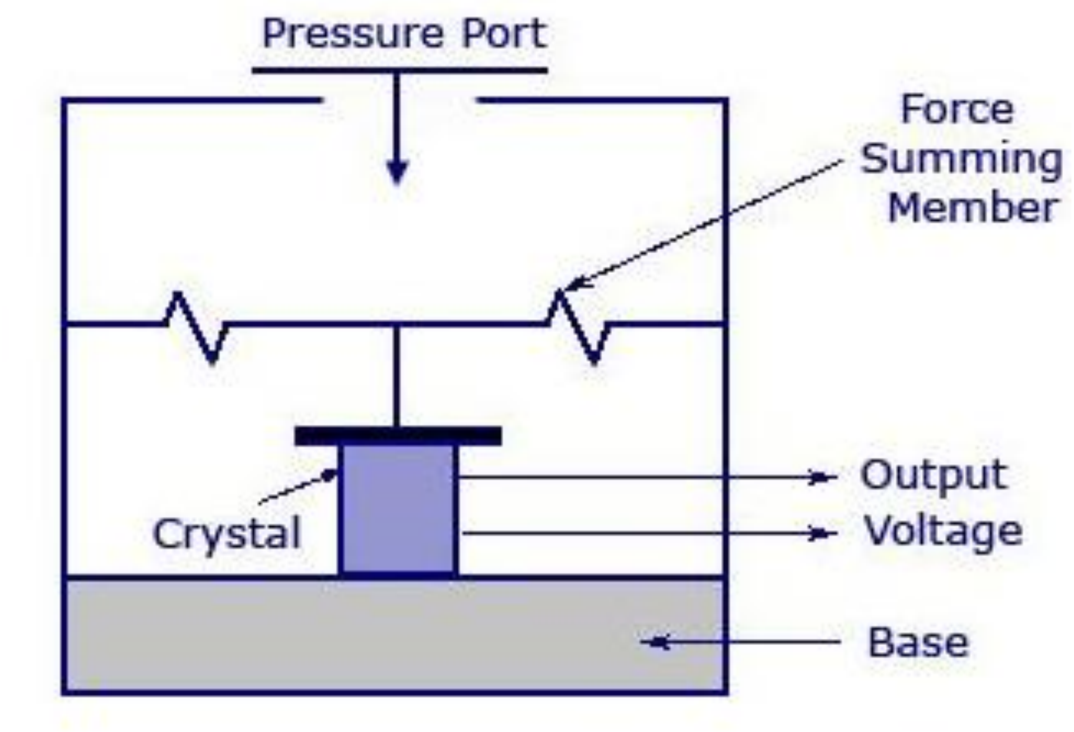


Figure 4. Piezoelectric device for pressure sensing (Editor, 2019).

The primary difference in the operation of the two types of the piezoelectric devices is the medium of application force. For acceleration measurement the seismic mass attached to the crystals generates the force induced due to acceleration while for pressure measurement the thin membrane delivers the force to the piezoelectric element.

The working environment of a piezoelectric devices might result in the occurrence of both the phenomena mentioned above at the same time i.e. the sensor meant for measuring pressure might show wrong output under the influence of vibrations. Thus, the pressure measuring devices are equipped with an acceleration compensation component. (Sirohi and Chopra, 2000)

Piezoelectric devices work as actuators as well. It converts an electrical signal into a mechanical displacement. When a potential difference or a force is applied on a piezoelectric material, they change the dimension. This mechanical force is created due to the change in the behavior of the piezo Christal under the influence of an external force. The output motion of piezoelectric actuators is precise. (Zhang 2008.)

Applications

Piezoelectric devices have reliable performance and dependable operation. This has led them to find applications in a variety of high-tech industries, including aerospace, nuclear and medical instrumentation. Apart from these, the mass-produced products like cell phones utilize piezoelectric devices for pressure sensing in touch pads. In automobiles these are in the engine heads, for monitoring the combustion of the engines.

Maturity

Piezoelectric devices have been in commercial use for a long period of time. The evolution of the material technology has led to the reliable and efficient operation of piezoelectric devices. The wide scope of uses of piezoelectric devices has resulted in their use in high performance applications for a long period of time. The variety of applications in a multitude of field makes the piezoelectric devices technically mature.

Although, the piezoelectric devices are not suitable for static measurements. Apart from that, high temperatures can lead to reduced sensitivity in piezoelectric devices. But under specified operating conditions these devices work efficiently. (ZHAO, LING and YU 2012.)

2.1.4 ERM

Introduction

An eccentric rotating mass motor (ERM) comprises of a DC motor with a non-symmetrical mass connected to its shaft. The mass is offset with respect to the axis of the rotatory axis of the shaft. ERM is also referred to as pager motor.

The rotation of the offset mass in an ERM generates non-uniformly distributed centrifugal force. This uneven distribution of force creates an overall centrifugal force, resulting in movement of the motor. High rotational speed produces increased movement of the motor. This movement tends to displace the motor from its fixed position due to asymmetric force. This system of non-uniform motion at high frequency causes vibrations.

The operation of ERM is contrary to the core principle of mechanics i.e. to reduce the vibration. This is done to avoid the unnecessary noise and wear. In case of an ERM the engineering is focused on generating vibrations in the most efficient way possible. The evolution of the ERM has been driven by the motivation to achieve non-turbulent and smooth vibrations. (Green, Champneys and Lieven 2006.)

Uses of ERM

The small size of the DC vibration motors makes their installation easy and cost efficient. Moreover, these motors effectively amplify the interaction between the device and the user. These motors are popular in commercial applications where the user requires feedback for the operation of the equipment, but the visual or audio feedback can not suffice the need due to environmental conditions. Miniature vibration motors are installed into such devices, so that the user receives a feedback from the sense of touch, in the form of vibrations. This eliminates the need of implementing visual or high-volume audio feedback devices. One of the most popular applications of such motors is in cellphones, since the vibration enables the user to sense that the phones requires attention. The vibration does not disturb the others that might be around the primary user. The most popular industrial application of small ERM motors is in the devices where a haptic feedback is intended to be generated. (Precisionmicrodrives.com 2019a.)

Working of ERM

The operation of ERM motors requires a direct current source with a constant voltage. The motor is connected to such source to obtain the rotational motion. A constant speed is achieved with the application of a constant voltage. This constant speed results in a stable amplitude of vibration and frequency as long as the voltage is applied. The voltage in the start is low so that maximum constant speed for the corresponding voltage is achieved in a short period of time. The applied voltage is then increased to maximum for optimum generation of vibrations. The voltage increment is performed in a very small spam of time.

ERM motors are the simplest in construction and efficient in performance, thus making them the most widely accepted commercial haptic feedback generators. The construction comprises of a DC motors mounted with an unsymmetrical mass. The off-center mass creates centripetal force upon rotation. When the motor is fixed with an object, the centripetal force tends to displace the object. Since the rational speed of a DC motor is above 100 revolutions per second, thus the frequency of the tendency to displace the object is very high. This movement of the object is restricted by fixing it to a reference. The fixture of the object results in the dissipation of energy in the form of vibrational motion. (Precisionmicrodrives.com 2019c.) Figure 5 is the ERM motor and its exploded view, produced by precisionmicrodrives

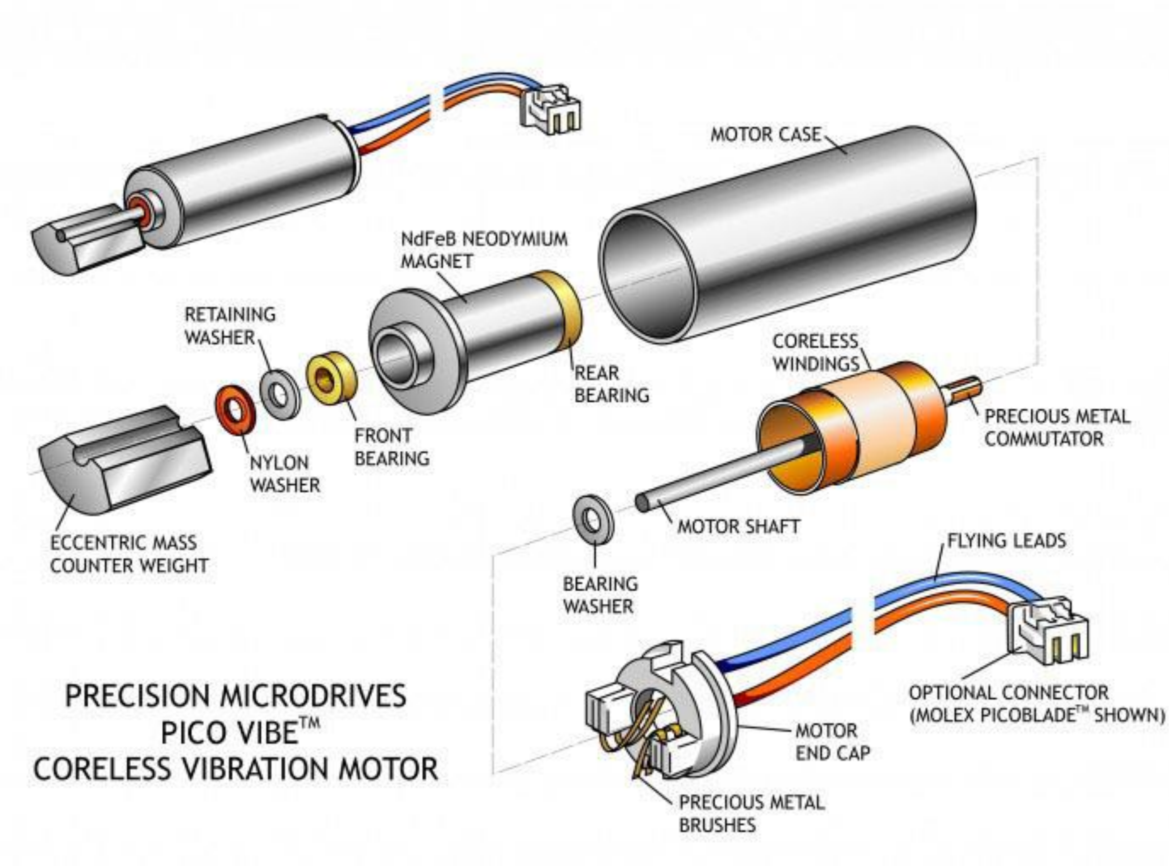


Figure 5. ERM motor by precisionmicrodrives (Precisionmicrodrives.com 2019a).

Applications

ERM motors are used in a wide variety of commercial applications. Most popular products with ERM motors include cell phones and tablets computers. Further, the ERM motors are used in high tech medical instruments operated by hand. The displays installed in the automotive include ERMs to notify the user. Industrial user interfaces e.g. control panel of CNC machines produce a vibrational haptic feedback using ERM motors. (Fictiv.com 2019.)

Maturity

ERM motors have been in use for a long time. During the previous decades the install ability of these motors has increased significantly. The evolution over time has resulted in the reduced size and enhanced generation of smooth vibrations. The hardware of the vibration motors has become more reliable and has a longer operational life. Consequently, the ERM technology is quite mature.

2.1.5 LRA

Introduction

Linear resonant actuators (LRAs) are an alternative haptic feedback generation devices to ERM motors. LRAs are gaining popularity as a replacement to ERMs due to the range of advantage that they offer. LRAs offer better haptic feedback performance and higher efficiency in operation. Touch screen devices are the most popular products that are adapting LRAs rapidly. (Texus Instruments 2019.)

Uses of LRA

LRAs are dedicatedly made to generate vibrations. The response time of LRA is less than that of an ERM motor. This is because the ERM motor takes time to reach the maximum speed. LRAs have evolved into compact sized, highly efficient haptic feedback generators. The vibrations are smooth and rhythmic. Since LRAs are used mostly in the handheld devices, so their energy efficiency allows the device to work longer on a single charge. (Hélin, Sadaune and Druon 1998.)

Working of LRA

LRAs use the movement of a tiny mass to generate vibration. The repeated movement of this mass about a mean position generates vibrations. Unlike ERM motors, LRAs do not have an off centered mass.

Like ERM motors, LRAs also use electric currents and magnetic field to generate vibrations. The major difference between the two is that LRAs have voice coil, which is equivalent to the armature in ERM motor, but the voice coil stays stationary. A magnetic mass is present in the space within the voice coil. This magnetic mass moves under the influence of electromagnetic field of the voice coil. LRAs work with AC current, to allow the alteration of direction of electromagnetic force of voice coil, thus changing the direction of motion of the magnetic mass. The magnetic mass is connected with a spring that brings the mass back to its center position. The movement of mass tends to generate a movement of the LRA thus producing vibrations. (Yamaguchi et al. 2008.) Figure 6 is the LRA motor and its exploded view, produced by precisionmicrodrives

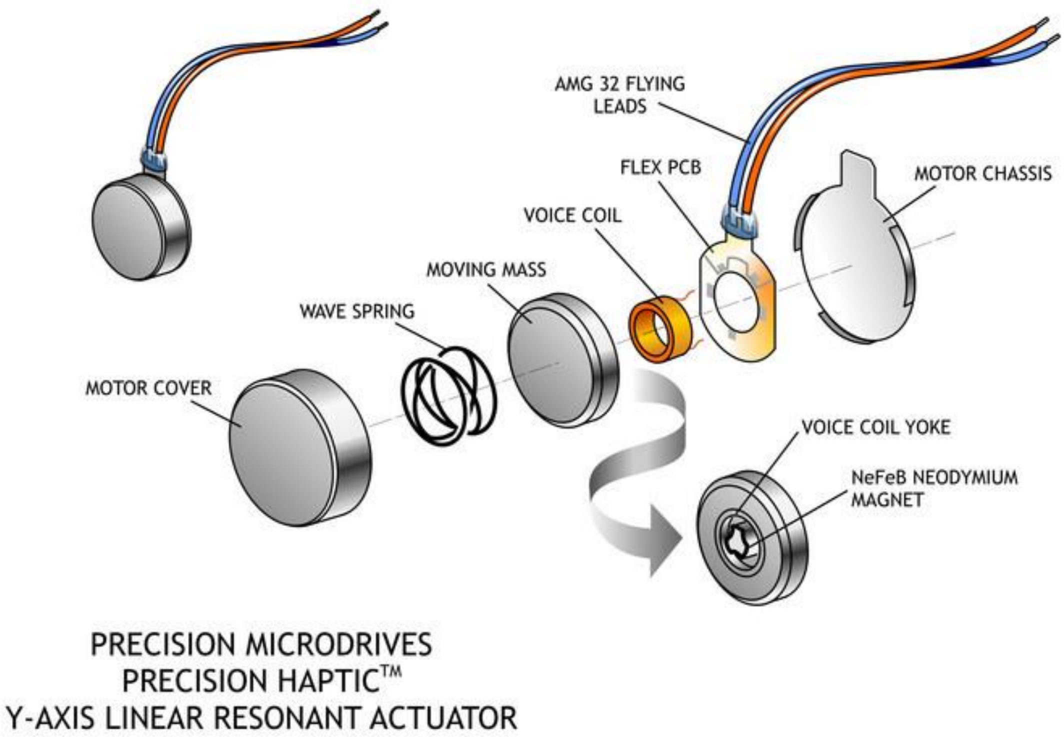


Figure 6. Construction of an LRA by Precision Microdrives (Precisionmicrodrives.com 2019b).

Applications

The applications of LRAs include mostly the handheld devices. LRAs are gaining popularity in the new smartphones since it enhances the performance of the alerts during silent mode of the device. Apart from that in the tables and E-readers the user interface haptics are made more effective and pleasant by using LRAs. The apple iPhones are an example of the smartphones that use LRAs. Also, the touch pads of the laptops, that have the feature of haptic feedback use LRAs. (Baolong Electronic 2019.)

Maturity

LRAs are more sophisticated than ERM motors. They have ergonomic designs and sizes that can meet the requirements of various applications. The technology itself is a simple mechanical structure working on the basic principal of electromagnetism. LRA have technology mature enough to be tried to be installed in the elevators.

2.1.6 Capacitive Electrosensory Interface

Introduction

Capacitive electrosensory interface (CEI) is a novel concept of haptic feedback in the touch interface displays. The technology is stimulated with the electro-sensation through a capacitive coupling. This creates a variable electrostatic pressure on the surface of the display. This variation in the electrostatic field is perceived through the sense of touch, thus creating a physical sensation of the texture being displayed. The electrostatic pressure is generated from the electric field that is present on the top of the display. This perceivable variation can be utilized as a haptic feedback in touch display devices. (Bai et al. 2016.)

CEI does not utilize any additional source of galvanic current, to create a variable electrostatic field. The display has an insulated surface and the capacitive field is generated by the coupling of the charges present on the display surface and on the skin. The haptic interaction occurs through the depression on the skin created by the electrostatic pressure present on the surface of the display. The capacitive coupling can be realized from without the contact between the skin and the display surface. (Linjama and Mäkinen, 2009.)

Uses of CEI

The rise in the popularity of touch screen devices in various applications has resulted in the replacement of the traditional devices in some commercial applications. The activation of traditional devices relied upon buttons that provided haptic feedback. Even though the input media to the touch devices has developed rapidly to much advanced levels, the feedback solutions from the touch interactions have significantly lagged in evolution. The touch screen devices are not classified as feel interface devices since they lack the physical sensation of the media being displayed. This inability to generate the feeling of the visible media has been recognized as a technical deficiency. (Hoggan, Brewster and Johnston 2008.) The use of CEI develops a mechanical sense of touch which is recognized as a more natural feeling that just an electrostatic feeling. Since the skin is receptive towards the electric or magnetic fields, thus the discernment occurs due to these fields. (Linjama and Mäkinen 2009.)

Working of CEI

Linjama and Mäkinen (2009) has described the working of CEI occurs through the creation of an electrostatic pressure on the surface of the display. This pressure is felt on the skin due to the vibrational frequencies of 100 to 200 Hz. Since the human perception to vibrations is most receptive at these frequencies, hence an excitation is felt on the skin in the form of a force. This force is perceived as a sensation of touch. Apart from this feeling of touch generated due to the presence of the electrostatic field, the contact to the surface on which the charges are concentrated, enhances the sensation of touch. Figure 7 shows how the effect of feedback is generated by CEI using electrostatic charges.

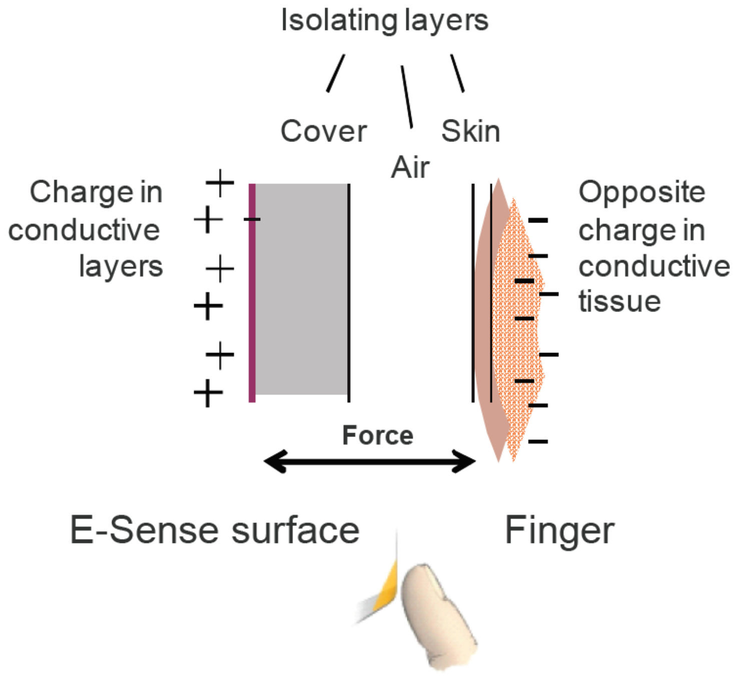


Figure 7. Working of CEI (Linjama and Mäkinen, 2009).

Capacitive electrosensory interface work with the help of a thin film coated on the surface of the display. These films work as an electrode when a small current is passed through it. This electrode works on the principle of Coulomb's law thus creating a force of attraction between the oppositely charged finger and the surface. This force of attraction is modulated with the help of an internal circuit, and various physical sensations are created. There are no moving parts in this technology, thus the working life of the components is free from mechanical wear and is silent. The commercial example of CEI is “Tixel” by Senseg, a Finnish based company. (Chester 2012.) Tixel coating location is shown in figure 8.

Figure 8. Location of charge inducing layer (Chester 2012).

Applications

Linjama and Mäkinen (2009) quote that the CEI can find application in all the flat screen touch display devices, to generate a haptic feeling on the surface of the display. The application can include multi point touch input and correspondingly obtain a multi-point haptic output. The commercial use of the CEI was in IPAD3 developed by Apple Incorporation.

Maturity

The discontinuity of the use of CEI in the commercial products like IPAD sold by Apple Incorporation indicates less acceptance by the consumers. The technology is dependent upon the sensitivity of the skin i.e. a hand with thick skin might not perceive the haptic feedback at all. The technology has been in existence for a while now but the acceptance in the industry is poor. This indicate a room for improvement in the offerings. (Hoggan 2010).

Based on the literature the CEI devices still in development and have not yet reached a reliable level of maturity.

2.1.7 ULTRAHAPTICS (Sound Waves)

Introduction

Ultrahaptics is a system that uses ultrasonic waves to create a haptic feedback above the surface of the touch user interface. The phenomenon has been presented as a commercial solution by United Kingdom based Ultrahaptics. The response from the device is obtained by projecting distinct points on the user's hand. This enables the user interface to produce numerous response locations in the mid-air. The experimentation has shown that the focal points are perceived differently with different tactile characteristics. (Carter et al. 2013.)

The excitation of human senses with the help of ultrasound was investigated as early as in 1970. It was observed that the use of focused ultrasounds can initiate the sense of touch that can activate the feeling of tickle, heat, pain and itch. Two different ways have been observed that can be applied to excite the skin through ultrasound. First is the use of acoustic emission force, that is created by the reflection of the sound waves. The haptic feeling originates due to the focused beam of sound that creates a prune wave on the skin which is distinguished as a feeling. Second method uses the direct excitation of the nerve fibers. This method is unsuitable for use over longer periods of time. (Vidal et al. 2008.)

The human skin has a tendency to feel these sounds waves. The integration of sound waves to a user interface to generate a haptic feedback is achievable. This integration of technologies gives the users a sense of touch even without touching the surface of the interface. By using specialized electronic equipment, the ultrasounds can be overlapped, and physically perceivable node points can be generated. (Long et al. 2014.)

The use of multitouch surfaces for providing information has gained immense popularity especially at public locations. Such applications present dynamic interfaces that provide information for various people by changing the display. This enables interaction of multiple users with the user interface at the same time. These user interface devices are time efficient and easy to relate with. The presented information changes continuously so the possibility of using a haptic feedback system reduces significantly. This creates a hurdle for users since there is no perception of a feedback after the input. The lack of feedback creates a challenge for the visually impaired. The use of vibratory feedback mechanisms could help in identifying the reaction of the device but still the task of finding the correct location on the surface of the device remains a barrier. The use of ultrasound presents the opportunity to make identifiable interesting locations for the users. This user can sense a location specific response from the user interface device. (Banter 2010.)

Uses of Ultrahaptics

Ultrahaptics is finding its applications in the situations where a contact with the device is not necessary to control it. There can be situation where it is not possible to divert attention towards a specific device to control it. One example of this situation could be while driving a vehicle, the driver should stay focused on the road. To change the volume of the speakers, he'll just have to use a hand gesture. Before this technology, the user had to use aiding equipment like body gear, to perform a contactless operation and receive haptic feedback. (Carter et al. 2013.)

Working of Ultrahaptics

The haptic feedback from the ultrahaptics is obtained through the concentration of acoustic radiation force. The acoustic radiation force is the one that is generated due to the echo of the ultrasounds from skin. The focused beam of ultrasounds results in the generation of shear wave in the tissues of the skin. These waves create the displacement in the skin tissue which result in the activation of the mechanoreceptors of the skin, thus giving a haptic feedback. The ultrasounds are projected onto the skin such that most of them are reflected back by the skin. This is done from safety point of view. The previous studies have depicted that the density of the reflected ultrasounds is considerably high. This is because the density of skin soft tissues is higher than air, thus the coefficient of reflection is very high. About 99.9% of ultrasounds are returned after striking the skin and only 0.1 % of them get absorbed in the skin.

Ultrahaptic technology creates the feeling of haptic feedback in midair by generating single or multiple concentration points of the ultrasonic energy, focused on to the skin of the user.

These concentration points are achieved through ultrasonic buffers aided by the algorithms obtained from signal processing. The frequency of the ultrasounds is kept at 40kHz. The human skin receptors are not capable of detecting this frequency, instead only the changes in the frequency are felt. Thus, to generate a haptic feedback a specific region of the ultrasounds is brought below the detectable range of the skin. (Carter et al. 2013.)

Applications

Ultrahaptics is a relatively new technology. According to the inventors there is a huge potential for this technology to be used in public settings, where user would prefer touchless operating systems. Some examples of such situations include ATM machine equipped with ultrahaptics technology, ticket vending machines and food vending machines. Apart from that, this technology will find popular application in automobile control e.g. temperature controls, volume controls and other gadgets of dash board. (Ultrahaptics 2019.) A concept UI, capable of giving haptic response in mid-air presented by ultrahaptics has been shown in figure 9.

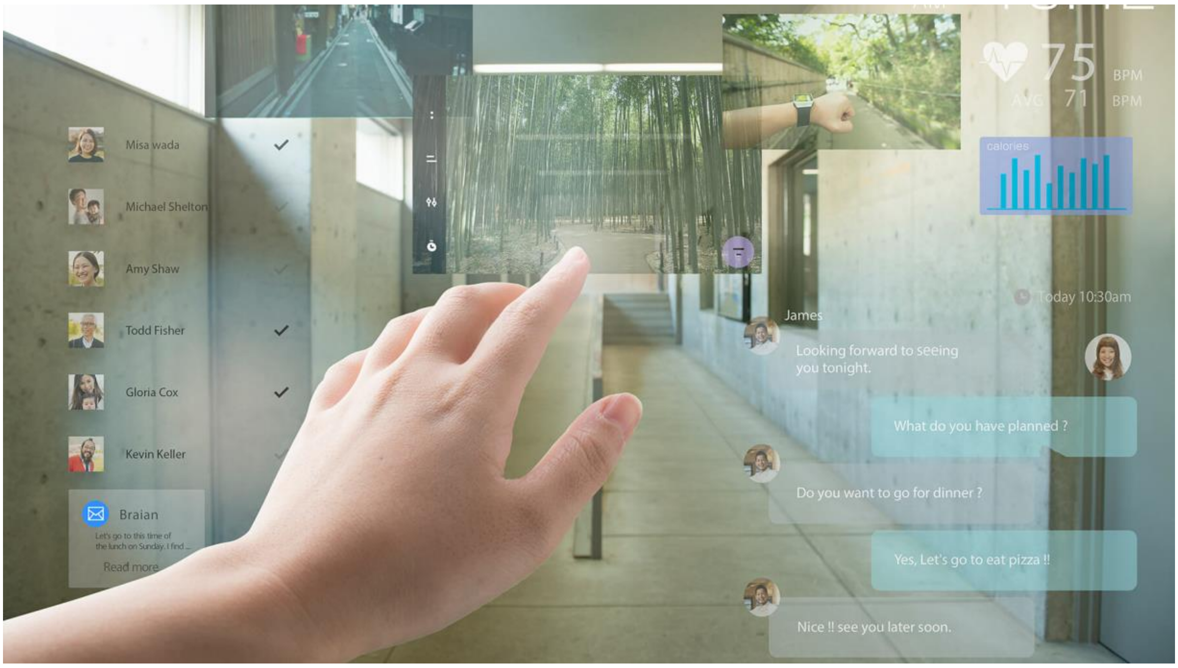


Figure 9. A UI concept with haptic feedback in midair by Ultrahaptics (Ultrahaptics 2019).

Maturity

Ultrahaptics is a new technology that has yet to make an appearance in a commercial product. As predicted by the developers of ultrahaptics, the technology will gain popularity in a variety of applications. However, there is a strong possibility that the users will find it difficult to perceive the tactile sensation. Further, there are high chances of lack of precision of the ultrahaptic devices. As exemplified by the developers, that this technology will be a great aid to the driver. There is a higher possibility that the driver might have to repeat the gesture more than once and still divert the attention towards the gadgets that he might be trying to control using hand gestures.

2.2 Practical Paradigm

The European standard defines the minimum necessities that are required for safe operation and freelance use of elevators by a comprehensive number of people, including the person with disabilities. EN 81-70:2018 defines the standards that are required to be met to obtain a safe construction and establishment of lifts, that are meant to be used for human and goods transport. The part 70 of the same standard outlines the accessibility standards for people including the disabled.

Section 4 of EN 81-70:2018 defines the perils and situations that obstruct the accessibility to the elevator by the users. The emphasis of the code relevant to this research work highlights the appropriate hazards that could occur due to the following aspects:

- Accessibility equipment
- Profile and position of the visual and audio feedback equipment
- Design, position and recognizability of the control devices
- The effort required by the user to access these devices

The code defines that the control devices should use push buttons with perceivable movement. In case of a user interface that uses a touch screen to obtain an input from the user, the usability by the disabled persons should also be considered. The control devices should have the following features in the design:

i. A minimum of $490mm^2$ of active area
ii. The active part of the control devices should be circle of at least 20 mm diameter
iii. The active part of the push button should be made physically perceivable and visually identifiable having different luminance than the surfaces around it.

iv. The face plate that houses the control devices should have a different spectrum of luminance, so that it can be identified from the operating distance as a unique surface.

v. The control devices should be activated within the operating force of 2.5 N to 5 N.

vi. Because of the operating force, the activation of the control devices should be signaled with a haptic feedback, that is perceivable by the user. For example, a traditional elevator button, comprises of a mechanical feedback, which is recognized upon pressing the button.

vii. Should have an audible and visual indication of the receipt of the activation signal.

viii. The button for the exit floor should protrude 5mm more than the other buttons and desirable color for this button is green.

ix. There should be a symbol in each activation part of the control device. This symbol should be 1mm in height.

x. Distance should be at least 10mm between the active parts of the control devices.

xi. There should be the braille code for the numbers, for the users with visual impairment. In specific cases the center button should have a dot for example, in case of a keypad, there should be a dot on number 5. (European standards 2018.)

3 METHODS

This chapter discusses the methodology that was adapted to achieve the objective of this thesis. The objective of the thesis is to choose the best technology for a haptic feedback capable signalization system.

The term “best technology” in this thesis has been defined as the technology that is most compliant with the European standard EN 81-70:2018 and is able to meet the industry requirements as described by the experts from KONE corporation.

This thesis is a comparative study for choosing a technology that can be used in the operation of the elevators. To accomplish this, qualitative analysis approach was adopted. The source of data and information was from the European standards that regulate the relevant aspects of the elevator, the experts of the industry and the literature of each technology. Following aspects of the methodology have been discussed in this chapter:

i. Selection of Technologies: The technologies selected for analysis in this thesis.
ii. Methodological Approach: Describes the kind of methodology that has been used to accomplish the objective of the thesis.
iii. Methods of data collection: Describes the media used to collect the information and data on the topic and research problem.
iv. Methods of Analysis: Describes the method used to analyze the information obtained from the collected data.

These aspects are discussed in detail in the subsequent sections.

3.1 Selection of Technologies

The selection of the technologies for analysis in this thesis was done with the help of online resources and expert opinion. An extensive online research resulted in the shortlist of available technologies that are used to provide a haptic feedback upon activation. The shortlisted technologies were discussed with the experts on multiple occasions keeping in view various aspects of practicality and maturity. The maturity of each technology was discussed in relevance to the usability in elevators. These criteria led to the selection of the following technologies that can be installed to obtain a haptic feedback:

i. Piezoelectric devices
ii. Eccentric Rotating Mass Motor (ERM)
iii. Linear Resonance Actuator Motor (LRA)
iv. Capacitive Electro-sensory Interface (CEI)
v. Ultra-Haptics (Haptic feedback using Ultra-sound)

The literature study of these technologies has been presented in the previous chapter. It was agreed among the experts involved in this thesis work to include only the literature of the Ultra Haptic feedback technology and exclude it in the interviews.

3.2 Methodological Approach

The choice of the most suitable technology for obtaining a haptic feedback upon activation depends upon several factors. These factors define the qualities that should be a part of the device for use in elevator operations. These qualities are outlined by the European Standard EN 81-70:2018. Apart from the standard code the operational qualities in an elevator environment are known to the experts of this field.

In this thesis, qualitative research methodology has been adapted. The objective of the study brought into question the qualities of the selected technologies. Qualitative analysis approach was found to be most suitable since this research is focused on the evaluation of the quality of the degree to which these technologies are capable of being in compliance with the set standards and industrial needs.

The experts from KONE corporation is the sample population from whom the information was collected. Since, this research addresses a practical problem from elevator industry, the most authentic source of available information was the experts involved in the relevant field. In this case, the experts from user interface devices category of KONE corporation act as the initiation point of all the new products and research work. These experts are aware of the customer needs, regulation standards and industry limitations. Owing to these reasons, this thesis considers the information from the sample population to be applicable to the elevators in general.

3.3 Methods of Data Collection

This research has been derived from three sources of information as shown in figure 10:

i. European Standard EN 81-70:2018: Source of information on accessibility code for user interface devices.
ii. Online resources: Source of information on the literature, maturity and working of the haptic feedback capable technologies.
iii. Expert Opinions: Source of elevator environment specific information.

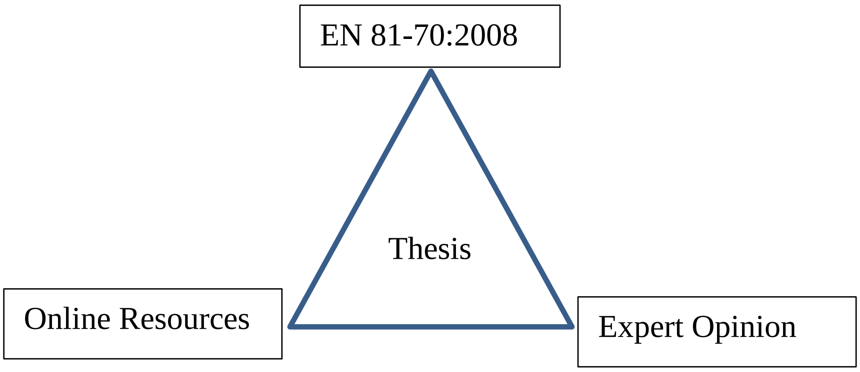


Figure 10. Three sources of information of this thesis.

The research was initiated with the benchmark set by the standard EN 81-70:2018. This requirements outlined in EN 81-70:2018 were studied, and the necessary features outlined in the standard were listed. This helped in the generation of the idea of the capabilities that a user interface signalization device should have.

After the familiarization with the requirements for the device to be installed in elevator, online resources were explored to find the technologies that are in use to generate feedback to the users. The identified technologies were identified and listed. These listed technologies were studied extensively, to develop a familiarization with their working, limitation, reasons of use and applications. Most of the literature was obtained through the online databases of ScienceDirect and jstor.

After the online exploration and short listing of the most feasible technologies that were expected to be compliant with the EN 81-70:2008, experts were asked for their opinions about each of these technologies. The expert opinion was obtained through a semi structured interview methodology. The interviews were accomplished over a period of over six months, where the experts were asked a question whenever it arose. The group of experts comprised of the experts from the user interface category of KONE Corporation. The experience and educational background of the experts included mechanical and electronics. This group of expertise was a suitable sample for this thesis, since it was expected that opinion on all the aspects of a haptic capable device can be obtained.

The questions for semi structured interviews were developed from the EN 81-70:2008 code. These questions were put together in a template and forwarded to the members of the user interface category of KONE corporation. Apart from the question added to the template, the opinions of the experts were also taken on various occasions. The knowledge gathered through the template and discussions has been analyzed in the results chapter of this thesis.

3.4 Analysis of Data

The research work has focused on identifying the qualities of the selected technologies that comply with the requirement of the European standard EN 81-70:2018. The information to be analyzed was obtained from three sources i.e. existing literature, European Standard EN 81-70:2018 and opinions from experts. Thematic deductive approach was adopted to analyze this information. The set of required qualities from EN 81-70:2018 was considered as a theme. The relevant qualities of each technology were used to deduce a technology specific theme.

A set of parameters was defined that needed to be met by the new technology. These parameters were obtained from EN 81-70:2018. The most suitable parameters were selected by the experts as the minimum requirements that the new technology should meet to be considered useable in an elevator environment. The literature review and information through expert opinion was aimed at evaluating each new technology in terms of the parameters listed below:

i. Knowledge of the working of each technology and their applications in daily life.
ii. Reliability of technology in giving a haptic feedback to the user
iii. Possibility of delay in haptic feedback
iv. Effect on the aesthetics of the product the technology would be used in
v. Ingress Protection (IP) code compatibility
vi. Availability of sufficient activation area
vii. Possibility to make activation area identifiable

viii. The identifiability of the feedback generated
ix. The space requirements to install the technology into an elevator environment component
x. The effect of each technology on the complexity of the system
xi. The possibility of improvement in working of the system by using the new technology in comparison to the traditional solutions
xii. The benefits, drawbacks and limitations of using each of the technology

4 RESULTS

This chapter narrates the outcomes of the expert opinion. The opinions have been classified in to the eleven parameters that had been selected to evaluate the validity of a new technology in an elevator environment. There are four sub-sections in this chapter that present the findings on each technology in terms of the selected evaluation parameters.

4.1 Piezoelectric Devices

This section of the chapter presents the findings obtained from the expert opinion on piezoelectric devices. The proceeding paragraphs describe the views of the experts on piezoelectric devices in terms of the milestone parameters.

Most of the experts were well familiar with the piezoelectric devices and their functioning. Some of them were not familiar with the daily life applications where piezoelectric devices are used. It was found that the experts with a background in electronics have a better understanding of the working and application of these devices.

During the discussions on the amplitude of the feedback, all the respondents agreed on the good capability of the piezoelectric devices to produce a haptic feedback. The haptic feedback from piezoelectric device was quoted as "*reliable, good quality feeling"* by one of the experts. Those experts who had experienced commercial applications equipped with piezoelectric feedback devices were optimistic about the recognizability of haptic feedback generated by piezoelectric devices in an elevator environment.

Moreover, the respondent with the electronics background believed there will not be a delay in response in giving a haptic feedback from the piezoelectric devices. One of the respondents quoted *"Delay will be mostly generated by system architectural design, not by piezo technology itself"*. He further explained that it might happen in some cases where a delay is intended in the execution of the input command. The respondents with a background in mechanics were unsure of the possibility of delay by piezoelectric devices.

However, all the respondents were of the same idea that there will not be any effect on the outlook of the product where piezoelectric devices will be used. Some experts were cautious that the quality of the outlook will depend upon the method with which the piezoelectric device will be integrated into the system.

While talking about the protection against water, the respondents were optimistic about the possibility of creating a setup that will be compliant with the IP rating. According to one of the interviewees, since the piezoelectric sensors do not need a direct contact in order to activate, so the sensor can be enclosed in a sealed cover, thus ensuring a good protection against water.

Similarly, the interviewees believed that EN standards compliant activation area can be developed while using piezoelectric devices. Some respondents corelated this aspect with the mechanical positioning of the piezoelectric devices. Furthermore, the mechanics experts argued that the achievement of EN standards depends upon how the elevator device is designed, but they added that the piezoelectric devices provide enough flexibility in the design of the elevator components that they can satisfy the requirements of the EN standards.

Likewise, all the respondents agreed to the possibility of achieving an identifiable activation area for the operation of the piezoelectric devices. Again, it was correlated with the method of integration of piezoelectric devices with the elevator device. The popular opinion was that the operational flexibility of piezoelectric sensors could conveniently lead to a design where the activation area can be made according to the relevant standard.

Proceeding with the discussion about the space required for the installation of piezoelectric devices, the experts believed that the space required to install a piezoelectric device is narrow, contrary to that, when asked about the availability of the space in a device for use in elevator environment, most of the respondents were unsure.

While answering the questions about the changes in the complexity of the system, most of the respondents were of the opinion that the use of piezoelectric devices makes the elevator system more complex. When asked about the reference to which they compared the complexity, the response in all cases was the complexity of the system that uses traditional haptic feedback technologies. Even though they believed that it’ll make the system more reliable than the traditional solution yet it brings complexity to the system.

During the discussion about the changes in efficiency of the elevator operation, respondents were unsure on how the system will improve by using the piezoelectric devices instead of the traditional solution. Most of them narrated that they can not comment on this, with surety since, there is no prior case where these devices have been used in an elevator environment.

Before concluding the interviewees narrated several benefits of using the piezoelectric devices. Some draw back and limitations were also speculated during the conversations. They anticipated that such benefits can be reaped and limitations can be overcome upon installation in the elevator.

4.2 ERM Motor

This section of the chapter presents the finding obtained from the experts opinion on ERM motors. This section progresses with the presentation of the views of the experts on ERM motors in terms of the milestone parameters.

About half of the number of interviewed experts were familiar with the operation of the ERM motor. But more than 80 percent of them were aware of its daily life applications. Like in case of piezoelectric devices, the experts with electronics background were more familiar with the ERM motor.

Since the understanding of operation of ERM motors was new to the knowledge of some experts, so they were unsure about the ability of the ERM motor to produce a haptic feedback response in an elevator environment. While narrating the wide acceptance in the commercial applications, most of the experts agreed that the operational reliability of the ERM motors is high and they can serve the purpose the of producing a good haptic feedback in an elevator environment.

During the discussion about the responsiveness, the interviewees with the background in electronics were of the opinion that there will be a delay in response in giving a haptic feedback from the ERM motors. When asked about the good responsiveness of ERM motors in the commercial applications, the common answer was that the elevator environment does not have any common handheld devices as part of the elevator system. The respondents with mechanical background were unsure about the delay in haptic response.

Concerning the aesthetics of the elevators devices, most of the experts believed that there will be no effect on the outlook of the product where ERM motor will be used. While exemplifying the common handheld devices some experts predicted that a variety of aesthetical features can be added to the design of an elevator device with the ERM motors.

Again, referring to the commercially available devices, the possibility to achieve a high IP rating was predicted by all the experts. They were optimistic that a sealed device housing an ERM motor can be developed for an elevator environment. Some experts were speculative about achieving IP compatibility in the case where more than one ERM motor might need to be installed.

While discussing about the possibilities of developing sufficient activation area according to the standards, experts gave a mixed response. Most of the experts expressed a positive opinion regarding the possibility to have enough area to feel the haptic feedback using an ERM motor but they cautioned that the intended location of the haptic feedback might vary with respect to the distance from the location of the motor.

Likewise, all the respondents agreed to the possibility of achieving an identifiable activation area for the operation of the ERM motor but again narrated the concern of poor haptic feedback based on the location of the activation area. Experts with background in mechanics correlated the good possibility to have an identifiable area with the sleek and ergonomic design of the ERM motor.

Contrary to that the respondents with the mechanics background showed a concern on the availability of the space for the installation of the ERM motors. While the experts with the electronics background were unsure regarding the availability of space by arguing the presence of various sizes of ERM motors. One of the arguments was *"Probably there are many different sizes of ERMs. Also, mobile phones use ERMs and are not so thick nowadays"*.

Continuing the interviews with the aspect of complexity of the system, most of the respondents were of the opinion that the use of ERM motors make the elevator system more complex. When asked about the reference to which they compared the complexity, the response in all cases was the complexity of the system that uses traditional haptic feedback technologies. When asked about how do they change the complexity in comparison to a system that uses piezoelectric devices, most of the respondents said that ERM motor equipped system will be more complex.

Furthermore, most of the experts were unsure on how the system will improve by using the ERM motors instead of the traditional solution. Some of them argued that the ERM motors have been used in elevators as a part of an existing commercial device, but any other means of installation could be a new experience in their experience. Before concluding, the interviewees narrated a number of benefits of using the ERM motors. Some draw back and limitations were also speculated during the conversations.

4.3 LRA Motors

The section presents the results of the opinions of the experts regarding the use of LRA motor for producing a haptic feedback in elevator environment. This section continues with opinions of experts regarding each selection parameter in terms of LRA motor.

Most of the experts were familiar with the LRA motors though some of them were not familiar with the daily life applications of LRAs. One of the experts from electronics background mentioned that *"I have a very basic understanding of LRAs"*. But like ERM motors, LRAs were considered by most of the respondents as a new device for elevator industry.

Moreover, the respondents were unsure about the reliability of the operation of LRA motors in an elevator environment. Even though most them were familiar with lRAs but they expressed that they were not familiar with the causes of failures of LRAs in the existing applications.

While talking about the possibility of delay in giving a feedback, the experts with the electronics background believed there will be a delay in obtaining a haptic feedback from LRAs. One opinion was that *"Because it is a moving physical mass, so some delay will be always be there. But not as much as for the ERM"*. The respondents with a background in mechanics were unsure of the possibility of delay.

Similar to opinions about ERM motors, most of the respondents believed that there will be no effect on the outlook of the product where LRAs will be used. Some of the respondents from the mechanical design background were optimistic about the possibility of have a agile design with LRAs. Since in their opinion, small LRAs can satisfy the requirements of a good haptic feedback.

Unlike with the case of ERM motors, most of the respondents were unsure about the possibility of achieving an IP compatible elevator environment component consisting of LRAs, while experts with electronics background agreed to the possibility of achieving the IP compatibility by using the LRAs.

While discussing about the minimum area required to activate an LRA in accordance with the standards, majority of respondents agreed that EN standards compliant activation area can be developed while using LRAs. Some respondents were unsure of this aspect since they corelated this aspect with the mechanical positioning of the LRA motor.

Moreover, all the respondents agreed to the possibility of achieving an identifiable activation area for the operation of the LRA motor. Again the experts with mechanics background expressed their views on the identifiability of the activation areas as a relative entity, depending upon the kind of design and the location of LRAs in it.

Moving on with the space requirements, the respondents agreed that the space required to install an LRA motors is narrow, on the other hand, when asked about the availability of the space in a device for use in elevator environment, most of the respondents were unsure, that how will the presence of an LRA will affect the space usage in a device.

When the changes in the system were brought in the interview, most of the respondents believed that the use of LRA motors makes the elevator system complex at least to similar level of complexity to a system containing ERM motor. Even though they mentioned that it is a mere concern, since they were not familiar of such devices in an elevator.

Equivalently, expressing their opinion on system improvement, most of the respondents were unsure on how the system will improve by using the LRA motors instead of the traditional solution. Most of them expressed the same concern of being unfamiliar with an elevator system equipped with an LRA device. To conclude, the interviewees narrated several benefits of using the LRA motors, which they expected will arise in the use of elevators. Some draw back and limitations were also speculated during the conversations.

4.4 Capacitive Electro-sensory Interface

The section presents the results of the opinions of the experts regarding the use of CEI for producing a haptic feedback in elevator environment. Following sub-section provide a glimpse of the opinion of experts regarding each selection parameter in terms of CEI.

Most of the experts had a basic idea about the CEI. Some of them were not familiar with the daily life applications of CEI. A few of them were aware of the working of the CEI devices, but they did have an understanding of the kind of features that CEI devices offer in relevance to the standards.

While discussing about the reliability of the operation, all the respondents were unsure about it. The common argument was that they were not familiar of the operation of a CEI device in an elevator environment. Moreover, they commented that the CEI devices are not very common yet, so it was difficult to comment on the operability of such devices.

Progressing the interviews with the aspect of delay in feedback, the respondent with the electronics background gave the opinion that there will not be a delay in a haptic feedback from CEI. They argued that since CEI is an technology used with touch user interfaces and the advanced evolution of such devices has resulted in a good response time of haptic feedback.

Discussing further about the effect of CEI devices on aesthetics of the elevator, most of the respondents believed there will be no effect on the outlook of the product. They mentioned that its their assumption that the elevator UI will look similar to the existing elevators with touch user interfaces.

Continuing the interviews with IP protection, most of the respondents were unsure about the possibility of achieving an IP compatible elevator environment component consisting of CEI, while some experts were confident that the IP compatibility is possible to achieve with CEI. They exemplified the existing touch user interfaces that have IP protection but they were cautious about the low rating of such devices.

Considering CEI as a new technology, most respondents were unsure on how enough activation area can be developed while using CEI. Even though some argued in the possibility of developing a sufficient area but according to them it'll depend upon the kind of application where CEI will be used.

Furthermore, most of the respondents also argued that as of today while using CEI, it is not possible to add a physical feature that can define a boundary of the activation area.. Some of the experts were of the opinion that it is possible to develop an identifiable boundary of the activation area, but they were uncertain on the quality and detectability of the boundary outline.

The respondents agreed that the space required to install a CEI is narrow, on the other hand, when asked about the availability of the space in a device for use in elevator environment, most of the responses were that there will not be enough space. They correlated the possibility of utilization of available space in elevator UI devices, with the size of available CEI devices.

While talking about the system complexity, most of the respondents were unsure on how the use of CEI will affect the complexity of the system. Even though some of them speculated that it might be add a manageable complexity to the elevator system but the cost to manage that might make it an unsuitable choice.

Continuing the interviews with the aspect of aesthetics, the popular opinion among respondents was that the use of CEI would add aesthetic improvement in the elevator components. Some of the respondents argued that the CEI would be a different experience for the user. Interviewees concluded with a talk about some benefits of using CEI. But quite many limitations were also pointed out.

5 ANALYSIS

In this chapter, the knowledge gained from opinions of the experts and literature review has been evaluated and analyzed by the researcher in terms of the parameters extracted from the EN81-70:2018 standard. Each of the four technologies has been discussed in the sub-sequent sections.

5.1 Piezoelectric Devices

The technology of piezoelectric devices is mature and has been in use for decades now. With the passage of time the piezoelectric crystal materials have become more reliable and efficient. The piezoelectric devices are well known among the industry experts. The commercial applications are gaining popularity in order to develop compact and reliable products.

The information on piezoelectric devices gathered through expert opinion and literature review validates that these can produce a noticeable haptic feedback. Since the sensor is itself the actuator, so the delay in the haptic feedback does not occur. Further, the commercially available piezoelectric devices are tested for a prolonged operational life cycle.

The compact assembly of a piezoelectric device makes it very convenient for use in elevator environment. The sensor does not require to be contacted directly to activate a signal. This implies that the device can be enclosed in a completely sealed environment where water cannot enter, thus making this a favorable device for creating IP compliant devices.

The elevator environment is space sensitive, especially the signalization devices have very little space available for gadgets and electronics. The sleek design of piezoelectric devices makes them favorable for use in devices in elevators. During the research work, it was observed that the piezoelectric devices occupy less volume as compared to the traditionally used solutions at KONE corporation. The piezoelectric device offers high flexibility of creating mechanical design that can meet the criteria set by the European standard EN 81-

70:2018. For example, creating enough area of contact to generate a signal from Piezoelectric device.

These devices do bring changes to the electronics with in the elevator components. The changes could lead to complexities, but the simple operating principle makes piezoelectric devices easy to work with. But the extract of the discussions with the experts at KONE corporation depicts piezoelectric devices as cost efficient solution with opportunities to explore more possibilities in UI devices. These were described as the modern version of the traditional solution. Even though the use of piezoelectric devices in the elevator industry has not been experimented before.

5.2 ERM Motor and LRA Motor

ERM and LRA motors are also a commercially mature solution that offers smooth haptic feedback. The ability to produce varying vibrations produced by the both motors provides the haptic feedback for various kind of inputs. The information on the operation of ERM and LRA motors is not common among the professionals of elevator industry, since it has not found its use in the elevator devices, so far.

ERM and LRA motors are preferably used in cell phones. With the evolution of smart phone, these motors have also evolved in the past decade. This has led to the development of highly reliable motors. The cases of failure of these motors in most of the commercial applications are rare. The use of an ERM or an LRA motor in an elevator environment will require a sensor, so that it can activate the motor for generating a haptic feedback. This use of a separate component will result in the delay in generating the haptic feedback. This delay could lead to non-compliance to the EN 81-70:2018 code.

The use of ERM or LRA motor does not affect the aesthetics of the devices in which it is used. Again, taking the example of the cell phone, the aesthetics are well groomed even though there is a haptic feedback motor inside the device. Since the location of activation signal might be different than the location where the motor might be installed, this could lead to poor haptic sensation to the user.

As argued by most of the experts from KONE corporation, the use of ERM or LRA can significantly increase the operational and manufacturing complexity. This could be because there can be a need of more than one motor in a device. Further, it will be cost inefficient to install multiple motors to improve the quality of the haptic feedback. With the increase in the number of motors the space consumption also increases, this could result in tightly spaced installation of electronic components.

As discussed above, the use of ERM or LRA motors require a separate sensor. This make the system more vulnerable to malfunctioning since the number of components increase, and malfunction can occur in any component. This can be argued that the activation sensor could be a traditional solution, or it could be modern solution. In case of the tradition solution being used as a sensor, the need of installing an ERM or LRA motor disappears, since traditional solution provide haptic feedback. In case of a modern solution, for example a touch screen, the requirements of EN 81-70:2018 cannot be met, this case is further discussed in the next section.

As speculated by the experts at KONE corporation the use of vibration as a medium of haptic feedback might come with the drawbacks like unpleasant sounds, design limitations for the elevator devices and poor haptic feedback in bigger devices.

5.3 CEI

The capacitive electrostatic interface is a new technology. The information about the working of CEI is not well spread, but still some experts from the interview group were familiar with the technology. Even though the working of CEI remained largely unknown to many experts.

The only way to implement CEI is through the use of touch screen interface in the user interface devices in an elevator. Touch screen devices come with a fine and reliable haptic feedback mechanism. The touch screen device mostly utilizes vibration motors to generate a haptic feedback. If an example of any touch screen tablet device is taken, it can be observed that the device gives a haptic feedback without any delay.

Historically, due to the lack of ability to completely comply with the European standard EN 81-70:2008, touch screens have not been used in the UI devices of elevators. As argued by most of the experts the addition of a touch screen interface will improve the aesthetics of the UI devices. This will make the assembly process efficient, since a touch screen with CEI technology can be outsourced and assembled to the main level assembly upon delivery. With the modern-day touch interface devices, the IP code compatibility is achievable.

The use of touch screen with CEI will permit a design flexibility to the mechanical and software designers of the user interface devices. The use of CEI will make it possible to physically identify the activation area. The possibility to make the activation areas boundaries identifiable is not yet achievable with a touch screen interface. Another, short coming in using a touch screen interface equipped with CEI is that, even though the activation area is identifiable with a difference in the charge concentration but for a visually impaired person, the first contact with a UI device is aimed at finding the correct activation area through the brail system. It is not achievable to create the brail markings on a touch screen interface, as required by the European standard EN 81-70:2018.

Furthermore, in case of a touch screen interface with high sensitivity, the first touch initiates the activation signal. For an elderly person or a visually impaired person, the first touch to the UI device might not be intended for activation of the elevator system.

The modern-day touch screen devices are sleek in design and occupy less volume. The operational life of a touch screen in a UI device might not be predictable. The touch screen devices are more prone to vandalism as compared to the technologies discussed earlier in this thesis.

It was difficult to assess that how the use of touch screen devices equipped with CEI will affect the complexity of the user interface devices and the whole elevator system. The experts also agreed on the fact that since it has only been used in some test environments. This still needs to be explored on how the use of CEI enable device tends to alter the elevator system.

6 DISCUSSION AND CONCLUSION

This chapter discusses the feasibility of the most suitable technology that can address research objective. The research was focused on the identification of a technology that can be used in the user interface devices of an elevator. The selection of the most feasible technology was partly dependent upon the capabilities of the technology to meet the European standard EN 81-70:2018 and partly on how the experts at KONE corporation view that technology based on their knowledge of the elevator environment and company standards.

The outcome of the research work was that, out of the four technologies that were expected to meet the European standard and expectations of the experts, piezoelectric devices were found to be the most suitable ones. The study demonstrates that the piezoelectric devices are most favored by the experts because of their qualities to meet the EN81-70:2018 code. The literature review depicts that the piezoelectric devices have in commercial use for well over three decades. The simplicity of the operating principal of piezoelectric devices make them a suitable component to be added to the UI devices.

Even though the CEI enabled touch screen would have been a much more modern and modular solution but the deficiency of this technology to meet the critical clauses of the EN 81-70:2018 makes it a less favorable technology. It was not anticipated that a CEI equipped touch screen devices will compliant with the EN 81-70:2018 at so many levels. Further research can be performed in finding out a solution that could enable a touch screen to be code compliant with EN81-70:2018 and more user friendly for visually impaired people. With the introduction of the foldable touch displays it seems a highly possible scenario that the touch interfaces will be able to meet the requirements of European standards for use in user interface devices in elevators.

It can be argued that the results are based upon the opinion of the experts from KONE corporation. This limits the results to be considered for researchers outside of KONE corporation. Further, the research was limited to the scope of identifying a technology that can meet the requirements set by European standard EN 81-70:2018. Any other standards that define the requirements for user interface devices have not been considered in this research work.

The research work concluded by answering both the research questions that are “What are the factors that influence the use of haptics in the user interface devices of an elevator? What is the most suitable technology for obtaining haptic feedback in the UI devices in elevator?” The study of EN 81-70:2018 contained the factors that set the requirements to be met by a UI device and the literature review of each technology presented the capabilities and limitations. Both these information sources answered the first question by highlighting the factors that influence the use of each device in UI of an elevators. Further, the second question was answered with the selection of piezoelectric device as the most suitable for obtaining haptic feedback in UI devices as a possible replacement of traditional devices.

Conclusively, the outcome of the research is that piezoelectric devices are the capable solution to replace the traditional haptic feedback mechanisms in user interface devices. The piezoelectric devices exhibit the qualities that make them capable of meeting the EN 81-70: 2018 code. The results from the expert opinion built on the evidence from the literature review that piezoelectric devices can be used in the elevator environment, where the use is rigorous and require reliability and aesthetics at the same time. This research can be continued to establish a solution that could permit the use of piezoelectric devices in user interface devices of the elevator.

LIST OF REFERENCES

Bai, Y., Neveln, I., Peshkin, M. and MacIver, M. 2016. Enhanced detection performance in electrosense through capacitive sensing. Bioinspiration & Biomimetics, 11(5), p.055001.

Banter, B. 2010. Touch Screens and Touch Surfaces are Enriched by Haptic Force-Feedback. Information Display, 26(3), pp.26-30.

Baolong Electronic. 2019. Linear Resonant Actuator (LRA) | Baolong Electronic Group. [online] Available at: https://www.vibrationmotors.com/vibration-motor-product-guide/linear-resonant-actuator/ [Accessed 30 Oct. 2019].

Blenkinsopp, R. 2019. What is haptic feedback? - Ultrahaptics. [online] Ultrahaptics. Available at: https://www.ultrahaptics.com/news/blog/what-is-haptic-feedback/ [Accessed 4 Jul. 2019].

Carter, T., Seah, S., Long, B., Subramanian, S. and Drinkwater, B. 2013. UltraHaptics: Multi-Point Mid-Air Haptic Feedback for Touch Surfaces. In: UIST '13 Proceedings of the 26th annual ACM symposium on User interface software and technology. St. Andrews, Scotland: Proceedings of the 26th annual ACM symposium on User interface software and technology, pp.505-514.

Chester, E. 2012. Senseg Technology Explained | Trusted Reviews. [online] Trusted Reviews. Available at: https://www.trustedreviews.com/news/senseg-feel-technology-explained-2910843 [Accessed 29 Jun. 2019].

E2e.ti.com. 2019. How does a linear resonant actuator work? - Analog - Technical articles - TI E2E Community. [online] Available at: https://e2e.ti.com/blogs_/b/analogwire/archive/2016/10/27/how-does-a-linear-resonant-actuator-work# [Accessed 24 Jul. 2019].

European standards 2018, Safety rules for the construction and installation of lifts - Particular applications for passenger and goods passenger lift - Part 70: Accessibility to lifts for persons including persons with disability, NEN-EN 81-70:2018, Royal Netherlands Standardization Institute, Netherlands.

Fictiv.com. 2019. Intro to Haptic Technology: Vibration Motors | Fictiv - Hardware Guide. [online] Available at: https://www.fictiv.com/hwg/design/intro-to-haptic-technology-vibration-motors#:~:targetText=Examples%20of%20ERM%20Vibration%20Motors,devices%20and%20automotive%20touch%20screens. [Accessed 30 Sep. 2019].

Galitz, W. 2007. The essential guide to user interface design. Indianapolis, Ind.: Wiley, pp.4-
Green, K., Champneys, A. and Lieven, N. (2006). Bifurcation analysis of an automatic dynamic balancing mechanism for eccentric rotors. Journal of Sound and Vibration, 291(3-5), pp.861-881.

Hayward, V., Astley, O., Cruz-Hernandez, M., Grant, D. and Robles-De-La-Torre, G. 2004. Haptic interfaces and devices. Sensor Review, 24(1), pp.16-29.

Hélin, P., Sadaune, V. and Druon, C. 1998. Theoretical and experimental study of linear motors using surface acoustic waves. Sensors and Actuators A: Physical, 70(1-2), pp.67-74.

Hoggan, E. 2010. Crossmodal Audio and Tactile Interaction with Mobile Touchscreens. International Journal of Mobile Human Computer Interaction, 2(4), pp.29-44.

Hoggan, E., Brewster, S. and Johnston, J. 2008. Investigating the effectiveness of tactile feedback for mobile touchscreens. In: CHI '08 Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. Florence, Italy: ACM New York, NY, USA, pp.Pages 1573-1582.

kone, E. 2019. KONE Destination Solutions. [online] Eritrea.kone.com. Available at: https://eritrea.kone.com/new-buildings/kone-people-flow-intelligence/elevator-destination-control.aspx [Accessed 7 Jun. 2019].

Linjama, J. and Mäkinen, V. 2009. E-Sense screen: Novel haptic display with Capacitive Electrosensory Interface. In: 4thWorkshop for Haptic and Audio Interaction Design. Dresden, Germany.

Long, B., Seah, S., Carter, T. and Subramanian, S. 2014. Rendering volumetric haptic shapes in mid-air using ultrasound. ACM Transactions on Graphics, 33(6), pp.1-10.

Mclean, K. 2000. In: (ICRA'2000. Designing with Haptic Feedback: IEEE Robotics and Automation.

Moubarak, P., Ben-Tzvi, P. and Zaghloul, M. 2012. A Self-Calibrating Mathematical Model for the Direct Piezoelectric Effect of a New MEMS Tilt Sensor. IEEE Devices Journal, 12(5), pp.1033-1042.

Partovi Shabestari, N., Rashidian Vaziri, M., Bakhshandeh, M., Alidokht, I. and Alizadeh, Y. 2019. Fabrication of a simple and easy-to-make piezoelectric actuator and its use as phase shifter in digital speckle pattern interferometry. Journal of Optics, 48(2), pp.272-282.

Precisionmicrodrives.com. 2019a. Eccentric Rotating Mass Vibration Motors - ERMs - Precision Microdrives. [online] Available at: https://www.precisionmicrodrives.com/vibration-motors/eccentric-rotating-mass-vibration-motors-erms/ [Accessed 16 Sep. 2019].

Precisionmicrodrives.com. 2019b. Linear Resonant Actuators - LRAs - Precision Microdrives. [online] Available at: https://www.precisionmicrodrives.com/vibration-motors/linear-resonant-actuators-lras/ [Accessed 30 Sep. 2019].

Precisionmicrodrives.com. 2019c. AB-004 : Understanding ERM Vibration Motor Characteristics - Precision Microdrives. [online] Available at:

https://www.precisionmicrodrives.com/content/ab-004-understanding-erm-vibration-motor-characteristics/ [Accessed 30 Apr. 2019].

Precisionmicrodrives.com. 2019d . AB-004 : Understanding ERM Vibration Motor Characteristics - Precision Microdrives. [online] Available at: https://www.precisionmicrodrives.com/content/ab-004-understanding-erm-vibration-motor-characteristics/ [Accessed 24 May 2019].

Robles-De-La-Torre, G. 2006. The Importance of the Sense of Touch in Virtual and Real Environments. IEEE Multimedia, 13(3), pp.24-30.

Sirohi, J. and Chopra, I. 2000. Fundamental Understanding of Piezoelectric Strain Devices. Journal of Intelligent Materials Systems and Structures, 11(4), pp.246-257.

Texus Instruments. 2019. [online] Available at: http://www.ti.com/lit/ml/sszb151/sszb151.pdf [Accessed 30 Sep. 2019].

Ultrahaptics. 2019. Ultrahaptics - Discover a new type of haptics. [online] Available at: https://www.ultrahaptics.com/applications/ [Accessed 27 Aug. 2019].

Vidal, F., John, N., Healey, A. and Gould, D. 2008. Simulation of ultrasound guided needle puncture using patient specific data with 3D textures and volume haptics. Computer Animation and Virtual Worlds, 19(2), pp.111-127.

Yamaguchi, T., Kawase, Y., Suzuki, S., Hirata, K., Ota, T. and Hasegawa, Y. 2008. Dynamic Analysis of Linear Resonant Actuator Driven by DC Motor Taking into Account Contact Resistance Between Brush and Commutator. IEEE Transactions on Magnetics, 44(6), pp.1510-1513.

Zhang, P. (2008). *Industrial Control Technology*. Burlington: Elsevier, pp.73-116.

ZHAO, H., LING, J. and YU, J. 2012. A comparative analysis of piezoelectric transducers for harvesting energy from asphalt pavement. Journal of the Ceramic Society of Japan, 120(1404), pp.317-323.

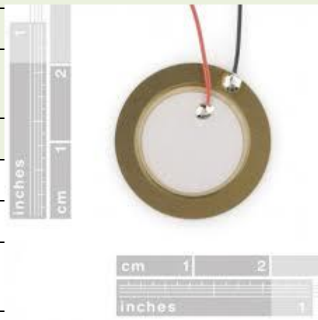
This interview questionnaire is focused on getting the opinions and thoughts of the experts from the user interface category from KONE corporation. This questionnaire can be followed up by a face to face interview.
The motivation behind this interview is to obtain industry oriented information and knowledge for haptic feedback technologies to achieve the objective of the research thesis as part of the project to develop the metal touch keypad.
The thesis is being investigated by Atif Malik from LUT University.
You can reach Atif through:
Phone: [redacted]
Email: [redacted]
For the authenticity of information obtained through this questionnaire, following information is requested from you:
Your Designation at KONE Corporation:
Your area of speciality:
Contact Information(optional):

Piezoelectric Sensors:

A piezoelectric sensor is a device that uses the piezoelectric effect, to measure changes in pressure, acceleration, temperature, strain, or force by converting them to an electrical charge. The prefix piezo- is Greek for 'press' or 'squeeze'.

Please visit the below link for a short video example of working of Piezoelectric sensor

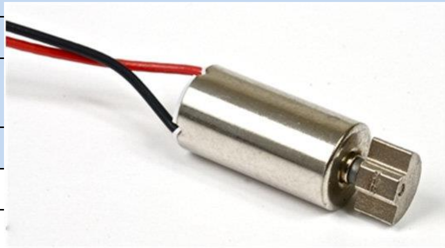
https://www.youtube.com/watch?v=TgyMZA9fHFE



Based on your expertise please reply to these question:

	YES	NO	UNSURE	My Remarks/ Thoughts/ Concerns
I am familiar with the working of piezoelectric sensors				
I am familiar with some daily life applications of piezoelectric sensors				
Piezoelectric sensors could give reliable media to provide haptic feedback to the user				
A delay in the haptic response is expected				
A compromise in the aesthetics would be needed to use piezoelectric sensors				
An IP code compliance can be achieved in a product with Piezoelectric as source of feedback				
A sufficient active area can be developed to receive a feedback				
The active area can be made identifiable e.g. with engraved or protruding boundary				
An operating feedback can be received by the user				
The feedback sensation is identifiable				
The available space could be narrow for piezoelectric sensor				
The system becomes complex by using piezoelectric sensors				
The working quality can be better than the traditional solution				
In my opinion, use of Piezoelectric sensors can yield following:				
Benefits:				
Drawbacks:				
Limitations:				

Eccentric Rotating Mass (ERM)				
The Eccentric Rotating Mass vibration motor, or ERM, also known as a pager motor is a DC motor with an offset (non-symmetric) mass attached to the shaft. As the ERM rotates, the centripetal force of the offset mass is asymmetric, resulting in a net centrifugal force, and this causes a displacement of the motor.				
Please visit the below link for a short video example of working of ERM				
https://www.youtube.com/watch?v=jvCSh5fgTZI				
Based on your expertise please reply to these question:				
	YES	NO	UNSURE	My Remarks/ Thoughts/ Concerns
I am familiar with the working of ERM				
I am familiar with some daily life applications of ERM				
ERM could be a reliable media to provide haptic feedback to the user				
A delay in the haptic response is expected				
A compromise in the aesthetics would be needed to use ERM				
An IP code compliance can be achieved in a product with ERM as source of feedback				
A sufficient active area can be developed to receive a feedback				
The active area can be made identifiable e.g. with engraved or protruding boundary				
An operating feedback can be received by the user				
The feedback sensation is identifiable				
The available space could be narrow for ERM				
The system becomes complex by using ERM				
The working quality can be better than the traditional solution				
In my opinion, use of ERM can yield following:				
Benefits:				
Drawbacks:				
Limitations:				



Linear Resonance Actuator (LRA)				
A linear resonant actuator is a precision vibration motor that produces an oscillating force across a single axis. Unlike a DC eccentric rotating mass (ERM) motor, a linear vibration motor relies on an AC voltage to drive a voice coil pressed against a moving mass that is connected to a spring.				
Please visit the below link for a short video example of working of LRA				
https://www.youtube.com/watch?v=ge_7qfv2c2Y				
Based on your expertise please reply to these question:				
	YES	NO	UNSURE	Thoughts/ Concerns
I am familiar with the working of LRA				
I am familiar with some daily life applications of LRA				
LRA could be a reliable media to provide haptic feedback to the user				
A delay in the haptic response is expected				
A compromise in the aesthetics would be needed to use LRA				
An IP code compliance can be achieved in a product with LRA as source of feedback				
A sufficient active area can be developed to receive a feedback				
The active area can be made identifiable e.g. with engraved or protruding boundary				
An operating feedback can be received by the user				
The feedback sensation is identifiable				
The available space could be narrow for LRA				
The system becomes complex by using LRA				
In my opinion, use of LRA can yield following:				
Benefits:				
Drawbacks:				
Limitations:				

Capacitive Electrosensory Interface				
Senseg is a Finnish start-up which is the pioneer of making touch screen with texture feeling with their iconic product "FeelScreen". It gives haptic feedback through LRA or ERM and also the texture on the screen can be felt with the hand.				
Please visit the below link for a short video example of working of FeelScreen by Senseg				
https://www.youtube.com/watch?v=eiOe64RPTwo				
https://www.youtube.com/watch?v=FiCqlYKRlAA				
Based on your expertise please reply to these question:				
	YES	**NO**	**UNSURE**	My Remarks/ Thoughts/ Concerns
I am familiar with the working of Senseg touch Screen				
I am familiar with some daily life applications of Senseg touch Screen				
Senseg touch Screen could be a reliable media to provide haptic feedback to the user				
A delay in the haptic response is expected				
A compromise in the aesthstics would be needed to use Senseg touch Screen				
An IP code complaince can be achieved in a product with Senseg touch Screen as source of feedback				
A sufficient active area can be developed to receive a feedback				
The active area can be made identifiable e.g. with engraved or protuding boundary				
An operating feedback can be received by the user				
The feedback sensation is identifiable				
The available space could be narrow for Senseg touch Screen				
The system becomes complex by using Senseg Touch Screen				
In my opinion, use of Senseg touch Screen can yield following:				
Benefits:				
Drawbacks:				
Limitations:				