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The Taxonomy of Indoor Home Interfaces

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Abstract

Taxonomies on interfaces are used in the field of human-computer interaction to classify and define interaction modalities, methodologies, technologies, and devices. However, most of these taxonomies and categorization methods have not taken into account the setting in which the interfaces might be utilized. Furthermore, they are frequently centered on technology or function rather than the purpose, making them prone to becoming out-of-date as technology advances. To address these issues, we suggest a new taxonomy based on the setting and purpose of indoor home interfaces. We distinguish between the private and public settings at home and consider a range of purposes when categorizing indoor home interfaces. This taxonomy aims to provide a comprehensive and timeless categorization of indoor home interfaces based on the setting as well as the purpose, and it may be used as a starting point for future home interface development, as well as to identify gaps in the development of home interfaces that may be addressed in the future by creating and developing new home interfaces.

Überblick

Taxonomien über Interfaces werden im Bereich der Mensch-Computer-Interaktion verwendet, um Interaktionsmodalitäten, Methoden, Technologien und Geräte zu klassifizieren und zu definieren. Die meisten dieser Taxonomien und Kategorisierungsmethoden haben jedoch die Umgebung, in der die Interfaces verwendet werden könnten, nicht berücksichtigt. Darüber hinaus konzentrieren sie sich häufig eher auf Technologie oder Funktion als auf den Zweck, was sie dazu neigt, mit dem technologischen Fortschritt zu veralten. Um diese Probleme anzugehen, schlagen wir eine neue Taxonomie vor, die auf der Einstellung und dem Zweck von Indoor-Home-Interfaces basiert. Wir unterscheiden zwischen privaten und öffentlichen Umgebungen zu Hause und berücksichtigen eine Reihe von Zwecken bei der Kategorisierung von Indoor-Home-Interfaces. Diese Taxonomie zielt darauf ab, eine umfassende Kategorisierung von Interieur-Home-Interfaces basierend auf der Umgebung sowie dem Zweck bereitzustellen und kann als Ausgangspunkt für die zukünftige Entwicklung von Home-Interfaces verwendet werden. Es kann auch verwendet werden, um Lücken in der Entwicklung von Home-Interfaces zu identifizieren, die in Zukunft durch die Schaffung und Entwicklung neuer Interfaces geschlossen werden können.

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Chapter 1

Introduction

People are interested in adopting convenient procedures over the internet to operate and monitor home appliances remotely, thanks to the introduction and rapid expansion of Internet of Things (IoT) and smart home automation systems [Hezam et al., 2020]. Computing systems are ubiquitous in nearly every aspect of human life, and they provide a variety of purposes. Traditional desktop PCs or industrial control systems, as well as mobile devices such as smart phones or tablets, are included in computing systems, as are more modern and pervasive innovations such as home control components or smart e-textiles.

Most areas of everyday life make use of computing systems

The development of home interfaces has been positively affected by the usage of Internet of Things (IoT) technologies and smart houses [Taiwo et al., 2020]. Smart appliances such as smart lighting control, smart televisions, smoke detectors, fire detectors, temperature monitoring, and so on have been implemented in smart homes as a result of IoT technologies, which has influenced the range of indoor home interfaces produced. Home interfaces are pervasive in our daily lives, encompassing work, health, education, and more. We are surrounded by home interfaces, which range from voice assistants to universal remote controls for controlling home equipment. To make essential home appliances and furniture used everyday interactive, various features and technologies are integrated in them. For example, an interactive

Internet of Things (IoT) and smart home have had an impact on the evolution of home interfaces

Interactive essential home appliances

couch [Pohl et al., 2015], chair [Shirehjini et al., 2014], cushion [Guanqing Liang et al., 2017], bed frame [Djakow et al., 2014], shower curtain [Funk et al., 2015] and bathtub [Hirai et al., 2017]. In addition to their extensive use, home interfaces are often used in human-computer interaction research, with applications ranging from home monitoring to home appliance control.

People with disabilities can benefit from home interfaces that provide basic care

The majority of home interfaces were created to make users' lives easier [Card et al., 1991]. Specially for people with disabilities indoor home interfaces create a comfortable environment by providing basic care. Home interfaces provide a number of benefits to consumers with disabilities, including the ability to operate home appliances, monitor users' health at home, and entertain them in a variety of ways.

Other taxonomies on interfaces focus on interaction modalities, techniques, technologies and devices

In the subject of human–computer interaction, most taxonomies on interfaces are used to identify and characterize interaction modalities, techniques, technologies, and devices. Bernsen [2008], for example, presented a taxonomy for input and output modalities, focusing on three categories: media visuals, acoustics, and haptics. Natural language and voice interfaces for operating home interfaces in a home context were examined by Möller et al. [2004], Potamitis et al. [2003], and Yates et al. [2003]. Jaimes and Sebe [2005] offers an overview of multimodal interaction methods, and Multi-party interaction, such as interactions between inhabitants and autonomous agents like mobile robots, virtual humans, and other smart items in the environment, is crucial, according to Nijholt [2008].

The purpose and setting of interfaces are taken into account in this taxonomy

While there are various helpful taxonomies and classification frameworks for categorizing and describing human–computer interaction approaches, none of them captures the whole scope of home interface goals and purposes. In this taxonomy we are concerned with the purpose of indoor home interfaces as well as the setting they may be used in. More specifically, we differentiate between private and public setting. A private setting is a room in the house where just one person is present, such as the bathroom and a public setting is a room or area in a residence where several people interact, such as a living room or kitchen.

This taxonomy also takes interfaces into consideration that can be used in both private and public settings due to the fact that there are interfaces such as *CapCouch* [Pohl et al., 2015], cushion [Guanqing Liang et al., 2017], and *GeeAir* [Pan et al., 2010] that can be used in both settings.

A list of purposes was created after the investigation of interfaces

The aim of indoor home interfaces can vary a lot, which is the reason why we take a variety of purposes into consideration. We studied several taxonomies as well as investigated over 160 interfaces and picked the suitable ones to reflect the purposes as well as the setting of the interfaces in order to develop a list that defines a wide variety of purposes that are now utilized in indoor home interfaces. The purposes utilized in our taxonomy to classify the interfaces investigated are: *comfort, communication, education, entertainment, health, security & privacy*, and *sustainability*.

The purposes chosen are comfort, communication, education, entertainment, health, security & privacy, and sustainability

Comfort is defined as the capacity to make a user's home environment pleasant, such as operating interfaces without the need for further movement or controller. Communication is specified in our taxonomy as an interaction between numerous individuals; it does not include human-computer interaction. Our understanding of education and entertainment is identical to that of the broader definition. Education is described as the ability to learn and be informed, whereas entertainment is defined as the capability to be entertained by an item. In our taxonomy health is described as the preservation of physical and mental well-being, as well as the treatment of conditions. The concept of security and privacy includes safeguarding the user's residence from invaders, natural disasters, and technological threads. The final goal we evaluate is sustainability, which is described as the management of energy and water use at home in order to decrease one's environmental impact. In Section 2.1, these purposes as well as the private and public settings will be outlined in further detail.

The following is an outline of the taxonomy's structure. The suggested taxonomy is then introduced in Section 2 before being thoroughly elucidated in Section 2.1. Sections 3-5 categorize and explain the interfaces that were studied. Section 6 discusses the interface interactions, followed by a brief summary and conclusion in Section 7.

Chapter 2

Taxonomy

This section primarily comprises our taxonomy proposal of indoor home interfaces based on the purpose and if the interfaces can be used in public or private settings. First the goals and scope of the taxonomy are briefly described, which are then subsequently detailed in further depth in the next section.

The classification is based on the setting and the purpose of the interfaces

The taxonomy is based on the requirements and desires of human beings and it is designed to classify not just all currently known interface and device purposes, but also those that may become accessible in the future. Indoor home interfaces provide a list of aims and goals, which the taxonomy is based on.

Home interfaces were developed to make living easier and to decrease resource waste [Card et al., 1991]. Their uses are various, but they may be monitored and controlled for safety, care, and convenience to fulfill these and many more goals. Home interfaces involve a wide range of devices, appliances, and sensors that are meant for different purposes around the house, for example, interfaces that provide users with comfort [93, 89, 59, 53] or entertainment [62, 105, 47, 116, 51] .

The goal of indoor home interfaces is to make life easier

To produce a list of purposes that encompasses the majority of the purposes used for indoor home interfaces, we look at other taxonomies.

Additional taxonomies were investigated in order to produce a list of purposes

Hezam et al. [2020] discuss the development of an Internet of Things (IoT) protected framework that enables different IoT objects to securely connect with the internet, where they

classified smart home objects into eight categories based on the hardware and capabilities of the objects: *Energy and Lighting*, *Security Cameras*, *Smart Detectors*, *Household Objects*, *Consumer Objects*, *Gateways*, *Smart Health*, and *Home Entertainment*. While this classification is based on the hardware used in a smart home, the specific purpose of the object is used in our taxonomy.
Home safety, healthcare, entertainment, control and monitoring of home equipment, and enhanced energy efficiency are just a few of the services provided by home interfaces, which is discussed by Taiwo et al. [2020].
They focused on a review of IoT-smart home automation systems. Taiwo et al. [2020] propose a taxonomy of IoT-smart home automation based on methods, technologies, application areas, and other components involved. The application area is categorized into five different categories: *Smart Home Healthcare*, *Smart Home Energy Efficiency*, *Smart Home Entertainment*, and *Smart Home Safety*. While Hezam et al. [2020] and Taiwo et al. [2020] chose different categories to classify smart home objects, there are some similarities which are used as an inspiration to find a taxonomy for indoor home interfaces.

The parallels between the taxonomies serve as inspiration for our list of purposes

As mentioned above our taxonomy is based on the specific purpose of the interfaces and if they can only be utilized in public or private settings.

Definition: *Private Setting*

PRIVATE SETTING:
A private setting is defined as space in a home that is not available to the public and where the user is alone.

Definition: *Public Setting*

PUBLIC SETTING:
A public setting is defined as a space in a house where several people may interact with one another.

The setting of the interfaces is critical for our taxonomy because certain interfaces are only supposed to be used in private settings in the house, such as the bathroom, while others can only be used in public settings, such as the living room with multiple users. Of course, a wide range of interfaces may be utilized in both settings, which is why we

Both private & public settings are also taken into account simultaneously

include that category as well.
The taxonomy takes into account private and public settings because the rooms in a home can be utilized for a variety of purposes. Although the living room had traditionally been regarded of primarily as a means of communication between the hosts and their visitors, the findings of Rechavi [2009] indicated differently. According to their results, the living room is utilized for a range of purposes, including secluded activities and receiving visitors. While the research by Rechavi [2009] is focused on the living room, it may also be applied to other areas of the house, such as the kitchen and bedroom. The majority of a home's rooms may be utilized for a number of functions, which is another reason why our taxonomy takes the private and public setting into consideration.

The setting is considered because the rooms in a house have a number of functions

As previously stated, the purpose of indoor home interfaces is another category covered in our taxonomy. In order to create a list of purposes that encompasses a wide range of purposes that are currently available in indoor home interfaces, previous taxonomies that include the functionality and purpose of smart home applications, as well as a large number of home interfaces developed were investigated. The fundamental purposes chosen for our taxonomy are as follows: *comfort, communication, entertainment, education, health, security & privacy*, and *sustainability*.

The purposes chosen: comfort, communication, entertainment, education, health, security & privacy, and sustainability

The reason why these aspects were chosen for our taxonomy of indoor home interfaces is explained briefly in the following sentences.

Comfort is one component of the taxonomy since the purpose of home interfaces is to make the user's environment at home as comfortable and simple as possible [Frontczak, 2011]. Interfaces that aim for the user not to move or to take action to control devices or subsystems in the house give comfort to the user. Comfort may also be archived via the configuration of interfaces, such as interfaces that are not an impediment to the user's everyday life and that make household duties simpler. This area was targeted the most in interface research, which is why comfort is included as a category in the taxonomy. The interfaces *GeeAir* [Pan et al., 2010] and *SmartSleeve* [Parzer et al., 2017]

Home interfaces are designed to make the user's home environment as comfortable and uncomplicated as possible fall into this category.

Human beings must remain linked and communicate with one another

Another purpose chosen to take into consideration for our taxonomy is human-to-human communication in homes. Human beings need to stay connected and communicate with each other and interfaces such as the *ShareTable* [Yarosh et al., 2013] provide exactly that. They ensure that a group's connection operates without interruption, and that communication between family members and those who are not at home is simplified. Winbow [2002] discovered that effective communication benefits us all in our personal and professional lives, making it a vital element of one's life. That is why communication is included in the taxonomy.

People desire to be entertained in their own homes

Aside from communication being an essential aspect of a person's life, entertainment is also vital. Brock and Livingston [2003] conducted a study about the importance of entertainment and found that people would only give up their TV in exchange for a huge amount of money. They concluded that humans desire to be entertained in their own homes and to appreciate their surroundings. As a result, various home interfaces, such as the *Ambient Wall* [Kim et al., 2011] and the *DJammer* [Slayden et al., 2005], ensure that this is accomplished. Music speakers, tabletop displays, and wall-mounted interfaces are just a few examples of how the user and their guests may be entertained at home.

Education is important for personal, social, political, economic, and cultural advancement

Part of the day-to-day life of human beings includes education and the desire to stay on top of the news around the world. Bhardwaj [2016] investigated the significance of education and found that the importance of education cannot be emphasized enough whether in personal, social, political, economic, and cultural progress. They concluded that education is available in all aspects of life, making it a crucial element of one's existence and that education is the key to future success and a plethora of opportunities in ones life. News is also an important aspect of a person's life since it keeps them updated about current events across the world. As a result, we include education as a category in our taxonomy. This category includes the interfaces *Read-It* [Sluis et al., 2004] and *Information Wall*

[Mäkelä et al., 2014], which ensure that consumers remain educated and informed while at home.

Everyone prioritizes their health, making it essential in their everyday lives

In addition to the previously listed categories, health is included in the taxonomy. Home interfaces that aim for the health of the users allow them to live a more independent and self-sufficient life Taiwo et al. [2020]. Health care offered through home interfaces includes the maintenance of the physical and mental quality of life, as well as the management of conditions. Since health is essential to everyone's well-being, we include it in our taxonomy. Even if they are medically well, most individuals prioritize health care in their daily lives. Some interfaces that fall into this category are *Movibed* [Djakow et al., 2014] and *SpiroVest* [Enokibori et al., 2013].

The rise of technology in the house brings complex new threats

The security & privacy of users in their homes is an essential part of their lives that should be accounted for in our taxonomy. Due to the increase of technology being used in homes security & privacy has become an important aspect in people's lives [Anwar et al., 2017]. The issue becomes increasingly complex and intriguing as new threats and weaknesses are identified regularly. Recent security breaches in smart home setups have led to various developments of indoor home interfaces which specifically insure the security & privacy of the users [Anwar et al., 2017]. For example Guo et al. [2018] and Kobayashi et al. [2018] both provide interfaces that fit under this category.

Sustainability improves our quality of life while also protecting our natural resources

Another aspect that is critical in our lives is sustainability, especially nowadays due to climate change [Clift, 2007]. It enhances our standard of living while also preserving our natural resources and the environment for generations to come. Sustainability in homes can be achieved in various ways, for example with energy management [Lashina, 2004] or managing the usage of water [Laschke et al., 2011] in homes.

The investigation of interfaces led to the selection of just these purposes for our taxonomy. The chosen purposes were highlighted and targeted when researching for exciting interfaces provided by various developers and researchers. As a result, the list of purposes was picked not only based on other taxonomies, but also on the interfaces discovered for this taxonomy.

A complete classification of interfaces

The intention behind this taxonomy is to give a comprehensive categorization of interfaces created depending on the setting and purpose. In addition, it will serve as a starting point for the future development of indoor home interfaces.

A starting point for new interfaces

Interfaces may be classified using the taxonomy depending on their purpose and setting. This may be required when introducing new interfaces, but it may also give a deeper knowledge of existing interactive settings. It can also be beneficial for developers as a starting point for deciding on the purpose and interface settings.

Research and development gaps can be identified

This taxonomy can also be used to detect interface research and development gaps. Researchers and developers may use this taxonomy to discover current and known gaps in the development of indoor home interfaces, which can then be used to create new interfaces that fill those gaps.

2.1 The Elements of the Taxonomy

The taxonomy is based on the setting and the purpose of the interfaces

This section delves into the specifics of our proposed taxonomy discussing its components individually. At first, it is crucial to note that the taxonomy is constructed around the setting and aims of each interface. Thus, the major principles are based on human needs and desires in their homes, but they attempt to capture both the purpose of home interfaces and the type of setting used to fulfill these objectives.

First, the setting is examined, followed by the purpose

Indoor home interfaces were created with the goal of making living easier and reducing resource waste [Taiwo et al., 2020]. They involve a wide range of devices and sensors that provide different services to the users but the purpose of these interfaces can be classified into categories. First, we distinguish between *private* and *public setting* in our taxonomy, and then we divide the interfaces into seven categories that encompass all of the goals and objectives of each particular interface: *comfort, communication, entertainment, education, health, security & privacy*, and *sustainability*.

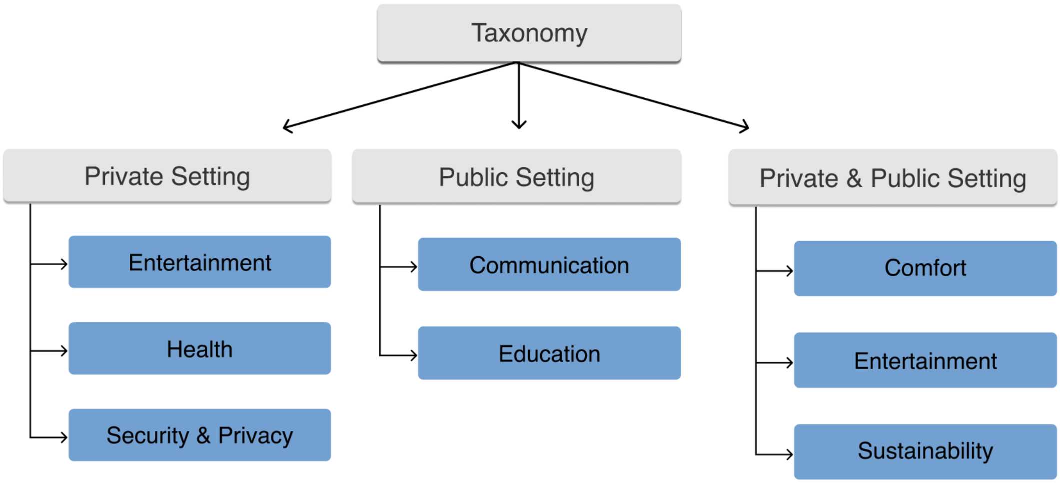


Figure 2.1: The categories of the taxonomy: The first level specifies the interface settings, which are classified into three categories: private, public, and private & public. The purpose is established at the second level.

2.1.1 Setting: Public vs Private

Our taxonomy distinguishes between private and public settings in a home at the top level as seen in Figure 2.1. The setting of the interfaces is included in our taxonomy since most interfaces describe the location utilized, but they may also be used in other scenarios at home. Also Korosec-Serfaty [1984] distinguished between spaces in the home that serve as communal social hubs such as the living room and places where a private, concealed existence takes place such as the bathroom. Although most indoor home interfaces do not provide the interface's usage setting, their use in a setting may be established. As a result, the private and public areas of a home are segregated in this taxonomy.

Our taxonomy distinguishes between private and public settings

A home, as described by Birch [2010], is a private space that is not available to the public. A home is intended for the family who resides there. Hall [1966] defines private property as an individual's area. We define private space in a house in our taxonomy as locations where one person is alone, such as the bathroom.

A private setting is one in which the user is alone

Our taxonomy's concept of a public place differs from Birch [2010]. A public environment is defined as a location to which everyone has access. In this taxonomy a public setting is a space in a house where several people may in-

A public setting is a place where many individuals may engage with one another teract with one another, such as a living room or kitchen. There are home interfaces that may be used in both private and public situations in the home, which is why a new category was created to capture those interfaces and their purpose (e.g. [62, 91, 68, 93, 105]).

Private setting is further classified as entertainment, health, and security & privacy

Our taxonomy analyzes the purpose of each interaction at the next level. Health, security & privacy, and entertainment are all regarded to be private objections in houses. The fact that certain interfaces are designed for bathrooms, which we consider a private place, explains why entertainment is included in the private setting. Aspects such as health, security, and privacy, which are self-explanatory, are also considered in private places. A person's health may be monitored in public places, but only by the user themselves.

Public setting is further categorized into education and communication

Communication and education are two goals that belong in public spaces. Human-to-human communication can only be done among people, making it an aspect that should only be examined in public situations. The sole reason education is part of the public setting is because of the researched interfaces that are intended for usage by numerous individuals such as the *Information Wall* designed by Mäkelä et al. [2014].

Private & public settings are further subdivided into three categories: sustainability, comfort, and entertainment

For the category private and public setting, the objectives of comfort, entertainment and sustainability are taken into consideration because they may be utilized in both private and public settings. Even though entertainment is also considered in a private environment, as previously stated, only interfaces developed particularly for private settings are taken into account. During the classification of this section, all interfaces that may be utilized in both scenarios are taken into consideration.

2.1.2 Comfort

Physical and human elements influence the comfort of a home

The concept of comfort is among the purposes of the indoor home interfaces already developed. While everyone defines comfort at home in a different way, there are a few aspects that everyone can agree on. Frontczak [2011] discovered a number of physical elements, such as air temperature, relative air velocity, and air humidity, as well as

human factors, like as activity level and clothes, that influence the comfort of the interior home environment. Other elements unrelated to the indoor environment, such as outdoor climate and personal qualities of building inhabitants, all impact comfort in a house, as do thermal, auditory, and visual comfort, as well as contentment with air quality.
According to Taiwo et al. [2020] comfort can be provided through interfaces that do not need the user to move or take action to control devices around the house such as controllers and phones. Also, interfaces such as sensors and wearable interfaces aim for the comfort of the user by providing an easy-to-use product.

Comfort is provided via interfaces that control appliances without requiring the consumers to move

An example of an interface that aims for the user's comfort is presented by Pan et al. [2010]. The interface *Geeair* allows the user to manage their home appliances without moving and using various modalities. Additionally, the *Geeair* can control anything in the house, eliminating the need for extra controllers.

2.1.3 Communication

A further element that has been explored as a reason for indoor home interfaces is interpersonal communication. Gilmore et al. [1982] discovered that children grow and learn at home as well as at school, which is why family contact is so important in their growth. The importance of adult conversation and interaction at home cannot be overlooked. Palmer et al. [2019] examined this and discovered that social connection is critical for individuals' mental and physical health. They came to the conclusion that communication has a significant influence on older persons' mental health and is the foundation of social engagement.

Communication is crucial for children's development as well as adults' mental health

It is not difficult to remain in touch with others these days via smartphones and other devices, and home interfaces make it even easier. For example, eye-free wearable interfaces that can be connected to a smartphone [Kikuchi et al., 2017]. However, communication remains a challenge for persons with disabilities [Caporusso, 2008]. Individuals with disabilities still have difficulty communicating with people who do not understand sign language, which is why different interfaces, like as the one given by

Communication is a barrier for individuals with disabilities

Gollner et al. [2012], try to overcome this problem. This interface allows people with impairments to communicate with others either on the go or at home.

2.1.4 Entertainment

One aspect of a social and lively house is entertainment

Aside from communication, which is a vital notion for humans, entertainment is also important, particularly at home. Entertainment is one component of a sociable and dynamic home. To enjoy their surroundings, humans want entertainment in their homes, such as watching movies, listening to music, and playing games with family and friends. Indoor home interfaces seek to improve the atmosphere and quality of life in households by providing entertainment.
Indoor home interfaces eliminate the need for a second remote control and make life easier at home by allowing users to manage many pieces of entertainment equipment from a single location. Others, such as access to media in the bathroom [Funk et al., 2015] or a table interface particularly designed for amusement [Kunz and Fjeld, 2010], are exclusively built for the users' enjoyment in private and public settings.

2.1.5 Education

People like to be entertained at home, but they also like to be educated and learn at home. A further motivation for indoor home interfaces that has been investigated is education. Our everyday lives and surroundings are filled with computational devices and a large amount of information about the current situation in the world. Indoor home interfaces make use of technology to ensure that consumers stay informed and educated at home. Some interfaces make use of objects at home [e.g. 87, 82] to ensure that users may obtain information that is relevant to them, such as weather forecasts or news.

To ensure education at home, everyday objects are incorporated

2.1.6 Health

Health is another aspect that has been considered as a purpose for indoor home interfaces, specially for elderly and people with disabilities. The avoidance, therapy, and control of diseases, as well as the maintenance of physically and mentally quality of life, are all aspects of health. Indoor home interface ensure a better quality of live for the youth and the elderly. Indoor home interfaces improve the quality of life for both young and old [Taiwo et al., 2020]. By using sensors, actuators, and wristbands to monitor the user's physical health, the home interface can help to avoid diseases. Not only diseases, but even health problems that the majority of people face, such as back pain caused by sitting or sleeping, can be avoided. Some interfaces evaluate the force of movement on the furniture or track the body's movement [Braun et al., 2015a, Djakow et al., 2014]. Indoor home interfaces for healthcare also attempt to fulfill the needs of the disabled by allowing them to use easily accessible devices to operate equipment [Gautam et al., 2014].

Aspects of health include illness prevention and treatment, as well as the maintenance of physical and mental well-being

2.1.7 Security & Privacy

For users to feel welcomed and at home, a house must be secure and safe, which is why security & privacy are being researched as a use case for indoor home interfaces. Security & privacy are important aspects of home interfaces, the issue becomes increasingly complex and intriguing as new threats and weaknesses are identified on a regular basis [Anwar et al., 2017]. Anomalies in the home, like power outages, fires, or illegal entry, can be recognized and avoided immediately using indoor home interfaces [Taiwo et al., 2020]. For undesired and illegal entry into the house, sensors and cameras can be utilized to alert the home owner via their smartphone or other device that they have with them at all times. Alarms, remote monitoring [Lukman et al., 2018], and, as previously noted, video surveillance [Soliman et al., 2017] are all used by indoor home interfaces to handle such circumstances.

The security & privacy of the home is guaranteed by detecting and avoiding irregularities in the residence, such as power outages, fires, and unwanted entrance

2.1.8 Sustainability

The existence of several energy-consuming appliances at home necessitates a reduction in consumption

Sustainability is considered as a possible cause for the development of indoor home interfaces. The goal of the indoor home interfaces presented is to create a house that is both sustainable and environmentally friendly. There should be a reduction in its consumption due to the presence of multiple energy-consuming interfaces. Indoor home interfaces enable users to manage and regulate the use of water, electricity, lighting, and other electrical devices in their homes, resulting in lower energy use. Interfaces achieve this objective in a variety of methods, such as a calendar that tracks how much water is used in the shower [Laschke et al., 2011] or sensors that turn lights on and off as needed [Lucero et al., 2006].

Chapter 3

Private Setting

The following chapters provide classification of existing indoor home interfaces, first based on the setting in which they can be used, and then subsequently on the purpose of the interfaces. In Section 2.1, the setting and the categories utilized for the purpose are described and explained in detail. This chapter classifies existing indoor home interfaces in private setting. Utilizing the interface in a private environment entails using the interface while the user is alone at home. The private context is included in this taxonomy because, while some spaces at home are designed to be utilized for social activities, they may be used for private purposes. In a private setting, interfaces are further classified into the categories of entertainment, health, and security & privacy. Entertainment is sub-categorized under private spaces, because the interfaces described here are exclusively suited for use in the bathroom. This taxonomy also considers entertainment interfaces that may be utilized in both private and public setting at the same time, which will be discussed in Section 5. Section 2.1.1 goes into great depth on why just these subcategories were chosen for the private setting.

The purposes categorized in the private setting are entertainment, health and security & privacy

3.1 Entertainment

In a private environment, the bathroom is a common place for entertainment

The living room is the common place for entertainment in a home, but when it comes to the private setting, the bathroom is where most of the interfaces are directed for entertainment, such as the interfaces given by Funk et al. [2015] and Hirai et al. [2012]. The majority of user interfaces designed for entertainment may be used in both private and public settings, however, the interfaces given below are designed for private settings such as the bathroom. The shower and bathtub were two locations where researchers investigated media consumption and interfaces in the bathroom.

Access to media in the bathroom as a source of inspiration for the interfaces

Access to media is the driving force behind the creation and development of these interfaces. There are just a few instances where digital media cannot be employed. The only everyday activities that prohibit access to and engagement with digital media are bathing and showering, which is why the presented interfaces are specifically intended for these environments.

Figure 3.1: The interactive shower curtain: information is projected on the shower curtain, which may be manipulated by touch. Image taken from Funk et al. [2015].

An interactive shower curtain to access media

Funk et al. [2015] identified the shower as a location where many users do not have access to the media. They designed an interactive shower curtain to allow the user to access various media sources on the internet (see Figure 3.1). As a result of a thermal camera, a touch-sensitive curtain is created outside the shower while retaining the user's apparent privacy. The system can be used to play music, sing karaoke, or read the newspaper as well as see how long the shower is taking. Funk et al. [2015] developed a working prototype for the system and tested it with a number of people, concluding that while the system allows users to utilize media and information in the shower, it will lengthen their shower time. The technology is exclusively focused on the shower and the display of information on the shower curtain. The bathtub, which is the goal of the forthcoming interfaces described, is not included. While only one shower interface was identified in our research, a couple more were found for the bathtub.

Bathcratch allows the creation of music in the bathtub

Melodies can be created by touching the bath rim

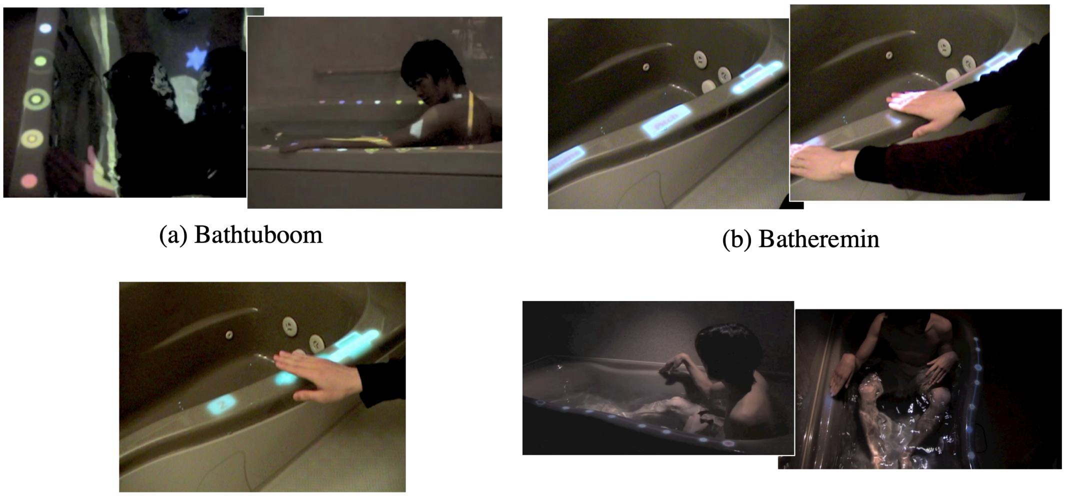
Hirai et al. [2012] invented a method that allows music to be generated in the bathtub. *Bathcratch* recognizes squeaks generated by the touch of the user on the rim of the bathtub as well as other similar sounds and turns them into melodic sounds. The bathtub is effectively transformed into the user interface for a DJ controller by inserting sensors that sense touch and sound. While their technology is fascinating as a bathroom interactivity system, their focus was strictly on listening to noises and did not include the ability to display nor manipulate information.

TubTouch as another interactive interface for the edge of the bathtub

Hirai et al. [2013] also developed an interface for the bathtub, the *TubTouch* which is a sensor touch user interface for users at the edge of the bathtub. The interface may be used to manage bathroom appliances such as lighting, water temperature, TVs, and music, as well as a range of applications. Users interact with the *TubTouch* using capacitive touch sensors mounted to the inner edge of the bathtub, and a projector installed above the bathtub projects a screen over the touch sensors.

Applications designed for *TubTouch*: Bathtuboom, Batheremin, BathCount, and Bathcratch

TubTouch, as previously stated, may be used to operate bathtub apps as well as entertainment applications. *TubTouch*'s entertainment applications include Bathtuboom, Batheremin, BathCount, and Bathcratch as seen in Figure 3.2. Hirai et al. [2013] showcased the system, as well as the



(a) Bathtuboom
(b) Batheremin
(c) BathCount
(d) Bathcratch

Figure 3.2: Entertainment Applications for *TubTouch*: a) *Bathtuboom*: music-listening application, b) *Batheremin*: the instrument theremin can be played, c) *Bathcount*: show numbers on the bathtub, d) *Bathcratch*: music can be created by touching the bath rim. Image taken from Hirai et al. [2013]

applications, at a number of trade shows and conferences. *Bathtuboom* is a music-listening application that employs touch sensors to activate sound phrases and listen to music. The second application is *Batheremin*, which employs touch sensors on the edge to play the electronic musical instrument theremin. Another system-supported application is *Bathcount*, which is used to show numbers on the bathtub and speak the numbers, allowing youngsters to learn to count while having a bath. The final use described by Hirai et al. [2012] is *Bathcratch*, which we have already discussed.

Hirai and Ito [2015] also propose an interface for the bathtub's edge. They suggest a bathtub edge interface that employs tapping, rapping, knocking, and slapping as modalities. The interface utilizes piezoelectric sensors, which detect tapping noises as acoustic indications of solid vibrations in the tub's body. Users may operate a range of applications using the tapping modality.
The idea of the notion of a bathtub interactive edge was investigated further, leading to the development of the

RapTapBath interface by Hirai et al. [2017]. Users interact with the program by tapping the bathtub's edge, which has numerous embedded piezoelectric sensors that detect tapping, rapping, knocking, and slapping. *RapTapBath* recognizes the tap position, tone, and pattern in order to operate equipment and applications. Games, bath drum 2 (musical instrument), and quiz buzzer applications may be utilized with the *RapTapBath* described by Hirai et al. [2017] to keep you entertained while bathing. *RapTapBath* was tested with a functioning prototype and a variety of applications, including a controller for current equipment, text input, and other amusement apps.

Tapping, rapping, knocking and slapping as modalities for *RapTapBath*

Figure 3.3: *Aquatop*'s application scenario: information is projected on cloudy water surface, and poking is the modality that is used here. Image taken from Koike et al. [2013].

Another interface created for the bathtub was introduced by Koike et al. [2012]. They created a way for presenting information on the water's surface. A Microsoft Kinect depth camera, a projector, and a PC are used in the interface. Also, cloudy water is created using bath salts for the water screen to enable better information projection. This concept was further refined and expanded, resulting in the *AquaTop* in-

The water surface is used to illustrate the interface

terface (Koike et al. [2013]). The interface *AquaTop* may be interacted with on the water surface using a variety of intuitive water-based motions. Koike et al. [2013] focuses on four modalities for controlling the interface: poking fingers from beneath the water (as shown in Figure 3.3), stroking water with the hand, scooping water, and striking the water. While bathing, users may modify information and surf the web using the *AquaTop*, which displays information on the water surface that can be interacted with. To do this, *AquaTop* is able to display text and images, browse the internet as well as play video content from YouTube. An overhead projector and bath salt are used to fog the water, allowing the projection to be seen and as described before a Microsoft Kinect sensor is used to recognize the interaction. Koike et al. [2013] assess the system's capabilities with a functional prototype.

Four modalities can be used to interact with *AquaTop*

3.1.1 Discussion

According to the findings of the study, there is a range of interfaces designed and developed for the amusement of bathroom users. The study pre-sets interfaces for the shower and bathtub, taking both into account. While there are much more interfaces intended for the bathtub, only one was discovered that was particularly made for the shower. This study reinforces the notion that users often do not take a long time when showering, which is the reason why not many interfaces are designed for the shower.
The typical shower lasts eight minutes, according to the Centers for Disease Control and Prevention (CDC) [Lindberg, 2020], which is not a long time, therefore most users do not need to use media at that time. Despite the fact that the average shower time is not long, the shower curtain presented by Funk et al. [2015] is useful if the users wish to use media while taking a shower.

Average shower lasts about eight minutes

The interface *AquaTop* [Koike et al., 2013], which is comparable to the shower curtain [Funk et al., 2015], was created for the bathtub. Both interfaces are projections of applications that may be utilized while bathing or showering. Other interfaces, like *AquaTop*, were created particularly for

Both the *AquaTop* and the shower curtain have projection of applications the bathtub. According to a study conducted by the energy firm E.ON, the average bath duration is 19.5 minutes [Mail, 2013], which is considerably greater than the average shower time. Smith [2016] discovered through a survey that most individuals enjoy utilizing media when taking a bath, which may be seen as one of the reasons why additional interfaces for the bathtub were created.

Interfaces for the bathtub with several modalities: touch, tapping, knocking and more

The interfaces listed above are designed to entertain people while they bathe, but they also consider their comfort. While the scenarios portrayed for these interfaces are restricted to the bathroom, they may potentially be utilized to play games with friends in public places like public pools and Jacuzzi. The interfaces for the bathtub might be further improved to serve a function other than pleasure, such as education.

The interfaces can be used in other scenarios such as pools

The concept of the shower curtain may also be used for normal curtains for viewing information. Users may save space while having an interactive curtain in other rooms of their home, such as the living room and bedroom.

Access to media ensured through the interfaces

The authors of the interfaces discovered that the interfaces give customers with delight when showering or bathing in the bathroom after evaluating them. They also ensure that users have access to media, allowing them to be contacted by others in the event of an emergency.
Because the average shower duration is just eight minutes [Lindberg, 2020], shower interfaces may not be as in demand as bathtub interfaces, which might explain why we found more bathtub interfaces created than shower interfaces.

In the future, other modalities can be used instead of touch

Despite the positive findings of the study, the question of what further may be produced for user entertainment in private settings such as the bathroom remains unanswered. Touch is the most common modality utilized in the interfaces studied, however other modalities such as gesture and speech can also be used to operate the interfaces. Even though the sound of water and continual movement makes it difficult to picture speech and gesture as modalities when showering, both modalities may be utilized to operate an interface while bathing. The connection and control of a personal device such as a phone with the interface might be a future development of the interfaces. One example of such progress is the connecting of a mobile phone to the *AquaTop* interface [Koike et al., 2013], allowing users to view the media stored on their phone while bathing.

3.2 Health

Health is another purpose used to classify interfaces

Health is another purpose that we take into consideration in this taxonomy as a component of private setting. While there are a number of interfaces that explicitly aim for this purpose, others can also be utilized to identify the user's health problems. Several interfaces were discovered throughout the research that employ common objects at home to monitor the user's health. The purpose for building an interface with the user's health in mind is to provide a better lifestyle for the user and to assist users with their health difficulties. The interface given by Shirehjini et al. [2014] suggests a solution for this problem, particularly when it comes to general postural health.

A chair used to detect user's health through their posture

Shirehjini et al. [2014] created a posture detecting chair. Using digital sensors mounted in various areas on the chair, the *Aware Chair* system recognizes seated body postures. The sensors are located on the sitting surface, the back resting region, and the armrests. The suggested system's chair can identify physical postures such as concentration working posture (upright sitting), leaning back, nervous flashing legs, and imminent orientation alterations. With the *Aware Chair*, the user's body position may be collected and evaluated for behavior. The user's posture reflects their concentration and mental condition when working and studying. The *Aware Chair* can identify user's current health problems by detecting their sitting posture and analyzing it to determine their general health. According to the findings of the performance evaluation, the average categorization accuracy of posture detection was high for individuals who had previously been detected by the system, but lower for those who had never been detected.

Capacitive proximity sensors have been utilized to detect user's motions in the interface *CapSeat* presented by Braun et al. [2015a]. While part of their research, Braun et al. [2015a] developed a vehicle seat equipped with sensors that could monitor the driver's motions as they drove. By recognizing signs of attention and fatigue in the driver, *CapSeat* is designed to keep the driver safe on the road. *CapSeat* analyzes the driver's motions and notifies them if there is a possible threat to their safety. The capacitive proximity sensors on *CapSeat* assess a wide range of physical movements to detect inattentiveness of the driver. Three anthropometric factors (occupancy, appropriate seat settings, and driver posture) as well as four activity measures (nodding, yawning, staring, and erratic steering) are monitored to identify inattention. It also enhance passive safety by allowing appropriate seat adjustment and posture detection, therefore increasing passive safety. Because the interface is critical for the safety and health of users while driving, it is classed as health. Braun et al. [2015a] tested the technology to the test by embedding it in an automobile that allowed for simple measuring of seat and body parameters. The results of the evaluation show that the test group has a high level of categorization precision.

A car seat that detects the user's physical status based on their posture

CapSeat detects inattentiveness of the driver by monitoring anthropometric and activity factors

Similar to the *CapSeat* [Braun et al., 2015a], Braun et al. [2015b] created an office chair with a sensor attached as seen in Figure 3.4. The purpose of the *Capacitive Chair* is to improve the health of its users, as sitting for long periods of time can lead to a variety of health problems, including lower back discomfort. The *Capacitive Chair* can assist users by identifying postures and activities and providing feedback to them in order for them to adjust the position in which they are seated. Three properties are measured with the *Capacitive Chair*: posture, activity, and breathing rate. While posture and activity rate may be assessed in a similar manner, breathing rate must be measured differently. The location of the body parts in respect to the sensors determines posture, and the change in position of the body parts in relation to the sensors determines activity.

Braun et al. [2015b] recognized that the breathing rate can be determined by the change of chest volume, so a single electrode is placed close to the chest to detect the breathing. The technology was tested on a prototype and achieved a high recognition rate.

Capacitive Chair is an office chair that detects the posture of the users

Capacitive Chair measures three properties: posture, activity, and breathing rate

Both the *CapSeat* and the *Capacitive Chair* are designed with the user's health in mind. While the *CapSeat* ensures the user's safety while driving, the *Capacitive Chair* identifies the user's body position at home to prevent health-related concerns.

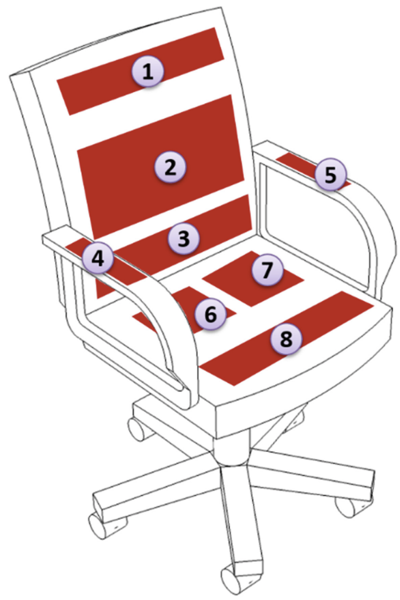


Figure 3.4: The *Capacitive Chair*'s electrode arrangement measures the users' posture, activity, and breathing rate. Image taken from Braun et al. [2015b].

An office chair, that proposes exercises based on posture analyses

Another office chair that was designed attached with sensors for the user's health is *ExerSeat* [Braun et al., 2015c]. Smart sensing chair *ExerSeat* employs eight capacitive proximity sensors to detect the posture of users on the chair as well as those who are close to it to track their motion. Braun et al. [2015c] designed a chair that analyzes a user's posture and proposes an exercise based on the results of that analysis. There is a computer training software that may be used with the chair to keep track of the exercise during short rests. The software operates in the background and encourages the user to complete basic workouts at intervals determined by them. While working long shifts, the user may keep active and avoid health concerns such as back discomfort. As mentioned *ExerSeat* is a posture tracking office chair as well as a workplace exercise tracking device, this is critical for the health of the user who spends extended periods of time sitting on a chair. According to the assessment using prototypes conducted by Braun et al. [2015c], the participants were able to utilize *ExerSeat*, but had worries about the usability and variety of the supported workouts.

A mirror that provides feedback on the user's health status *Persuasive Mirror* has three modes: feedback on recent behaviors, statistics on the behaviors and reflection

It was the goal of del Valle and Opalach [2005] to create a mirror that shows both the user's reflection and other information, such as weather forecasting. In the *Persuasive Mirror*, there are three modes: feedback on recent behaviors, statistics on the behaviors as well as the traditional reflection of oneself. Aiming to keep people healthy, del Valle and Opalach [2005] provide users with visual awareness of daily activity to motivate them toward a healthier lifestyle. The *Persuasive Mirror* provides users with specialized coaching in the form of feedback, which makes it simpler for them to live a healthier lifestyle. The *Persuasive Mirror* collects data about the user's physical health using a combination of sensors, which is then evaluated and shown to the user on a daily basis. The sensor used to monitor the user's activities and state is a combination of ubiquitous, health-tracking and wearable sensor.
Once the prototype is completed, del Valle and Opalach [2005] plan to conduct user research in partnership with psychology specialists to determine how the *Persuasive Mirror* effects human behavior.

Examining the user's sleep movement to determine sleep stages

Djakow et al. [2014] developed a bed frame, which detects the movement of the user's body while asleep (see Figure 3.5). The *MoviBed* uses capacitive proximity sensors attached to the bed frame to detect the sleep phases of the user while they are sleeping. The interface can be easily integrated into homes allowing the user to recognize their sleep phases throughout the night. Unusual sleep patterns can be discovered using *MoviBed*, and this is the first step in finding an appropriate treatment for the condition. With the use of the interface, users will experience a comfortable sleep as well as improved health. Djakow et al. [2014] assessed the system in an extended prototype for the capacity to identify various motions as well as sleep phase detection, and concluded that *MoviBed* represents a crucial step in allowing normal consumers to perform some minor sleep analysis at home.

Figure 3.5: *MoviBed* prototype: sensors are mounted to the bed frame in order to assess the user's movement while sleeping. Image taken from Djakow et al. [2014].

Wheelchair that can be controlled by user's gaze

Gautam et al. [2014] adopted a different method, extending the wheelchair used by people with disabilities. Because of the varied impairments, several alternative interfaces for wheelchair mobility have been created [Nguyen and Jo, 2012, Nithya et al., 2019]. Wheelchairs may be controlled using a variety of modalities, such as a joystick or head movement, however many individuals with disabilities are unable to utilize these modalities because they lack the capacity to control a powered wheelchair. As a result, Gautam et al. [2014] employed an optical-eye tracking system to control a powered wheelchair. The powered wheelchair may be operated by shifting the eyes at a different angle, making it easier for people with disabilities to manage the wheelchair. The system is for the user's health in a private environment since it ensures the control of people with disabilities' mobility.

Assistance system for people with disabilities that can be controlled using the gaze

Bissoli et al. [2019] created an eye-tracking device for controlling home appliances to help people with disabilities with daily chores around the house. Despite significant advancements in technology to aid individuals in their homes, many people are unable to interact with these devices due to impairments. The assistive system presented by Bissoli et al. [2019] is based on eye-tracking for monitoring and controlling smart homes. The user's eye gaze is sensed by a gadget controller that employs an eye tracker and simultaneously, an external user (caregiver) can initiate the usage of an assistance system on a device. A person with severe disabilities can manage commonplace household appliances, and their caretaker can watch them remotely. The user's health is assured by the assistive system. Thanks to the eye-tracking system, users with severe impairments may operate and monitor their houses without the direct assistance of caregivers, which is critical for their health. The assistive system was tested with non-disabled and disabled participants, which resulted in a positive feedback from the participants.

The use of e-textile in healthcare

Mecnika et al. [2014] investigate the use of smart textiles with sensing and actuation functionalities in health care. Their work is motivated by an increase in the number of senior patients as a result of population aging, which necessitates more investments in medical disciplines, leading to the creation and production of wearable textile-based healthcare systems. They define smart textile, as „textile products with added value, i.e., textiles having common qualities, but with extra functionalities, provide appealing solutions for a wide variety of application sectors, such as healthcare, protective gear for sports and the automotive industry.“ (Mecnika et al. [2014]). Smart textiles for healthcare, according to Mecnika et al. [2014], include textile sensors, actuators, and wearable electronic systems embedded into textiles that can be used for multiple functions. Body temperature, respiration, mobility and posture, humidity and pH levels, as well as the patient's pulse, can all be monitored using smart textiles. For the patient's health, all of these smart textile capabilities are essential since they aid in the healing process, enhance safety, and provide comfort.

E-textile can measure body temperature, posture, humidity and more

The *SpiroVest* is a wearable e-textile-based spirometer created by Enokibori et al. [2013] (see Figure 3.6). The typical spirometer used to identify the early indications of lung illness is unpleasant for the users according to Enokibori et al. [2013]. To use a modern medical spiro-

SpiroVest is a wearable spirometer

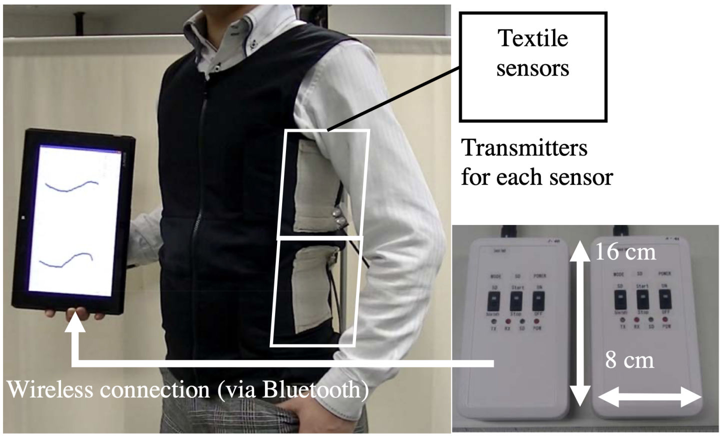


Figure 3.6: *SpiroVest* prototype: e-textile-based wearable spirometer with two textile sensors on two girths. Image taken from Enokibori et al. [2013].

meter, users must squeeze their nose with a clip and hold a mouthpiece in their mouth, which can be uncomfortable for the users. The *SpiroVest* is a wearable spirometer that estimates the lungs based on two torso-girth movements, making it more comfortable for the user. Furthermore, they devised an error reduction method to reduce estimation errors caused by changes in posture while wearing the *SpiroVest*. The accuracy of the wearable *SpiroVest* was not verified in comparison with a conventional spirometer.

MuscleSense may be used to detect weights during strength training

When the majority of the interfaces provided monitor the user's actions while working or sleeping, this interface assures the user's health while working out. Lim et al. [2020] presented *MuscleSense*, wearable surface electromyography utilized to sense weights in strength training, as another way to ensuring the user's health. They discovered that strength training enhances user's overall health and well-being. They state that four criteria may be used to determine the effectiveness of a training session: exercise type, number of repetitions, movement velocity, and workload. *MuscleSense* uses wearable surface electromyography and machine learning to evaluate the effort of a training session. When muscles contract, nerve impulses are detected by surface electromyography, which is connected to muscular contraction intensity. *MuscleSense* is ideal for measuring workload during strength training for the user's health.

3.2.1 Discussion

The human health is a very important aspect of our life, and interfaces maintain it have long been in great demand [Hezam et al., 2020]. Every step people take in their daily lives may now be used to measure their health. Users may monitor and regulate their health while working or studying using the interfaces of the *Aware Chair* [Shirehjini et al., 2014], *Capacitive Chair* [Braun et al., 2015b], and *Exerseat* [Braun et al., 2015c]. While all three interfaces employ similar concepts, such as posture detection, they examine various aspects of the user's behavior while on the chair.

The office chairs examine a variety of factors about the user

While the *Aware Chair* [Shirehjini et al., 2014] only recognizes the user's posture while sitting and determines their emotional state, the *Capacitive Chair* [Braun et al., 2015b] measures the user's posture, activity, and breathing rate and analyzes their health condition based on all of these factors and *Exerseat* [Braun et al., 2015c] analyzes the user's posture and recommends a set of exercises based on the results. As a result, the interfaces are identical in concept and technique, but they examine distinct properties. The exhibited interfaces either focus on physical health or mental health. Despite the fact that the future strategy for the interfaces is to focus on dynamic posture tracking and approaches to increase the systems' accuracy, we may see subsequent enhancements to the interfaces to evaluate and anticipate not only the user's physical health but also their emotions.

Different parts of the user's activity are examined by the chair interfaces

Future work includes dynamic posture tracking and an increase to systems' accuracy

The concept of placing pressure sensors on an office chair to assess a user's health may also be applied to a couch, a wheelchair, and other human-made furniture. The principle underlying these interfaces might also be applied to other areas, as demonstrated by *CapSeat* [Braun et al., 2015a], a car seat that monitors user gestures and detects driver inattention while driving. *CapSeat* identifies risky situations based on the driver's position, ensur-

The usage of a pressure sensor on a car seat to keep the user's health in check

CapSeat detects potentially dangerous circumstances depending on the posture of the driver, ensuring that danger is averted on the road

ing that danger is avoided on the road. This can have a significant influence on our society, as the number one cause of road accidents is driver inattention [Steinger, 2021]. While not paying attention to the road, a type of alarm would assist drivers to concentrate on driving safer.
Braun et al. [2015a] mention two areas where *CapSeat* can be improved in the future. The first is to combine data from existing sensor devices that currently contribute to an Assistance System, and the second is to extend the system's processing to identify other qualities.

Bed frames with pressure sensors can be used to assess sleep habits

Pressure sensors may also be used in other pieces of furniture to protect user's health, such as the *Movibed* [Djakow et al., 2014], which incorporates sensors attached to the bed frame to monitor user's sleep phases, as previously stated. Djakow et al. [2014] discovered that *Movibed* is a significant step forward in allowing normal consumers to conduct small sleep analysis in the comfort of their own homes. Aside from the interfaces displayed, sensors and the modality pressure may be employed in a number of ways to improve the user's comfort, as it is used to control household appliances. The comfort Section 5.1 will cover these interfaces.

The interfaces described can be used to replace everyday items

Persuasive Mirror has the potential to encourage people to adopt a healthier lifestyle

People use items on a regular basis where these interfaces, including the ones described, may replace them, as demonstrated in the examples above. The majority of individuals utilize chairs in their daily lives when working or studying, sleeping in a bed, and checking their appearance in a mirror. Another interface that depends on a common object to assure the user's well-being is the *Persuasive Mirror* [Fujinami and Kawsar, 2008]. The *Persuasive Mirror* shows the user's health condition on the mirror, encouraging them to live a better lifestyle. Because people use mirrors on a regular basis, particularly in the morning in the bathroom, the interface may serve as a powerful motivator to start the day.

Smart e-textiles are being used to maintain the users' health

The usage of smart textiles or wearable interfaces is another way to create interfaces that are essential to a user's well-being [Hildebrandt et al., 2015]. The concept is similar to the one used by a wearable spirometer called *SpiroVest* [Enokibori et al., 2013], which is used to monitor the user's health and comfort.

Other interfaces that aim for the health of the users are designed specifically for individuals with disabilities. Both wheelchair [Gautam et al., 2014] and assistive system [Bissoli et al., 2019] interface employ eye-tracking to operate the interfaces. The user can control and maneuver the wheelchair, and with the assistive system, they can operate household appliances with their eyes. Eye-tracking technology may be utilized in a variety of various indoor home interfaces to assure the user's health as well as comfort. In addition to the living room where the assistive system is set up, we observe that the eye-tracking device may also be utilized in other rooms of the house such as the bedroom and kitchen to control appliances like the lights or air conditioning.

Eye-tracking as a modality for interfaces that aim to improve the comfort and health of individuals with disabilities

Regardless of the conclusions and advances of the study, no indoor home interfaces designed specifically for persons with chronic conditions such as diabetes, cancer, or heart disease were discovered. There are a few interfaces created specifically for persons with disabilities, however, they do not take into account the many types of physical disabilities. As a result, not everyone with a disability can utilize these interfaces. Future interfaces designed particularly for these people can be envisioned as a result of smart textile research.

3.3 Security & Privacy

For indoor home interfaces, security & privacy are also important considerations that we include in our taxonomy. As Anwar et al. [2017] found that new threats and weaknesses are being discovered on a regular basis which makes the issue of security & privacy more complex and intriguing. They divided the security threats in home into three categories: intentional threads, malfunctions, and unintentional threads. Identity fraud and data tampering are two examples of intentional threads. Accidental data/policy changes and data leaks are classified as unintended threads by Anwar et al. [2017]. Malfunctions can take many forms,

Home security threads are characterized as intentional, malfunctioning, or unintentional including Internet outages and communication link failure. Also as a result of recent security breaches in smart home setups, consumers are more likely to embrace and use new technology that is specific to a type of threat, making it important to take a critical look at the issue at hand.

Providing protection with a Bluetooth-enabled door lock

A Bluetooth-based door lock system [Guo et al., 2018] is one of the interfaces that seek to improve consumer's security at home. Guo et al. [2018] created a door lock system that interacted with the client over Bluetooth. The client in this case is a smartphone, which allows the door lock to be controlled through Bluetooth signals. This door lock system design is secure because it incorporates contemporary mobile Internet technology, integrated technology, and security protection technology. According to Guo et al. [2018], the design allows for intelligent control of the door lock through a mobile terminal and is simple to build and install in a house. Guo et al. [2018] did an examination of the system's encryption technology and found that the system's architecture is very dependable and sufficient for usage in everyday life.

Smart door system for home security

Lukman et al. [2018] also present an interface designed with the goal of ensuring the security and privacy of the users at home. They developed a smart door system that protects the safety and security of its users. For security, the smart door employs access control, integrated sensors, and alarm systems. Wireless technology is used to regulate and monitor the admission, user authentication, authorization, and administration of smart devices. A 4x4 hex keypad at the door is utilized to gain admission to the residence when the right password is entered. In addition, users are notified via SMS about a valid and incorrect inputted password, ensuring home protection against intruders. Through a comprehensive analysis, Lukman et al. [2018] found that the system is dependable, maintainable, and accessible to users based on a detailed analysis of the developed system. They also proposed system improvements to the smart door in the future, such as application design and an integrated surveillance camera.

The system uses wireless technology to alarm the users

A thorough examination of the system revealed that it is dependable, maintained, and accessible

A security system that ensures the security and privacy of the users are presented by Bamisaye and Adeoye [2016].

A micro-controller-based mobile phone and keypad-operated door that may be used to control the door

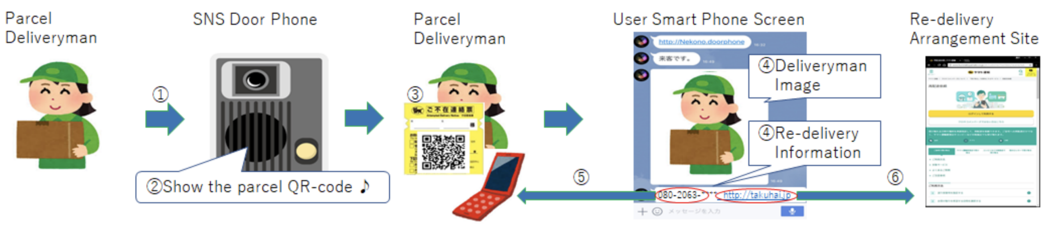


Figure 3.7: The steps of the SNS (Simple Notification Service) Door Phone interface: the deliveryman presses the button and is required to show a QR-Code of the parcel, the user may communicate with the deliveryman or arrange a re-delivery on a web site. Image taken from [Kobayashi et al., 2018].

They describe a mobile phone and keypad-operated door based on micro-controllers that can be used to control the door. The system can control the door remotely by using a mobile phone or a keypad as a transmitter. Bamisaye and Adeoye [2016] proposed four key modules for the design: mobile communication, control and decoding, and switching. The primary function of this system is to lock and open a door using a mobile phone and matrix keypad and a unique code input using the matrix keypad and mobile phone. The results of Bamisaye and Adeoye [2016]'s tests reveal that the system is successful in both software development and hardware assembly, which leads to a confirmation of the system's functioning.

Door system for parcel delivery

Kobayashi et al. [2018] introduce an interface that uses a smartphone to protect the user's privacy and security. They created the SNS (Simple Notification Service) Door Phone, a door device that allows for more pleasant parcel delivery while also protecting the consumers' privacy. The technology combines SNS and a QR-code mechanism to alert people about their shipment via smartphone. The deliveryman must scan the package QR-Code in the first stage of the SNS Door Phone as seen in Figure 3.7, after which the user receives an image of the deliveryman as well as a re-delivery operation converted by the QR-Code through SNS. This method protects the user's privacy and security since the users select when the parcel should be delivered, even if they are at home. Stolen parcels will no longer be an issue because the users manage the delivery period without an arrangement difficulty. Kobayashi et al. [2018] also determined that, while this approach is efficient for consumers, it is a lot of effort for the deliveryman since people rearrange the item arrival when it is already at their doorway.

Keeping children and animals safe at home by restricted access to the kitchen

Zhang et al. [2020] offer yet another type of smart door. They created an automated door barrier system to keep children and animals safe at home. The smart door restricts entry to a room from dogs and children, keeping the home safe when no adults are there.The smart door may be used in a number of applications, including restricting access for children and pets in the kitchen. Access to a room may be restricted remotely, reducing the dangers for children and pets. When the weight of the object standing on the motion sensor is more than the specified value, the door can be opened; when the weight is less, the door remains closed, preventing access. This interface is critical for the safety of children and pets at home when adults are not there, because the kitchen, for example, is a dangerous location where they might injure themselves.

Smart home system for monitoring and controlling the home

While most displayed interfaces have one clear purpose, Soliman et al. [2017]'s smart home automation system has multiple purposes. Soliman et al. [2017] created an interface out of a desire to be able to regulate household appliances and safeguard the safety of their users. They demonstrated a smart home automation system built using the Arduino micro-controller kit and the LbbView platform. Through a security camera, the system may be used to control lighting, manage temperature, and monitor house security. The monitoring which we are interested in is based on the signals received from the system's installed sensors. The system use motion detectors to activate the camera and record a video of the item that triggered the detector, assuring the user's safety and security.

Security system for controlling and monitoring the home

Kodali et al. [2016] also introduce a security system based on monitoring and control. They created a smart wireless home security system that monitors the home and sends warnings to the user in the event of an intrusion, as well as providing them the choice to raise alarms. Because of the WiFi-connected micro-controller utilized, this notice in the form of a voice call can be received from anywhere, thus the user may get the notification on their smartphone no matter where they are. Kodali et al. [2016] go on to list a number of benefits that this system has over other comparable systems, such as the low cost of the system, the fact that users do not require an internet connection to receive voice calls, and the fact that users may be notified from anywhere owing to the use of WiFi.

Figure 3.8: The construction of the security robot which senses a variety of subsystems, including fire, intruder, obstacle, environment, and power detection subsystems. Image taken from Luo et al. [2009].

Intelligent security robot for ensuring the safety of the users

Luo et al. [2009] developed a security robot that falls within the category of security and privacy. They developed an intelligent security robot with a variety of features (see Figure 3.8), including fire detection and intrusion detection which was first introduced in Luo et al. [2006] and subsequently refined in Luo et al. [2009].

Six systems make up the intelligent security robot: software development, obstacle avoidance, mobility planning, The robot senses a number of subsystems

image system, sensor system, and remote supervision system. The robot detects a number of subsystems at home using the systems included: fire, intruder, obstacle, environment, and power detection subsystems. The user may operate the robot using a smartphone or other internet-connected device. In this approach, if a security breach occurs, the robot may alert the users. The intelligent robot protects people not only against intruders at home but also from other circumstances that pose a threat to their safety by alarming and transferring the detection findings to the user's mobile phone.

3.3.1 Discussion

Various forms of home security and privacy breaches have been found

Security and privacy are two important components of one's everyday life, especially when it comes to home safety. The majority of the interfaces offered are intended to protect consumers against intruders at home but as Anwar et al. [2017] concluded there are multiple types of security breaches at home, which should be taken into consideration while designing new interfaces for the security of a home.

The majority of interfaces are door locks

Most interfaces found in the research are door locks using a different types of techniques to stay secure, such as a keypad or the connection to a mobile device [Bamisaye and Adeoye, 2016, Zhang et al., 2020]. These interfaces secure the home from intruders and not other dangers that might occur such as fire. Taking the research done by Anwar et al. [2017] into considerations malfunctions such as internet, network or failure of the device can cause security threats to the interface and the users. Most of the interfaces are connected to the cell phone, creating a possibility for these malfunctions to emerge.

Only invaders are considered in the interfaces given

Other threads highlighted by Anwar et al. [2017] include deliberate and unintentional threads, such as data leakage (unintentional), identity fraud (intentional), and other. The authors of the presented interfaces did not offer any solutions to the above-mentioned issues. They only viewed unauthorized entrance to the residence as a potential issue.

Thus these defects can emerge, these systems have a lot of advantages. They make sure the users feel safe at home by alerting them if any security breaches were recognized. The interfaces also alert the users when they are not home giving them the option to raise alarm and inform the police if any intruders occur. The interface presented by Luo et al. [2009] also alerts the user, if any other type of danger occurs at home, which has a big impact on the life of the users.

The interface secures the users and their home

The scenario used in all of these interfaces is home but they can also be utilized in other locations where human beings feel the need to stay secure from intruders such as an office or even restaurants. Aside from these locations that the interfaces can be used, they also can be developed further to secure the homes from other aspects than they currently do, especially the door lock systems used to monitor the house. They can be developed to predict distorts before they occur, such as fires, floods, and hurricanes, and alarm the users when triggered.

Application of the interfaces in other scenarios such as offices or restaurants

Chapter 4

Public Setting

Beside the private setting in a home, the public setting is also taken into consideration in this taxonomy, which is defined as a space in a home where invited people have access to and may interact with several individuals, such as a living room or a kitchen. The public environment is included in this taxonomy because there are locations in the house that act as community social centers, welcoming guests and allowing family members to enjoy each other's company. In a public setting, interfaces are further classified into the categories of communication and education. This distinction is taken into account since interpersonal communication can only be done in groups of individuals, not alone. Education is considered in this section because the interfaces studied and classed in this category are intended to be utilized by a large number of people. Section 2.1 explains why these purposes were classified as public in detail as well as the reason why these purposes were chosen for this setting.

Public setting is also taken into consideration in this taxonomy

Public setting is further subdivided into communication and education

4.1 Communication

Palmer et al. [2019] investigated the effect of human-to-human communication on mental and physical health and found that social interaction is essential for people because

Another purpose taken into account is communication, which has an impact on user's mental and physical health communication disability is a strong independent predictor of major characteristics of individuals' social function and shows two different paths to loneliness and depression. The interfaces given make it easier for users to contact with faraway friends and family members while staying at home. This Section also considers communication for persons with disabilities by addressing the communication barrier for deaf and deaf-blind people. Most interfaces for interpersonal communication are motivated by the idea that people should be able to connect with distant relatives and friends more easily even if they are in different time zones, or by the reality that people with disabilities are excluded from daily conversation. Furthermore, these interfaces do not require the continual presence of a caregiver who acts as a translator with an external world arranged for hearing and sighted persons in order to engage with others.

Most presented interfaces make communication with distant people easier or provide a solution for the communication barrier for people with disabilities

Tang et al. [2013] introduce *HomeProxy*, a video communication interface that allows dispersed family members to stay connected. It makes it simple to share activities with family and friends by employing a tangible artifact devoted to them. The interface's features include filming a video message, watching back a video message, and entering into a live, simultaneous video chat while someone was recording a video message. *HomeProxy* is intended to be easily incorporated into a house, which is why it features a slightly curved rear-projected screen, fabric sides, and a wood top to create a more consumer-like ambiance. The interface's design also enables for mobility between the many rooms in the house where family activities take place. Instead of buttons or user interface controls, the interface continually senses the presence of humans in its surroundings. Tang et al. [2013] also designed the communication system to switch between recorded and live video communication, if both participants are accessible at the same time. The findings of Tang et al. [2013]'s user study with the produced prototype revealed that the participants loved the rapid access to video chatting and the home look design. They intend to test the system in real-world circumstances to see how effective the capabilities are in facilitating contact with distant relatives and friends.

HomeProxy is a video communication interface that helps you stay in touch with family and friends that live far away

The interface allows you to record and play movies as well as communicate with others in real time

Yarosh et al. [2013] also shows a communication system that may be used to communicate with distant family members. The *ShareTable* offers an easy-to-use video chat as well as a shared tabletop surface. The system consists of two cabinets, one in each user's house, and to simplify the start of a connection, Yarosh et al. [2013] uses cabinet doors to reach out to the other party, so to establish a call, the user just needs to open the *ShareTable* cabinet doors. The *ShareTable* in the other house rings like a phone, and users may respond by opening the cabinet doors. When the cabinet doors are closed, the call comes to an end. When a connection is established, the *ShareTable*'s monitor display shows a traditional face-to-face video chat, and the local table surface displays a projected picture of the distant table surface, and vice versa. The technology has advantages over earlier communication systems, such as the projection of the remote table surface. Yarosh et al. [2013] built the system specifically for parent-child remote communication to make it simpler for them to connect, but it may also be used by friends and other family members. The method was tested for a month each with two divorced families, and the findings reveal an increase in the number of communication sessions started by the child.

ShareTable is a communication solution that includes an easy-to-use video chat feature and also a shared table surface

The technology was designed primarily for distant communication between parents and children

Telepresence robots are another interface that may be utilized to keep in touch with distant relatives and friends. Yang and Neustaedter [2018]'s study looked examined how telepresence robots may fit into the variety of communication methods used by long-distance couples. Given the telepresence robots' movement and physicality, acts of engagement and independence between couples might be supported. According to the study communication with a telepresence robot boosted interactions in five areas: involvement in monotonous daily activities, sentiments of sharing a home, connection with one's partner's family and friends, enhanced willingness to help, and the enjoyment of calm conversation.

Telepresence robots can also be used to communicate with faraway family and acquaintances

Kikuchi et al. [2017] also propose an interface that may be utilized for human-to-human communication. By gently tugging the ear and sensing the deformation, *EarTouch* transforms the ear into an interface input device for controlling appliances. Optical sensors detect ear deformation

EarTouch is an ear-based input method that works by gently tugging the ear and sensing the deformation using an improved earphone device

Figure 4.1: The *ShareTable* prototype being used by a Parent and child at home: the display shows the distant parent, while the local table surface shows a projected picture of the parent's table surface, where he is sketching. Image taken from Yarosh et al. [2013]

produced by contacting the ear, enabling for eye-free engagement. The interface uses support vector machine to recognize various movements. *EarTouch* allows the user to control appliances such as answering phone calls, music players, and navigation systems. In essence, the user may run their smartphone via the interface and it can be used to facilitate user communication. The smartphone may be operated with *EarTouch*, making phone calls and communication simpler. The findings of the evaluation demonstrate that little changes in facial expression have no influence on the accuracy of the interface, but vigorous movement, such as jumping, may cause issues since the interface may move.

A smart device can be operated with *EarTouch*

The forthcoming interfaces are designed to help individu-

The presented interfaces can be utilized everywhere als with disabilities overcome communication barriers, and one of the reasons that interfaces for deaf or deaf-blind people are included in this taxonomy is that they may be used everywhere. Because of their compact size, the offered interfaces are usually wearable or readily transportable. As a result, these interfaces may be used both inside and outside the home. Another rationale these interfaces should be included is because they can serve as inspiration for future home interface development aimed at bridging the communication gap for individuals with impairments, which is one of the taxonomy's goals. For example, the interfaces may be linked to a piece of household furniture, such as a couch, and the user could use it while sitting down. *Lorm Glove*, presented by Gollner et al. [2012], is an interface that might be used as an example of this form of inspiration.

The interfaces can serve as a model for future home interfaces with the same purpose

Gollner et al. [2012] developed an interface that support deaf-blind people communicate. They discovered that individuals with impairments are excluded from many types of communication, so they created an interface to assist them converse and become more self-sufficient. The *Lorm Glove* is a wearable mobile communication and translation device which converts text into Lorm alphabet and vice versa. The Lorm alphabet is a hand-touch alphabet for deaf-blind people, which places letters on various parts of the hand. The user may utilize the glove to create a message by wearing the glove on their left hand and writing the text with their right hand by tapping the buttons, which can be seen in Figure 4.2. The user of the interface can receive a message on their phone, which is then transmitted into the glove through Bluetooth and translated into the Lorm alphabet, and the messages are seen by the user via micro vibrating motors put into the glove. The *Lorm Glove*, which can be worn anywhere, allows deaf-blind individuals to communicate. The prototype garnered mostly good responses from deaf-blind persons, according to Gollner et al. [2012].

A wearable mobile communication and translation glove

Users can write message by tapping the button on the glove with their right hand

A similar wearable glove system for communication is developed by Caporusso [2008] which implements the Malossi alphabet, a language that is simple to learn by deaf-blind people. The Malossi alphabet is a hand-touch alphabet for deaf-blind people, which places letters on the palm of the hand. *DB-hand* is an assistive software sys-

DB-hand, a wearable glove system which implements the Malossi alphabet

Figure 4.2: The *Lorm Glove*'s input surface: The left hand may wear the *Lorm Glove*, while the right hand can tap the buttons that depict the letters. Messages may also be received on the phone and translated for the user into Lorm alphabet via micro vibration motors. Image taken from Gollner et al. [2012].

Users can compose messages by interacting with the buttons

tem that allows users to engage autonomously with their surroundings, develop social interactions, and access information sources without the need for an assistant. Tactile switches on the palm surface must be pushed and pinched to interact with the glove and convert text into sequences of tactile sensations. Malossi employs discrete symbols allowing for a simpler design. An experimental investigation evaluated several prototypes of the interface with normal and deaf-blind people, and an experimental research is planned to validate the system's efficiency in real-life settings. Caporusso [2008] intend to improve the software by incorporating methods that allow the system configuration to be adaptable, which means that the settings should update automatically based on the user's progress.

BrailleBand is a wearable interface that allows blind users communicate

Savindu et al. [2017] also considered the communication needs of the blind community and created an interface to help visually impaired people communicate. Savindu et al. [2017] created the *BrailleBand*, a wearable interface that enables for passive reading (see Figure 4.3). The suggested interface is a wearable wrist band with six vibration nodes corresponding to the standardized braille dot code to deliver information from a smart device to a blind user. It is Bluetooth-connected to the smart device, and applications produced on the device can be utilized with the wearable interface. The applications were developed by Savindu et al. [2017] to assist the blind people in learning how to use the *BrailleBand* and to integrate existing smart mobile applications such as messenger and navigation with the interface. The findings of the product practicability tests were promising in terms of reading speed and accuracy, which increased with experience. Based on the findings of the experiments, an average Character Transfer Rate (CTR) of 0.4375 characters per second was reached with a character gap of 1000 milliseconds.

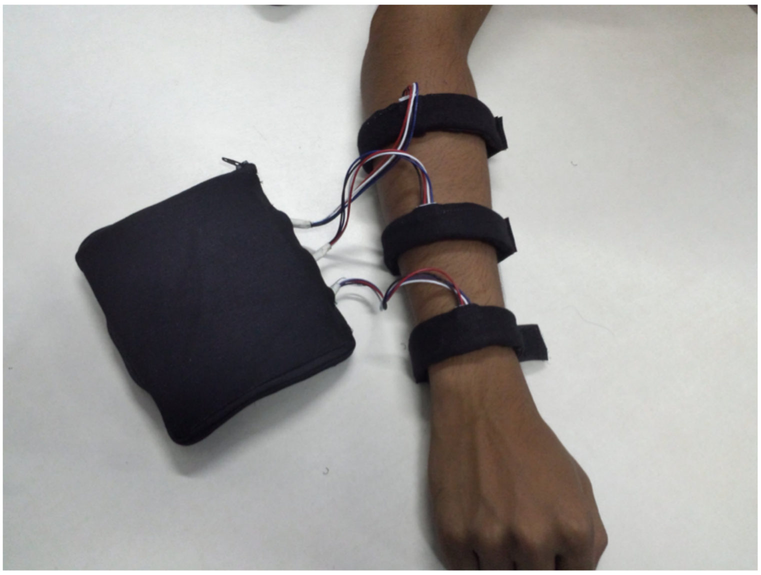


Figure 4.3: The prototype of the interface *BrailleBand*, which is a wearable wristband with six vibration nodes that match to the standardized braille dot code that allows a blind person to receive information from a Bluetooth-connected smart device. Image taken from Savindu et al. [2017].

Another solution for the communication barrier for individuals with impairments was presented by Ramirez et al. [2014]. They present *myVox*, a portable keyboard and speaker system that a deaf-blind user may use to interact with others. The system consists of keyboards which may be used to type phrases that the user

myVox is portable keyboard, speaker and display wishes to convey to others and vise versa, a speaker can replicate the speech synthesized version of the written message, a braille refresh-able display, a LCD display and vibration motor to notify the user of a message. A deaf-blind individual can use *myVox* to communicate with others. While the interface is designed to be portable and usable everywhere, users may also use *myVox* at home to interact with family and friends. Deaf-blind persons have a difficult time talking with strangers in public places, as well as at home, if their communication partner does not understand sign language; thus, the interface may be utilized at home. A deaf-blind collaborator tested the system at home, and it has shown to be a valuable tool for communicating with people without the assistance of an interpretation.

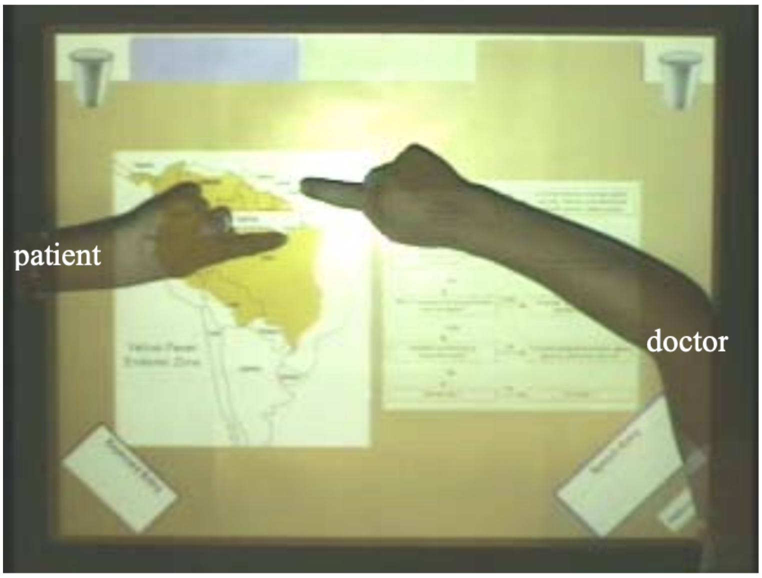


Figure 4.4: The digital table prototype is being utilized by a deaf patient and a non-signing doctor: The physician can indicate a location on the globe while asking a question that the patient can respond to using the speech bubbles. Image taken from Piper and Hollan [2008].

An interactive tabletop that allows a physician and a deaf patient to communicate

Piper and Hollan [2008] presented a tabletop interface designed to aid deaf people in communicating. They created an interactive multi-touch tabletop display to allow a physician and a deaf individual to engage medically (see Figure 4.4). The tabletop interface is intended to be used simultaneously by the patient and the clinician. While the physician speaks through a microphone, the deaf patient can type on the keyboard, and their speech will be shown on the tabletop. They determined via their research that the interface has significant capabilities such as voice recognition, visual display, and touch input for enabling deaf and hearing individuals to converse, as well as promoting privacy and independence. While Piper and Hollan [2008] focused on communication between a deaf patient and a physician, the tabletop interface may also be utilized at home. The interface allows a deaf person to communicate with non-signing family and friends. As previously stated, the interface detects voice and text written on a keyboard, improving communication between a deaf and a non-signing person. The tabletop interface software can be expanded further to incorporate a gaming application, allowing deaf people to enjoy games with their friends at home.

4.1.1 Discussion

Communication is essential for human growth since a lack of communication may lead to loneliness and melancholy [Palmer et al., 2019]. The offered interfaces are aimed at improving communication at home, regardless of whether the individual is there or not. Most people may convey with others at any time by just using their mobile phone, making it simple for them to communicate. Phone calls, text messages, and voice messages are all ways for people to connect with one another.

Communication using smart devices is simple nowadays for people

However, individuals with impairments still face a communication barrier, which is why they are unable to engage in regular discussion with others. A deaf person, for example, cannot interact with a non-signing friend or family member at home, which is why this taxonomy includes interfaces that assist persons with impairments communicate.

There is still a communication barrier for those with impairments

ShareTable, *HomeProxy*, and the telepresence robot are all interfaces that attempt to link individuals who are far away from their homes. While *ShareTable* is designed to facilitate contact between a remote parent and their kid, *HomeProxy* is intended for use by family and friends. Both of these

ShareTable, *HomeProxy*, and the telepresence robot can be utilized with relatives and friends that live far away interfaces are suitable for communicating with family and friends. *HomeProxy* has an advantage over the *ShareTable* in that it can record and play video, allowing messages to be left via the interface, which is not possible with the *ShareTable*. On the other hand *ShareTable* reflects the opposite table surface onto the local one, enhancing user engagement by allowing them to play games, draw, and do much more together even if they are not in the same room.

The benefit of these systems is obvious: they make it easier for people to stay connected and communicate with their distant friends and families. The disadvantage is that these interfaces may diminish physical interaction between individuals. The *ShareTable*, for example, is particularly built for divorced parents to interact with their distant child. Because parents and children may communicate at any time, there may be less physical interactions than in the past because users do not see the need to meet in person. If this circumstance arises, it may cause issues in the users' relationships.

Physical interaction might be overlooked when there is a lot of communication conducted through the interface

The difficulty with utilizing *HomeProxy* is that if both users are present at the same time, live video communication is activated automatically, which may not be what the users want. Users may only wish to check for new video messages or leave one, but the interface detects their presence and initiates a video call.

Even if the users do not want it, *HomeProxy* starts a video call

The interface *EarTouch* presented by Kikuchi et al. [2017] enables mobile phone control easier by simply touching the ear, enabling smart phone control eyes-free. *EarTouch* was not created for people with disabilities in mind, which is why it can be used by anyone to control smart devices eyes-free. Kikuchi et al. [2017] discovered that vigorous movements can cause issues, which is why it is planned to investigate an on/off switch that determines the start and end of a gesture.

EarTouch can be used by everyone to control smart devices

Vigorous movements can cause issues

Other wearable interfaces were created to allow individuals with impairments to interact with others. To communicate with others, the interfaces *Lorm Glove* [Gollner et al., 2012], *DB-Hand* [Caporusso, 2008], and *BrailleBand* [Savindu et al., 2017] utilize a form alphabet such as the Lorm or Malossi. The input sentences are converted into English text via these interfaces, and vice versa.

Wearable interface specifically for people with disabilities

Another feature shared by wearable interfaces is the use of the touch modality. By pressing the buttons, users may create text that can be seen by others.

Gollner et al. [2012] express worry over the *Lorm Glove*'s thickness and plan to replace the employed flexible wires with elastic printed electronics, for example. They also want to add an interface for accessing a larger range of information, such as websites and e-books, to the present system. Both Gollner et al. [2012] and Caporusso [2008] agree that a real-world investigation is necessary to determine the systems' operation and usefulness. A long-term research, according to the authors, is also required to determine how the proposed system can alter user behavior in ordinary life.

Due to the Lorm Glove's thickness, the material used in it is planned to be replaced

The *Lorm Glove* and the *DB-Hand* need to be tested in real-life situations

Another issue that may cause users discomfort is the inability to utilize the hand that the glove is on. So, if they have the glove on their right hand, they can't use it for anything else since the glove would be activated. One solution to this problem would be an on/off switch, allowing users to control when the glove is required.

Also the non-wearable interfaces Ramirez et al. [2014], and Piper and Hollan [2008] facilitate communication between people with impairments and non-signing person. Ramirez et al. [2014] found through a long term user study that the interface *myVox* is helpful for deaf-blind people. They also intend to improve the system by utilizing the ability to connect to the Internet and enable the installation of custom applications. The system's design will also be altered in terms of size and cost. *MyVox* should be easier to travel and more affordable, according to Ramirez et al. [2014].

Improvements to the technology and the architecture of the *myVox* interface are planned

While the other interfaces provided may be used everywhere and at any time, the interface presented by Piper and Hollan [2008] was particularly designed for communication between a patient and a doctor. As mentioned the results of the evaluation done by Piper and Hollan [2008] show that the interface has key qualities for facilitating communication between deaf and hearing persons and it improves the privacy and independence of the patient. At home, the interface may also be used to interact with non-signing friends and relatives. The program displayed on the tabletop may be expanded to in-

The digital tabletop can also be used at home to communicate with friends and family clude games that can be played by several people. The interface may also be used in public places, such as restaurants, to help persons with impairments communicate with wait staff. When the user wishes to eat , he or she does not need to rely on a caretaker.

Everyone with a disability will not be able to use the interfaces created for people with disabilities

As stated in Section 3.2, the interfaces designed for individuals with impairments cannot be utilized by everyone with a disability. Gollner et al. [2012], for example, offered an interface for deaf-blind individuals, whereas Piper and Hollan [2008] produced an interface for deaf persons that cannot be utilized by deaf-blind people. Even though the interfaces did not account for all impairments, they ensure communication between a person with disabilities and a non-signing person.

4.2 Education

Education is a vital aspects in one's life

Engaging and interacting with physical items helps children learn more effectively

Education is also considered as a subcategory because it is an essential component of our life. According to Bhardwaj [2016]'s research on the value of education, there is no way to overstate the importance of education in terms of the individual's, social, political, economic, and cultural advancement. Their conclusion was that education can be found in every aspect of one's life, making it a vital part of one's existence, and that education is the key to future success and an abundance of chances in one's lifetime. According to Agrawal et al. [2013], the motivation for developing interfaces that aim to educate the user is based on previous educational research that highlights the importance of a youngster engaging with tangible items in his environment for the general development of his intellect, as well as the fact that children learn about the world around them and absorb information far faster when they touch, manipulate, explore, and test it rather than when it is presented to them in written format [Strommen, 2004]. One of the interfaces researched that falls into this category is a tabletop interface presented by Ahn et al. [2010].

An interactive tabletop interface that can be used for variety of applications

Ahn et al. [2010] proposed a tabletop interface with touch-controllable LCD displays, mirrors, and infrared cameras, which was designed and developed further a few years later [Ahn et al., 2015]. The suggested system uses a hybrid recognition strategy that combines Frustrated Total Internal Reflection (FTIR) with Laser Light Plane (LLP) to identify multi-touch inputs and dragging actions more successfully and efficiently. The purposed interface can be conveniently utilized on any table, and users can use it to control a variety of applications, such as playing games or reading e-menus. Ahn et al. [2015] mention a few public places where the interface can be utilized in such as restaurants but we recognize that the tabletop can also be used at home for studying. Users can project educational games onto a tabletop and use them to learn, which can motivate users, particularly children, to study more. The results of Ahn et al. [2015]'s examination with a puzzle matching game demonstrate that the suggested interface is both efficient and effective.

The interface is suitable for usage both at home and in public areas such as restaurants

Khandelwal and Mazalek [2007] developed an interactive tabletop interface aimed at pre-kindergarten children's education. The *Teaching Table* system assists children in learning fundamental numbers by enticing them to interact with the interface through voice. The interface comprises of a table, an enhanced surface, a speaker, and blocks that the children utilize. The children must respond to the voice input by placing labeled blocks at appropriate positions on the table. The interface activities attempt to engage children by providing positive feedback and tips, as well as visual information on the tabletop. The system was created by Khandelwal and Mazalek [2007] to fit into a classroom setting (public setting) and provide learning activities for the students as well as support for the teachers. The *Teaching Table* approach may also be used at home to encourage kids to learn fundamental math in groups. Since most pre-kindergartners spend more time at home with their parents or babysitters, the interface could become a part of their daily routine. Khandelwal and Mazalek [2007] also suggested expanding the *Teaching Table* method to incorporate activities in areas such as language and literacy, such as science and creative development. They also propose a three-phase user study that will be used to test and assess the system in the future. The first part involves examining the classroom environment, while the second establishes

Interactive tabletop aimed at pre-kindergarten children's education

The interface attempts to persuade the children by giving them visual and audio feedback the interface's viability in a classroom setting as well as the chosen methods of measuring children's progress in learning basic math abilities. The last stage assesses whether the system is physically accessible to children and whether the engagement activities are age-appropriate.

Read-It is an interactive tabletop that aids children in the learning of reading

Sluis et al. [2004] also developed an augmented tabletop application aimed at young children's education. *Read-It* is a multi-modal tabletop interface application that helps children learn to read. It is a collaborative tabletop environment that combines the features of physical tabletop games with desktop activities. Physical bricks, as well as other learning strategies like memorization, practice, and collaboration, are used in the game to promote participation. To create a user-friendly user interface (UI), *Read-It* was created with the assistance of children. The interface encourages children to work together to learn by displaying educational content onto the table. The tool might be utilized in a classroom in the future, according to Sluis et al. [2004], and because the *Read-It* is a tabletop interface, it may be easily incorporated into a household and utilized by children to learn. According to a user test conducted by the authors, learning to read using the interface can benefit children between the age of five-to-seven years.

ChemicAble is an interactive tabletop interface that assists students in understanding ionic compound formation

Agrawal et al. [2013] presented a tabletop aimed at older children's education. They created an interactive tabletop interface to assist students in learning chemistry, which can be seen in Figure 4.5. The *ChemicAble* interface is composed out of a table, a projector, a camera, a glass and tokens that represent atoms. The first 20 elements of the periodic table are represented by 20 hemispherical tokens. When an atom token is placed on top of the table, the token's valence shell (outermost shell) is shown around it. *ChemicAble* promotes collaborative learning among students to assist students understand ionic compound synthesis. They discovered through a user test that overall, students appreciate using *ChemicAble* to comprehend ionic compounds and that the interface is simple to use. Although Agrawal et al. [2013] intend for the interface to be used in schools, it may also be developed and used at home to learn ionic bond formation in chemistry with friends. The interface can easily be integrated into a student's bedroom and used to prepare for

ChemicAble may be utilized both at home and at school

Figure 4.5: *ChemicAble* prototype: 20 Hemispherical tokens were used to represent the first 20 elements of the periodic table. When an atom token is put on top of the table, its valence shell is displayed surrounding the token. Image taken from Agrawal et al. [2013].

class with other classmates or their parents after school or on weekends.

Mäkelä et al. [2014] provide a public information display that allows users to view relevant local information on the wall. Using remote pointing and mid-air gestures, the interface *Information Wall* is a gesture-controlled public information display that allows multi-user access to contextualized specific information. Users can display any sort of data on the wall, as an example Mäkelä et al. [2014] used lunch menus. The interface detects user movement with a Microsoft Kinect sensor and displays information on the wall via a projector. Considering Mäkelä et al. [2014] did not define what sort of content should be presented or not, the interface may be used to view news and school assignments, guaranteeing that users are well-informed. According to the findings of Mäkelä et al. [2014]'s user survey, the system's usefulness in public displays was fairly low.

Media may be shown on the *Information Wall* and controlled with mid-air gestures.

The product *Mui* can also be used to display information

Mui is a smart home control center that features a hardwood touch panel display technology

Figure 4.6: The smart home management hub *Mui*: Smart devices may be connected to the interface through an application, and messages, calendar events, and weather forecasts, as well as household appliances such as lighting, can be shown and managed. Image taken from Oki [2016].

and control home appliances [Oki, 2016]. Founded by Oki [2016], *Mui* is a smart home management hub with a wooden touch panel display technology. It not only allows you to connect various smart home gadgets, but it also has its own functions such as alerts, light and music control, messaging, and calendar sharing. The device was created for the comfort of customers as part of their home furnishings. The hardwood touch panel display may also be utilized to read information such as the weather forecast. Despite the fact that *Mui* is designed to be put on a wall, as a result of our additional investigation, the display may also be mounted to the office desk and utilized for learning.

4.2.1 Discussion

Education is a vital element of human existence, and it is critical to be educated no matter where one lives. The interfaces presented are intended to educate people in public settings. The research of the interfaces suggested that there are a few interfaces developed for the education of children at home using different methods such a tabletops.

To assist children with studying at home, the tabletop interface [Ahn et al., 2010], *Teaching Table* [Khandelwal and Mazalek, 2007], *Read-It* [Sluis et al., 2004], and *ChemicAble* [Agrawal et al., 2013] utilize tabletop interfaces. While *Teaching Table* and *Read-It* aim for younger children who are just learning to read and do arithmetic, *ChemicAble* focus at high school students who are studying chemistry.

A few tabletop interfaces have been created with the goal of educating children of various ages

Khandelwal and Mazalek [2007] intend to expand the interface *Teaching Table*'s exercises. While the current research focuses on the development of arithmetic abilities, it may expand to include themes like as languages, literacy, science, and creative development in the future. They also intend to develop small-group cooperative activities. Agrawal et al. [2013] has a similar notion to expand the *ChemicAble* interface to include other science fields that are difficult for most students to understand, such as biology or physics.

Expansion of the *Teaching Table* and *ChemicAble* interfaces to accommodate more areas

As previously indicated, the other tabletop interface created by Ahn et al. [2010] was intended for usage in public settings like as restaurants, although we understand that, like the other tabletop interfaces shown, it may also be used at home. Ahn et al. [2010] intends to merge the tabletop interface with other interfaces. For group collaboration, a smart phone or a tactile interface will be integrated into the suggested tabletop interface.

The tabletop interface may also be used at home

The benefit of tabletop interfaces is that they employ a piece of furniture that everyone in the house uses, making the integration of the interface easier. User testing on the tabletop interfaces also indicated that they were beneficial and practical for the users.

Tabletop interfaces offer the advantage of utilizing a piece of furniture that everyone uses

Aside from the aforementioned interfaces, we discovered others that are just intended to inform consumers. The *Information Wall* [Mäkelä et al., 2014], and *Mui* [Oki, 2016] interfaces were created with the goal of informing users. The goal of *Information Wall* is to project information on the wall for people to see, which may be manipulated with a midair gesture. Oki [2016] created a device that manages the home and displays information to consumers using a piece of wood. Both of these interfaces may be improved to comprehend and control a wider range of applications than they now do. The *Information Wall*, for example, might be

The goal of these interfaces is to inform users about the topic they want to learn about built to control and monitor household appliances, and the product *Mui* could be integrated into tables.

To educate users, the interfaces make use of readily integrated elements

All of the interfaces described above employ ordinary items to teach users, such as tables, and in the future they may be expanded further to manage and handle more programs than they presently do, as previously indicated. They were designed to be used in public locations like classrooms and offices, so they may be utilized at home with numerous people. Tabletop interfaces aimed at educating children, in particular, are designed to be used by a group of students in a classroom, but because they can be readily incorporated into a home, they may also be used at home with classmates after school or on weekends.

Chapter 5

Private & Public Setting

Our taxonomy also considers both private and public settings at the same time. That is, the interfaces presented in this chapter can be utilized in both scenarios. Users can enjoy the interfaces whether alone at home or while socializing with friends and family. This category was considered since many of the interfaces investigated can be utilized in both settings. The interfaces in the private and public settings are further divided into the subcategories of comfort, entertainment, and sustainability. The reason comfort is a subsection is that the interfaces stated strive towards the user's comfort regardless of the setting in which they are utilized. This section also includes entertainment since the offered interfaces amuse users in both private and public settings. Sustainability is a subcategory in this area since everyone should be sustainable at home and control their water and energy consumption. The reason for these subcategories were chosen is explained in detail in Section 2.1.

Both private and public settings are taken into consideration

Comfort, entertainment, and sustainability are the three subcategories of this category

5.1 Comfort

According to our research on interfaces, many interfaces aim for the purpose comfort. As stated in Section 2.1.2, comfort can be defined in a variety of ways. While Frontczak [2011] found that physical and human ele-

The comfort of a house is influenced by both physical and human elements

ments influence the comfort of indoor home interfaces, Taiwo et al. [2020] mention that interfaces that do not require users to move give comfort. When classifying the investigated interfaces, our taxonomy takes both of these concepts into account. The motive for considering this objective while creating and developing interfaces is that users want to feel comfortable at home, and comfort may be increased through these interfaces.

The assistive system also aims for the comfort of the users at home

Bissoli et al. [2019] showed an assistive interface which controls home appliances with the gaze that falls into this category which was previously introduced in Section 3.2. The reason why the interface presented by Bissoli et al. [2019] is also placed in the comfort category because it strives for the comfort of its users by ensuring the control of essential home appliances with the gaze. A detailed description of the system was already presented in Section 3.2.

GeeAir, a multi-modal controller for remote control of home appliances

An interface for controlling home appliances that also aims for the comfort of the users was presented by Pan et al. [2010]. The interface *GeeAir* is a multi-modal remote control device that can control appliances in a variety of modalities (see Figure 5.1). Speech, gestures, joysticks, buttons, and light can all be used to operate home devices. Due to the range of modalities integrated, the interface can also be used by people with physical and visual limitations. The test findings from Pan et al. [2010] reveal that the *GeeAir* prototype achieves remarkable performance and that *GeeAir* has a clear advantage over universal remote controllers.

Smart kitchen cabinet that can identify products from the store in the cabinets

Karuppiah [2012] designed a smart kitchen cabinet that can detect supermarket items in the cabinets. Sensors in the cabinets measure the weight of each item, which is subsequently stored in a database whenever items are inserted or taken from the cabinet. Because the position of the items is established by radio-frequency identification (RFID) tags on the objects, moving them to a different cabinet than before will not be an issue. Other kitchen cabinet features, including as inventory management and automatic shopping list production, are also helpful and aid customers in effectively managing kitchen operations based on database information. According to the findings of load sensor test

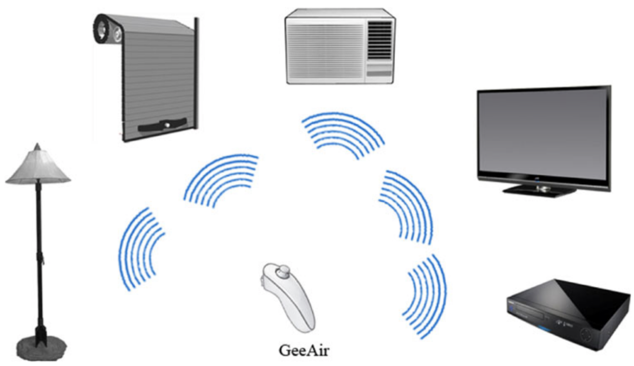


Figure 5.1: *GeeAir*, a multi-modal controller for remote control of home appliances, is depicted here: *GeeAir* has a joystick, microphone, speaker, and two buttons that may be used to operate the appliances. Image taken from Pan et al. [2010].

by Karuppiah [2012], the error rate was very significant for small weights, but it reduced to almost zero for weights over 1 kg.

Kitchen system for controlling kitchen appliances via mid-air gestures

The kitchen was also examined by Panger [2012] as an area in the house where an interface might be built. They created and built a kitchen system that uses Microsoft Kinect to operate applications via mid-air gestures. Users may operate a recipe navigator, a timer, and a music player using the interface. The findings of the study revealed that users could readily put the interface, but that preventing inadvertent instructions was a difficulty for all users. When sweeping the hand across the screen during concentrated engagement, especially when changing directions, inadvertent presses happened. Nonetheless, the interface strives for user comfort in the kitchen, since users can easily manage apps even with filthy hands thanks to the mid-air gesture.

Button presses by accident were prevalent

CounterActive is an interactive cookbook with recipes

Ju et al. [2001] presented an interactive interface for learning one of the most common household jobs, cooking. The interface that has been proposed *CounterActive* is a recipe-based interactive cookbook that teaches users how to cook by displaying recipes. The interface employs a projector to display the recipes on the kitchen counter for the users. It

The recipes are projected on the kitchen counter was created to make the cooking process easier and comfortable by projecting the recipe on the counter top. According to user testing done by Ju et al. [2001], the *CounterActive* system has to recognize the user's actions in order to truly teach cooking and offer adaptation. To accomplish this goal, they proposed to employ tagging technology to track ingredients and materials as users prepare meals.

eyeCOOK aids users in learning how to cook and may be controlled by vocal and gaze guidance

An interface that also assists the users with the cooking process was proposed by Bradbury et al. [2003]. The suggested interface *eyeCOOK* is a multi-modal attentive cookbook that users may manage using their gaze and vocal instructions. The *eyeCOOK* reacts to orders digitally and vocally, resulting in a non-physical contact. They improve the user interface (UI) by adding numerous features to make it more user-friendly. An automated timer is one among the features, as is adaptive display, which detects eye gazing and displays information appropriately, and adaptive input channels, which are utilized for voice commands. If users are unable to control the interface with their eyes because the sensors are out of reach, they can manage the interface vocally, guaranteeing a pleasant usage of the interface. If the user is within the range of the eye tracker, speech instructions are combined with the gaze; if not, more precise voice instructions are enabled, and eye gaze input is suppressed until the user is back in range.

Wearable interface that allows users to manage household appliances

According to our research, there are a variety of wearable interfaces aimed at enhancing user comfort at home but also everywhere else. These interfaces are considered in our taxonomy because they might be developed further to controls home appliances. An interface that control home appliances was developed by Ha and Byun [2012].

Wearing the interface allows users to operate appliances using mid-air gestures

Ha and Byun [2012] designed an interface that pursues for comfort by demanding less movement from users when operating home appliances. Wearing the user interface gadget and waving their hand in mid-air allows users to manage home equipment such as the TV and air conditioner. Other appliances can be controlled based on the users' position by drawing a clockwise circle in mid-air. For example, if the users are in the living room, they can control the TV with the stated motion, but if they are in the living room, they can also manage the air conditioner. The home-care system also features a fall detection feature, which means that if the user does not move their hand for an extended period of time, the system will send a fall alert message to a family member's phone.

Dobbelstein et al. [2015] presented a wearable interface that assures the comfort of its users. They created and implemented an interactive belt. The belt is a touch-sensitive e-textile input device for wearable screens that wraps around the user's hip. Because of the huge horizontal input space, information and applications are easily accessible. Various apps, such as a digital wallet, social media, contacts, and a music player, may be placed anywhere on the belt and accessed through touch. Dobbelstein et al. [2015] describes a belt as an item that is worn by the majority of people and is near to the user's hands' resting height, implying a suitable input device. Users considered this interaction as socially acceptable in public, according to Dobbelstein et al. [2015]'s user study. The user's comfort is ensured by the belt's ability to provide eyes-free and quick access to a variety of apps. The interface may be used to control household appliances and eliminate the need for many controllers at home.

An interactive belt that may be used to access a variety of applications

Saponas et al. [2011] demonstrated another interface that allows for eyes-free engagement. They created the *PocketTouch* interface, which is a capacitive sensing prototype that is supposed to reside in the user's trousers or shirt pocket as seen in Figure 5.2. The prototype created by Saponas et al. [2011] consists of a multi-touch capacitive sensor that is put on the back of a smartphone and can be interacted with by touching or brushing the interface's surface. The stroke-based gesture input is one of the most helpful applications for text input, according to Saponas et al. [2011], which is why the interface performed well.

PocketTouch interface, which is a capacitive sensing prototype that can be interacted with by touching or brushing the surface

Karrer et al. [2011] also introduced wearable interface called *Pinstripe*. The interface *Pinstripe* is a textile user interface element that involves pinching and rolling a piece of cloth between your fingers for hands-free interaction in smart clothing. Wearability, durability, and fashion com-

Pinstripe is a user interface element made of cloth that may be manipulated by pinching and rolling

Figure 5.2: Touching or brushing the interface's surface interacts with the *PocketTouch* interface, a capacitive sensing prototype. Image taken from Saponas et al. [2011].

patibility are all key factors to consider while designing smart clothing. *Pinstripe* can be used to control a variety of apps, such as a music player's volume, a mobile device's graphical menu or home appliances. Karrer et al. [2011] performed two user tests to determine an appropriate position for the users' garments, as well as a qualitative research in which people interacted with pinstripe in a real-world setting, which had positive results.

DigitSpace is a one-handed input system that uses a thumb-to-finger interaction

Huang et al. [2016] developed a new user interface that assures users' comfort both at home and on the go. *DigitSpace* is a wearable device that uses magnetic tracking to provide a thumb-to-finger interface, allowing for one-handed input without the need of one's eyes. Two ergonomic considerations are also addressed in the interface: hand anatomy and touch precision. The first aspect, physical comfort during interactions, is impacted further by the fact that the thumb's movements are restricted owing to hand structure. Touch accuracy is a human factor that determines how precisely users can use touch widgets placed on their fingertips, and therefore effective widget layouts. Huang et al. [2016] conducted three experiments to determine the areas of the fingers where thumb-to-finger touch interactions may be performed comfortably, as well as how to organize two common touch widgets, buttons and touch pads, for successful discrete and continuous touch input. The study's findings indicated elements that needed to be addressed while creating the prototype *DigitSpace*. The interface may be used to operate household equipment like TV or air conditioner.

The *NailDisplay* interface is a finger-mounted display

In addition, Su et al. [2013] created and built a wearable interface that is constantly accessible to users. The *NailDisplay* interface is a display that is worn on the finger. Su et al. [2013] shows three distinct apps that may be used with the interface (see Figure 5.3). The interface can be used to show small targets more precisely on the display in the first application and in the second application, the interface can be used to help users learn imaginary interfaces and reassure a function such as playing music by touching the music player. In the third application, *NailDisplay* can be used to control applications by swiping the finger in different directions. For example when users wish to go on to the next song, they may just swipe their finger. *NailDisplay* ensures the users' comfort by allowing them to manage and utilize certain applications without having to move around much. The interface can be used to control home appliances, such as the TV or the lights. Because the only action required is a finger movement, the Interface can also be beneficial for those with severe impairments.

A general input surface placed on the nail

Kao et al. [2015] present a wearable interface that makes use of the finger/nail. *NailO* is a gestural input surface placed on nails. The interface, which was inspired by commercial nail stickers, is configurable and removable and integrates into the user's body. Capacitive sensors on printed electrodes are used in the interface to detect real-time gestures with great precision. *NailO* can transfer sensor data wireless to a smartphone or a computer. Two use examples for the interface *NailO* are shown by Kao et al. [2015]. The first

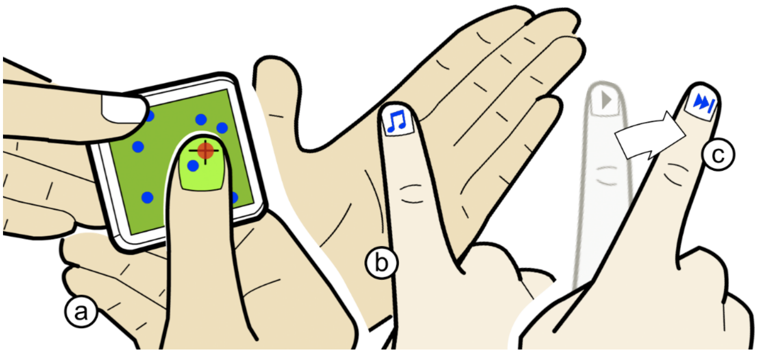


Figure 5.3: *NailDisplay* used in three different scenarios: a) allowing users to choose tiny targets accurately with their fingers b) the interface may be used to assist people in learning fictitious interfaces and confirming a function c) With *NailDisplay*, users may switch to the next music selection by sliding their fingertips rightward. Image taken from Su et al. [2013].

program acts as a remote control, while the second serves as an additional input space for mobile phones and other devices.

Skinput is an interface that uses the skin as an input surface

Harrison et al. [2011] created and built another interface that leverages the skin as an interactive canvas. They created a device that analyzes mechanical vibrations while contacting the skin as an input surface. *Skinput* detects finger taps on the arm and hand using a sensor array worn as an armband. The device performed effectively for taps on the skin, even while the users were moving, according to Harrison et al. [2011]'s study. The interface guarantees the users' comfort by being simple to use and accessible at all times.

iSkin is a single and multiple touch input sensor that is worn on the body

Weigel et al. [2015] also designed and developed interface worn on the skin or the user's comfort. The *iSkin* interface is a body-worn touch input sensor that enables single and multiple touch regions of configurable form. Because *iSkin* is thin and flexible, it may be made in a variety of sizes and forms. Touch sensors may be modified for specific applications and body locations, as well as for aesthetic appeal and button layouts, due to the *iSkin* design. Other skin-worn interactive sensors, similar to *iSkin*, were invented and developed by Kao et al. [2016a,b] and Nittala et al. [2018], all of which can be adjusted to the users' preferences.

Aside from assistive systems for operating household appliances, various interfaces designed particularly for a furniture with the user's comfort in mind. Gautam et al. [2014] is another interface that guarantees the users' comfort and was previously described in Section 3.2. They created a wheelchair that can be controlled by the user's eyes. The motorized wheelchair can be controlled by changing one's gaze to a different angle, making it easier for persons with impairments to maneuver. It also guarantees the users' comfort by ensuring that those with severe impairments can operate the wheelchair without difficulty or pain.

Wheelchair that can be controlled with the gaze

An interface on a furniture was presented by Joshi and Vogel [2019]. Touch input was conceived and implemented along the edge of a table-like surface. They designed an interface that can be implemented on the edge of table-like surfaces utilizing SAR (Spatial Augmented Reality) projection and motion tracking. Various programs may be projected using the interface. It may be used as a notification tray for emails, weather forecasts, and reminders or as a smart home control for managing lights, air conditioning, and other home equipment, as seen in Figure 5.4. Touch modalities such as tapping and crossing can be used to interact with the interface. The modalities tapping, crossing, and dragging were tested by Joshi and Vogel [2019], and the findings suggest that the top ridge movement duration is comparable to the top face while tapping or dragging. By making the edge of a table-like item at home functional, the interface assures the comfort of users at home. Because the edge of a table is rarely utilized, comfort may be assured by providing an interface that controls different objects around the house.

Touch input on the edge of a table for viewing applications

Tapping, crossing, and dragging are the touch modalities employed

Wingert et al. [2017] present an office desk ensures the users' comfort at home. The interface *ProDesk* is an interactive office desk with a projection-based touch surface technology that expands the screen space of a user's display, such as a laptop or desktop. To produce a high-resolution display surface in a regular workstation, the

ProDesk is a projection-based touch surface device that expands the screen space

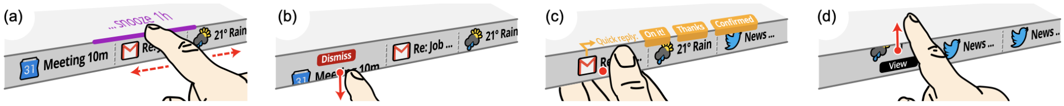


Figure 5.4: Example applications for the edge-of-table: a) To set the notification snooze time, drag along the top ridge b) Dismiss a notice by crossing the bottom ridge c) To expose shortcut activities such as email quick responses, tap on the front face d) View notification details by crossing the top ridge. Image taken from Joshi and Vogel [2019].

technology blends front-projected surfaces with capacitive touch sensing. Users may interact with *ProDesk* in the same way they would with other touchscreen devices. Wingert et al. [2017]'s evaluation revealed that the interface can be utilized in a real-world setting.

An office desk that can be interacted with mid-air gestures

Hermann et al. [2004] created an office desk that expands the traditional input devices like keyboard and mouse by arm and hand motions, similar to the interface *ProDesk* [Wingert et al., 2017]. With a mid-air motion, users may manipulate the desk's aural displays.

Magic Desk, an interactive multi-touch surface on an office desk

Bi et al. [2011] also designed an interactive office desk similar to *ProDesk* [Wingert et al., 2017]. Theoretical and practical challenges linked to building and designing a multi-touch surface into a desktop computer environment are explored by Bi et al. [2011]. They created a set of desktop interaction approaches based on the findings of a study. The prototype's design and execution of the input devices keyboard and mouse are also taken into account by *Magic Desk*, resulting in an effective arrangement of the interactive screen on the desk.

CapCouch, a posture-sensing couch that can control home appliances

Pohl et al. [2015] designed and implemented furniture aimed at enhancing user comfort at home. The user interface *CapCouch* is a posture-sensing couch that can adjusts the room's appliances based on the user's position. When users sit down on the couch, for example, the TV turns on automatically, and the lights turn out automatically when they lie down. The six electrodes placed on the couch, which are concealed behind the cover, detect the users' position. Pohl et al. [2015] took sure to allow consumers the ability to bypass the system and utilize other items to operate the appliances, such as a remote control to switch on/off the television. They developed a prototype and conducted a user research, which had positive results. *CapCouch* ensures the users' comfort by assisting them in their daily activities and taking care of their chores by sensing their position.

A couch with smart e-textile that recognizes the users' position

Rus et al. [2017] is another interface that makes use of the sofa as a device and wearing electrodes to identify the users' position. To expand the application of smart e-textile beyond the on-body wearable, they created a sofa that recognizes the user's positions when sitting or lying down. A user research was done using the prototype, which had positive results. Unlike *CapCouch* (Pohl et al. [2015]), Rus et al. [2017] did not suggest a specific usage for the various postures. They are planning on doing a more in-depth examination of the user's posture and extend the detection to include things like breathing.

A pillow with the ability to control household appliances

Suzuki et al. [2020] introduced a new technique for controlling household appliances that makes use of everyday things. To control smart home gadgets, they utilize a cushion interface. To identify time-sequenced gestures on the cushion, the system employs an acceleration sensor array and a CNN. The interface detects 13 different motions, including right-side push and slide down. These interactions may be used to manage household equipment in a variety of ways, like turning on/off the TV and changing the stations. The findings of Suzuki et al. [2020]'s user research revealed a high average gesture recognition accuracy.

A smart curtain as an interactive display

Takashina et al. [2015] present an interface that ensured the consumers' comfort at home. They created an interactive smart curtain for the living room that has four benefits: it ensures a boundary between indoors and outdoors, it has a natural structure, it has a large area that can be used to display information and images, and it achieves context awareness by detecting the surrounding environment and the curtain's condition. Touching and moving the curtain allows users to interact with it. The smart curtain may be used to show information such as the weather or information on an object near the curtain. Takashina et al. [2015] also built a proof-of-concept prototype. They ensure the ease of use of the interface while also assuring the comfort

Interaction through touching and moving the curtain of the users at home by making an object that is utilized in every household into an interactive interface.

Gardeene, a curtain integrated with capacitive textile sensors

Heller et al. [2016] also created a curtain interface that improves consumers' comfort at home. They demonstrated a capacitive detecting curtain with improved gestural interaction when opening and shutting it. Heller et al. [2016] discovered that motorized curtains are typically used on large windows and that consumers require more than one action to open them. This concept resulted in a sensing pattern that allows the curtain to open and close with a single movement. Heller et al. [2016] intend to assess the broad acceptability and usability of the interface *Gardeene*.

The *SmartSleeve* is a deformable textile sensor that detects both surface and deformation motions in real time

Textile-specific interfaces were also developed to assure the users' comfort, like the interface *SmartSleeve* [Parzer et al., 2017]. Parzer et al. [2017] designed the wearable interface *SmartSleeve*, which is a deformable textile sensor that can detect both surface and deformation motions in real time. Twisting, spinning, and stretching the cloth are examples of deformation movements, whereas swiping in different directions and stroking the textile are examples of surface motions. According to the evaluation done by Parzer et al. [2017], the *SmartSleeve* can accurately recognize motions. The interface assures the customers' comfort by transforming an item of clothing into an interface that can manage a variety of applications, including smart home gadgets. *SmartSleeve* also has a number of motions that may be used to communicate with the system. Schneegass and Voit [2016] produced another interface that leverages the sleeve as input, similar to *SmartSleeve*.

SwitchBack may be used on different objects to make them interactive

Hughes et al. [2014] provides an additional e-textile interface that ensures the user's comfort. They created *SwitchBack*, an input device that can capture a variety of different forms of input with minimum calibration. The interface investigates the use of non-traditional conductive materials to develop on-body interfaces that can handle a variety of one-handed, eyes-free input. *SwitchBack* may be placed in a variety of things, turning them interactive, such as a backpack or sleeve, as seen in Figure 5.5. Only theoretical formulation, device and circuit design were demonstrated by Hughes et al. [2014].

Figure 5.5: *SwitchBack* may be used to a variety of items to make them interactive. For example, on a backpack, on tie, beneath the pant leg and on a sleeve. Image taken from Hughes et al. [2014].

Wu et al. [2020] demonstrated a wearable touch sensor for textiles. The interaction with the touch sensor *ZebraSense* is a woven touch sensor with a dual-sided top and bottom surface that can identify and differentiate interactions. The interfaces employ a capacitive sensing approach, in which each sensing element simultaneously contributes to touch detection on the sensor's bottom surface, as well as an industrial multi-layer textile weaving technique. According to the evaluation done by Wu et al. [2020], *ZebraSense* is a dependable, effective, and precise approach for sensing user gestures in a variety of dual-sided interaction scenarios.

ZebraSense is a dual-sided touch sensor

Ku et al. [2020] created and developed a new interface that takes use of a zipper, which can be used for a number of things. The interface *Zippro* transforms the standard zipper used on clothing and other objects into an interactive interface that may be used for a variety of purposes like security, health monitoring, and controlling smart devices. The placement of the zipper, touch movements on the puller surface, and grip type were among the inputs recognized

Zippro is an interactive interface that can be used on zippered items by Ku et al. [2020]. Refer to Figure 5.6 for an example of *Zippro* in action, where the prototype was installed on a backpack. The user receives a warning on their phone if the zipper is left open, assuring the users' safety. The system only turns off when the detected operator is not the user.

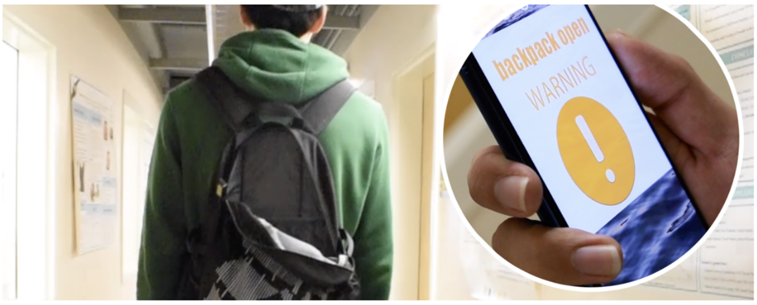


Figure 5.6: *Zippro* used on a backpack: The user receives a warning if the zipper is opened. Image taken from Ku et al. [2020].

5.1.1 Discussion

Many interfaces strive towards comfort, although it may not be the primary goal

Many interfaces, according to the research, are designed to make people feel more comfortable at home. Even though the interface's primary purpose isn't comfort, the authors make sure that users feel comfortable while using it, which is why some of the above-mentioned interfaces were also classified in other categories. There are other interfaces that are just designed to provide comfort to users at home, either by controlling appliances without the use of an additional controller or by making daily living easier for users.

Compared to universal controllers, *GeeAir* offers an advantage

One of these is the interface given by Pan et al. [2010]. *GeeAir* is a multi-modal remote controller that can operate numerous household appliances using a range of modalities. The interface, according to Pan et al. [2010], has distinct advantages over universal remote controllers. They intend to conduct an evaluation with actual home users in the future, with various sorts of participants, in order to enhance the design of *GeeAir*.

Interfaces that use mid-air gestures to control household appliances

In addition, Panger [2012] demonstrated an interface for manipulating objects in the house via mid-air gestures, specifically in the kitchen. Ha and Byun [2012] presented a wearable interface that may also be used to control home appliances via mid-air gestures. The wearable interface also has a fall detection feature that will notify friends and family if the user does not move for an extended period of time. To provide a better and proactive service, Ha and Byun [2012] plan to integrate a person tracking and activity identification technology into the interface.

The disadvantage is accidental control

Accidental control of household appliances is a downside of these interfaces that might be a concern. *GeeAir* users may control the wrong object at home because to the variety of modalities available. Instead of turning on the television, they, for example, switch off the air conditioner. Because all of the appliances are controlled by a single controller, unintentional activation of other appliances is unavoidable. The difficulty of avoiding unintentional instructions was also noted by Panger [2012]. Because the Panger [2012] and Ha and Byun [2012] interfaces are handled by mid-air gestures, they can be accidentally triggered while the users are doing something else. The fall detection timer is another flaw in the interface provided by Ha and Byun [2012]. The fall detection can be activated for no apparent cause, for example, if a user falls asleep and does not move their hand for a long period of time, the fall detection will be triggered and a family member will be notified.

The fall detection can be activated at any time and for no apparent reason

There are a few wearable interfaces that strive towards comfort

Other wearable interfaces used to operate smart devices include the interactive belt, *PocketTouch*, *PinStripe*, *DigitSpace*, *NailDisplay*, and *NailO*. While all of these interfaces are wearable, they may be worn in a variety of locations on the body. *PocketTouch*, for example, may be worn in a pocket or purse, the interactive belt around the hips, and *NailDisplay* on the nail surface.

All of the interfaces discussed aim for increased comfort and resolution

The future development of these interfaces comprises a variety of things, but they all have one thing in common: increased comfort and improved resolution. Dobbelstein et al. [2015], Karrer et al. [2011], and Saponas et al. [2011] each intend to undertake a user case and further tests in order to assess the interfaces offered. Dobbelstein et al. [2015] also intends to develop the interactive belt further by adding a high-resolution touch for text entry and implementing rotation-based touch gestures for faster navigation. According to Karrer et al. [2011] users interact with *pinstripe* using different gestures, a fact that will be taken into account in their future work.

The interfaces have not been evaluated in real-world circumstances

The integration and usefulness of these interfaces in real-world circumstances is a drawback that can be identified in all of them. All of the aforementioned interfaces have not been tested in real-world scenarios (except *Pinstripe* by Karrer et al. [2011]). While the notion of interfaces appears to be beneficial in daily life, additional testing is required to assure usability and efficiency. Extreme circumstances, such as use by someone else and data security, must also be considered by the authors in their review. Because these interfaces are linked to a smart device, third parties may be able to manipulate it. Nonetheless, the interfaces are designed to improve user comfort not only at home, but also everywhere. They guarantee that smart gadgets are accessible to everyone.

Data security and usage by others must also be addressed

Non-wearable interfaces that prioritize user comfort

Apart from wearable interfaces that attempt to provide comfort to users, there are a variety of interfaces that rely on furniture to provide comfort. The table interfaces *ProDesk, Gesture Desk, MagicDesk* and the one presented by Joshi and Vogel [2019] are designed with the user's comfort in mind. While the interface given by Joshi and Vogel [2019], *ProDesk*, and *MagicDesk* all increase the screen space by projecting on the surface or utilizing the table's edge, *Gesture Desk*'s concept adds mid-air gestures as a controlling technique to the usual input devices. While the idea of *Gesture Desk* is still in its early phases, it should be emphasized that there is a risk of unintentional input, as is the case with practically every interface in our taxonomy that leverages mid-air gesture as a modality.

Due to the mid-air mode, unintentional input can occur

The authors' objectives are to develop the system and conduct user case studies

The authors' suggestions for future work on desk interfaces include system improvements as well as user case studies to increase the interfaces' interaction quality. The concept of utilizing the desk to guarantee the user's comfort may be used to different areas of the house, not just the office.

User interfaces that aid users in the kitchen

Bradbury et al. [2003] and Ju et al. [2001] designed interfaces that seek to teach people in a specific space at home, the kitchen. By presenting recipes on the kitchen counter,

the interfaces educate users how to cook comfortably. Unlike *CounterActive* [Ju et al., 2001], which focuses solely on projecting recipes on the counter and manipulating them by touch, *eyeCOOK* [Bradbury et al., 2003] can be controlled both visually and verbally. The advantage of both of these interfaces is that they seek to assist users in learning to cook by guiding them step by step.
CounterActive [Ju et al., 2001] employs the notion of projecting interactive applications on kitchen counter top, and Joshi and Vogel [2019]'s concept of using the table's edge as the surface may also be used on kitchen counter tops or other table-like items.

Pressure-sensing furniture designed with the user's comfort in mind

The interfaces presented by Pohl et al. [2015], Rus et al. [2017], and Suzuki et al. [2020] are examples of other interfaces that use furniture to enhance the comfort of users. Pressure-sensing is used in all of these interfaces to operate home items like the television. While Rus et al. [2017] did not identify the postures employed while using the pressure-sensing couch, Pohl et al. [2015] provided examples of how the interface *CapCouch* may be utilized. Suzuki et al. [2020] also define several movements and pressures that may be utilized to regulate household appliances with the smart cushion.

In the future, changes in user behavior must be considered

Even while using pressure sensors to regulate appliances at home might be beneficial, one concern that remains unanswered is how users' behavior would alter. Users, for example, do not want to watch TV every time they sit down on the sofa. While Pohl et al. [2015] intends to concentrate on finding a solution for this problem in the future, the future goals of Rus et al. [2017] and Suzuki et al. [2020] include improved sensor resolution and gesture estimation.

Interfaces made of e-textiles that can be embedded into things, also have comfort of the users in mind

While we explored a number of interfaces that employ everyday things to ensure user comfort, there are a number of textile interfaces that may be incorporated into clothing or other objects to transform them into interactive interfaces. As an example, consider the interfaces *SwitchBack* [Hughes et al., 2014], *ZebraSense* [Wu et al., 2020], and *Zippro* [Ku et al., 2020], which are all interactive interfaces that may be implemented on objects. Unlike the touch sensors provided by Hughes et al. [2014] and Wu et al.

[2020], which may be used on a range of things, *Zippro* can only be used on zippers.

In this case, as well, accidental activation is a problem

Accidental activation of the interface and use by another person are two issues that arise with these interfaces. These concerns were also raised in other interfaces since the interfaces are used on things that are close to a person's body, and both of the aforementioned issues can arise in a crowded environment. The use of the interface by a third party is mentioned in Ku et al. [2020], which is why the interface may identify whether the user is not the one interacting with *Zippro*.

The use of speech as a control mechanism for appliances is also possible

Regardless of the positive findings of the study, the topic of what else may be created for consumers' comfort at home that is not irritating remains unresolved. The study of interfaces found a wide range of interfaces that make use of commonplace things, as well as wearable interfaces that are designed for the purpose. All of the interfaces employ a number of modalities to assure user comfort, including pressure, touch, and mid-air gestures, but speech may also be utilized to interact with them. Even if there are many speech interfaces, such as Amazon Echo and Google Home, that may be used to operate home appliances and make the home more pleasant, the provided interfaces can be improved to incorporate speech or link to the stated devices.

5.2 Entertainment

Indoor home interfaces provide entertainment to improve the environment and quality of life in homes. Because of the interfaces identified, this objective was previously taken into mind particularly for private settings. The investigated interfaces may be used in both private and public situations, which is why the taxonomy likewise considers entertainment in this category.

An interface can be used for entertainment at home was already presented in Section 4.2. Ahn et al. [2010] created an interactive tabletop interface that can be used to operate a wide range of programs, including games and e-menus reading. Because it may be used for amusement, the interface might be considered as such. On the tables at home, users may play games or watch movies.

CRISTAL is a tabletop integrated remote control system

Seifried et al. [2009] also presented an interactive tabletop that provides consumers with amusement. *CRISTAL* (Control of Remotely Interfaced Systems Using Touch-based Actions in Living Spaces) is an integrated remote control system that they conceived and built. *CRISTAL* is a centralized, interactive tabletop system that allows many users to control home media devices using a digitally enhanced visual depiction of the environment. Because it manages media devices such as the television, the interface provides enjoyment for users at home. The findings of the system's initial user survey validated many of its design decisions and gave further design recommendations for future *CRISTAL* versions, such as how to better fit some households' limited space.

It manages media devices around the home

The *Ambient Wall* is a wall-mounted interface that allows users to operate household appliances

Kim et al. [2011] introduced a wall interface designed for the customers' amusement as well as their comfort. The *Ambient Wall* interface lets users observe what's going on in their house at a glance and control their surroundings with a single gesture, all without the need for a physical interface device like a remote controller. A projector projects the interface onto the wall, and it may be interacted with using mid-air motions identified by Microsoft Kinect. Users may use the interface to operate home equipment like the TV

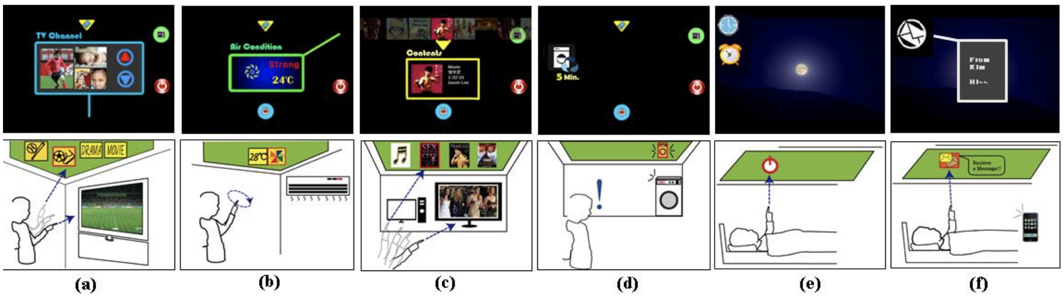


Figure 5.7: The *Ambient Wall* used in different scenarios: Users can a) browse TV channels, b) control the air conditioner, c) share content, d) get notified, e) turn the system off, and f) check messages. Image taken from Kim et al. [2011].

and air conditioner, but they can also exchange material, watch movies, and play games with it, indicating that the interface is designed for users' comfort as well as entertainment at home, as seen in Figure 5.7. By prototyping the interface Kim et al. [2011] were able to confirm its efficacy and feasibility. They also consider the system's benefits for persons with impairments who have difficulty moving their bodies without the support of their guardians and intend to develop a new control mechanism that is more suited for severely disabled people than hand gestures.

A wall display that can be controlled using the whole body

Shoemaker et al. [2010] also introduced a wall display aimed at providing people with amusement. They conceived and built a wall-mounted application that supports interaction with the display using a body-centric approach. The entire body, not just the hands, may be used to interact with the interface. Instead of the applications utilized in this work, Shoemaker et al. [2010] focused on body-centric physical-based interaction, but the applications may be expanded further to aim for user entertainment at home. For example playing games with family and friends on the interface using the whole body can be possible in the future.

Wearable DJ System ensures that the DJ may walk around while making music

Another interface that ensures the entertainment of the users was presented by Tomibayashi et al. [2009]. They noticed the difficulty a DJ confronts in moving away from the DJ booth while still performing, which is why they devised and built the *Wearable DJ System*. Using wearable computer and gesture recognition technologies, the wearable DJ system overcomes this problem. DJs may use the recommended method to perform DJ skills by using intuitive gesture operations with wearable acceleration sensors. The *Wearable DJ System* may be used to entertain oneself, family, and friends in both private and public situations. The *Wearable DJ System*'s effectiveness in DJ performances was proven by the results of the assessment and field tests. Also the suggested interface has been deployed on several event stages already.

The interface has been used in few events already

Slayden et al. [2005] also provided a DJ interface. They present the *DJammer*, a technology that lets users modify digital music with the use of a small handheld sensor. Users may now have control over their music that was previously only available with turntables thanks to the *DJammer*. DJs may "air-scratch" digital music using basic hand movements similar to those used when scratching vinyl records, fade the music, and skip to a specific position within the song using a wireless sensor designed to fit in the DJ's palm. According to the findings of a research conducted with experienced DJs, the *DJammer* may be utilized as an add-on that would allow them to step away from their consoles during performances, allowing for more creativity and personalization.

DJammer, a portable sensor that modifies digital music

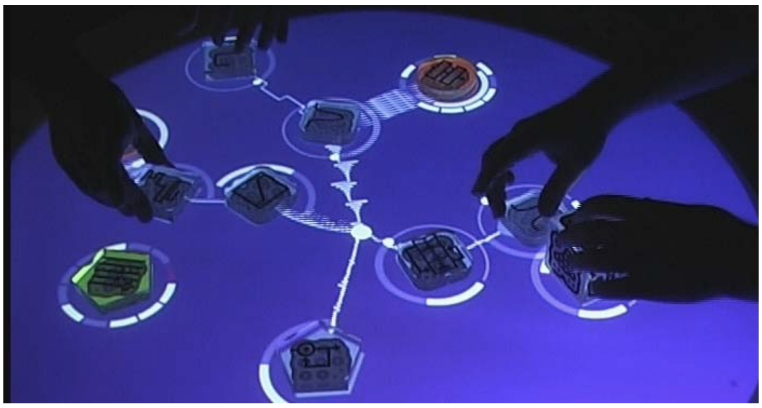


Figure 5.8: Several musicians can share control of the *reacTable* by caressing, rotating, and moving physical artifacts on the luminous surface, creating various audio topologies. Image taken from Jordà et al. [2007].

ReactTable is a tabletop interface that may be used to make music

Jordà et al. [2007] presented a new musical instrument aimed at providing customers with fun at home. The *reacTable* is a tabletop interface-based musical instrument. By stroking, rotating, and manipulating physical artifacts on the luminous surface, as well as building alternative audio topologies, several musicians may share control over the *reacTable*, as seen in Figure 5.8. Because it may be utilized by one or several people at the same time, the interface can provide amusement to users at home. Since its debut, the *reacTable* has been shown at a number of festivals, conferences, and events. The response has been dominantly positive, demonstrating that the *reacTable* can be thoroughly enjoyed.

5.2.1 Discussion

Due to the fact that the interfaces built for the bathroom are geared toward the private environment only, we consider the purpose entertainment for both public settings and public & private settings in this classification. The interfaces provided in this section can be used simultaneously by one or more users in both configurations.

Tabletop interfaces that aim for the entertainment of the users

Ahn et al. [2010] and Seifried et al. [2009] provide tabletop interfaces that may be used to entertain people at home. While the tabletop interface interface [Ahn et al., 2010] may be used to play games and other enjoyable applications, *CRISTAL* [Seifried et al., 2009] can be used to operate home media devices such as the television. Furthermore, the tabletop displayed by Ahn et al. [2010] may be used in public locations such as restaurants to display e-menus or play games with children while they eat but *CRISTAL* can only be used at home because it functions as a remote controller for home media equipment. The downside of these interfaces is that they must be used on a coffee table that is frequently crowded with other items. Seifried et al. [2009] consider a design investigation for this problem. They intend to do research in the future to better understand the design trade-offs between enabling individual control and group sharing of media and gadgets in informal, social settings.

The drawback is that most coffee tables are crowded with various items

Interfaces on the wall are another sort of interface that aim for the entertainment of the users. This category is represented by the interfaces Kim et al. [2011] and Shoemaker et al. [2010]. Users may operate household appliance via mid-air gestures with the *Ambient Wall* [Kim et al., 2011], and the entire body can be utilized to interact with the Shoemaker et al. [2010] interface. Both of these interfaces may be used to display entertainment media on the wall, such as games and movies. When these interfaces are turned on, one thing that cannot be avoided is unintentional input. Users can control the media by mistake since the can be controlled via mid-air gestures.

The entertainment material can be shown on the wall interfaces

When the interfaces are turned on, accidental input cannot be avoided

Kim et al. [2011] discovered that their system is extremely beneficial to people with severe impairments, which is why they want to develop a new control mechanism that is better suited to severely disabled people than hand gestures. In the near future, Shoemaker et al. [2010] plans to perform a complete investigation of the body-centric interaction strategy and associated system.

The *Ambient Wall* can be beneficial for people with severe disabilities

Music-creating interfaces are another type of interface that aims to entertain users at home. The *Wearable DJ System* [Tomibayashi et al., 2009], *DJammer* [Slayden et al., 2005], and *the reacTable* [Jordà et al., 2007] are examples of interfaces for controlling instruments and music sounds. All of these interfaces have previously been utilized at a number of festivals and music events, ensuring their efficiency. Despite the fact that these interfaces were designed for usage at large events, users may use them at home to create music alone or with others. While the *DJammer* and the *Wearable DJ System* are both wearable interfaces that allow a professional DJ to produce without being tethered to a DJ booth, the *reacTable*, on the other hand, is a table that can be used to make music by numerous people.

Professionals have utilized the music interfaces at events

Tomibayashi et al. [2009] consider providing a script language and a user interface in the future that will allow users to more easily allocate between a gesture and a DJ function, as well as to improve the power of movement expression by including additional types of sensors. Slayden et al. [2005] are presently looking on methods to make the gadget more customizable, as well as continuing to look into the concept of DJ mobility.

Future enhancements to the system are planned

Notwithstanding the positive results of the research, the issue of what further may be produced for customers' at-home entertainment remains unanswered. While the interfaces discovered all attempt to amuse users at home in various ways, we might envisage future interfaces pursuing this goal. For example, a tabletop interface that can be used to play board games digitally with multiple people. This way, there is no need to buy board games to play, nor find space at home to keep the boxes. Also all the games can be found in one place, and users don't have to worry about losing pieces of the game.

5.3 Sustainability

Sustainability is also a purpose considered in this taxonomy. This purpose is an important aspect that needs to be considered at homes because it improves our level of life while protecting natural resources and the environment for future generations. Home sustainability may be done in a variety of ways, such as through water management which was presented by Laschke et al. [2011].

The *Shower Calendar* tracks how much water is consumed when showering

Laschke et al. [2011] presents an interface that guarantees water conservation at home. The *Shower Calendar* tracks how much water is used when showering so that users may conserve water. A flow meter, a micro-controller board, a number pad, a computer, and a screen make up the *Shower Calendar*. The flow meter is installed between the faucet and the flexible tubing of the shower head. For each liter used, the computer lowers the colorful dot on the screen by one liter. The interface is an effective tool for raising water awareness and communication among family members. In the long run, it has the ability to result in positive behavioral change in the user.

Show-Me is a physical installation gadget designed to help people save water when showering

The *Show-Me* (shower water meter) interface, created by Kappel and Grechenig [2009], is a physical installation device aimed to assist individuals in conserving water when bathing. It provides information about current water consumption so that individuals might minimize it. *Show-Me* is made up of a flow meter, a microprocessor, and LED lights. In the form of LEDs arranged on a stick, the interface indicates the quantity of water utilized during one shower (see Figure 5.9). The LEDs depict a fictitious water level that rises with the continual flow of water. The evaluation done by Kappel and Grechenig [2009] found that the capacity to regulate shower water and the usage of an ambient display to offer feedback were both beneficial.

Figure 5.9: An example of the *Show-Me* interface in use in the shower: the LEDs are built right into the shower's sliding bar, putting them right in the user's line of sight. One LED light represents 5 liters of water used. Image taken from Kappel and Grechenig [2009].

A web-based water gateway that monitors water consumption in the home

Erickson et al. [2012] created another interface that was created to encourage consumers to use less water around the house. The web-based *Dubuque Water Portal*, which they demonstrate, is a system meant to allow voluntary water consumption reductions and is set to be adopted city-wide. It provides feedback on each household's water usage while also encouraging water conservation through tactics such as social comparison, weekly activities, news and discussions. The system was evaluated with volunteer households for a long period and resulted in positive feedback from the portal users. The vast majority claimed they had a better awareness of their consumption, realized that the adjustments they made had an impact, and discussed it with individuals both inside and outside their families.

A greater understanding of water use

Other interfaces aimed towards reducing water usage at home

Arroyo et al. [2005] and Kuznetsov and Paulos [2010] also present interfaces that try to raise awareness on water consumption at home. Arroyo et al. [2005] show a variety of persuasion strategies for raising water conservation awareness in the kitchen, particularly around the kitchen sink. *WaterBot* is a mechanism that encourages people to turn off the tap while they are not using it. Kuznetsov and Paulos [2010] created the interface *UpStream*, which provides information on water usage so that individuals may minimize their water usage at home.

The *Stroppy Kettle* is designed to break people's habits of boiling more water than they need

Cowan et al. [2013] created and built a kitchen interface that is environmentally friendly. They created the *Stroppy Kettle*, a kettle that aims to change people's habits of boiling more water than required. A water fill monitor that detects the quantity of water in the kettle by weight, a control system that monitors the power usage, and a punishment system that employs a nearby mobile phone are all features meant to prevent overfilling of the *Stroppy Kettle* (see Figure 5.10). The punishment system requires users to determine the quantity of water they need to boil, and if they overfill the kettle, it will give them a tedious chore to do, with the kettle only starting to boil the water if the task is completed correctly. The concept of the *Stroppy Kettle* indicates a considerable expense in energy usage, which is what Cowan et al. [2013] is aiming for.

The electro-magnetic field detector *Ghost Hunter* monitors the intensity of an electro-magnetic field in the surrounding

Banerjee and Horn [2014] built yet another interface that aimed towards sustainability. The interface *Ghost Hunter* combines a smart device with an electro-magnetic field (EMF) detector to measure the strength of an electro-magnetic field in the vicinity. Banerjee and Horn [2014] designed the system to engage parents and children in informal learning activities such as searching their houses for hidden sources of electricity. The goal of the initiative is to give parents and children with informal learning opportunities on energy use and sustainability in their own homes. Banerjee and Horn [2014]'s study of seven families revealed a variety of ways in which parents manage and support their children's interactions, as well as an unexpected source of energy use.

Figure 5.10: The *Stroppy Kettle* prototype and the punishment system on a mobile device used to punish the users, when they overfill the kettle Image taken from Cowan et al. [2013].

5.3.1 Discussion

Because users may be sustainable no matter where they are, sustainability is a goal that can be pursued in both private and public contexts. The majority of the interfaces discovered for this category are geared on reducing water use at home.

Show-Me and *Shower Calendar* focus on the consumption of water in the shower

The *Show-Me*, *Shower Calendar*, and *Dubuque Water Portal* interfaces are all aimed towards reducing water use at home. Both the *Shower Calendar*, and the *Show-Me* help customers save water when showering. While the *Show-Me* may be installed in the shower, the *Shower Calendar* displays consumption on a screen outside of the shower.

The *Dubuque Water Portal* displays water use across the home

The web-based *Dubuque Water Portal*, on the other hand, displays water use across the home, taking into account all of the numerous ways customers utilize water at home, such as in the kitchen. Users appreciated the features of the *Shower Calendar*, according to Laschke et al. [2011], and indicated that the feedback elements were useful for lowering water consumption, establishing goals, comparing consumption with family members, and more.

The systems will be expanded and improved in the future

The prototype's technological improvement, as well as its extension to a display of warm water usage, will be incorporated into *Show-Me* [Kappel and Grechenig, 2009], as this is the most essential component of shower energy consumption. A permanent incorporation of the *Show-Me* interface into the faucets is also envisaged. One disadvantage of the interface is that it attempts to conserve water while using electricity, which is also the case with the other interfaces. Erickson et al. [2012] also intend to expand the *Dubuque Water Portal*'s capabilities. They are exploring features such as a comparison of water use with anonymous households in town, as well as a motive for users to discuss in the chat, which was not used in the user survey they conducted.

The *Stroppy Kettle* should help users from overfilling their kettles

The other interfaces in this category are focused at reducing energy consumption and boosting energy awareness in the household. The *Stroppy Kettle*, created by Cowan et al. [2013], attempts to raise awareness about how much water and energy is used when boiling water. Users must first determine how much water they want to boil, and if the kettle is filled with more than the required quantity, they will be penalized with a tedious task, which is an excellent habit-forming strategy. Incorporating behavioral psychology methods in the examination of how *Stroppy Kettle* technologies effect overfill behavior is planned in the future. The downside of this system is that users may become frustrated with the work and replace the system entirely, and users can also abuse the system by determining the incorrect amount of water needed. The method may be enhanced by displaying the amount of energy wasted and saved at the conclusion of each week to users. The tool may also show users' long-term progress, which motivates them to keep exercising.

Users' dissatisfaction is a disadvantage

Demonstrate to children the hidden sources of energy use

The *Ghost Hunter*, on the other hand, enhances energy consumption awareness by exposing the home's hidden source of energy usage. The purpose of *Ghost Hunter* is to show kids how much energy they use at home so they may be more conscious of their surroundings and reduce their consumption.

Even if these interfaces strive for a more sustainable lifestyle at home, many variables that may be regulated to make it more sustainable, such as energy use, are not taken into account. While the interfaces may be used to minimize water use at home, energy consumption should also be monitor and regulate. For example, by employing outlets that display the amount of energy consumed and a system that links to all of the energy-consuming gadgets in the home and can be regulated, energy consumption may be reduced. Food waste may also be minimized, in addition to water use. There should be a mechanism that weighs the quantity of food cooked, similar to the *Stroppy Kettle*, which weighs the kettle and guarantees that users boil the correct amount of water. For instance, a system that counts the number of servings of food being cooked so that less food is wasted.

Chapter 6

Discussion

The interface classification provides a thorough categorization of indoor home interfaces based on the private and public setting as well as the purpose of the interfaces. This taxonomy can potentially be used as a starting point for future home interface development. The intention of this categorization is to identify gaps in the development of home interfaces that may be addressed in the future.

The taxonomy's goal is to give a comprehensive classification while also identifying gaps

The taxonomy's research found a diverse set of interfaces created for a variety of reasons, some of which serve several uses. The interfaces explored revealed a number of modalities and interactions that were utilized to engage the interfaces. Touch, mid-air gestures, gaze, pressure, and speech were all employed.

The categorization indicated a wide range of modalities

Touch is the most prevalent interaction for home interfaces (66%), according to our research, followed by pressure (18%) and mid-air gestures (10%). As a result, this emphasizes the use of touch-based interior home interfaces to control and monitor home appliances. We discovered only a few interfaces that use speech (3%) as modality in the home, which might be because many households currently use voice interfaces like Amazon Echo and Google Home and are satisfied with them [Purington et al., 2017].

The most common interactions found were touch, mid-air gestures, and pressure

Furthermore, in some situations, such as the bathroom, speech interaction may even be troublesome due to the volume of the shower. The interface may not detect the user's voice or interpret the command incorrectly, causing discomfort to the user, which may be one of the reasons why the interactive interfaces investigated for entertainment in private settings mostly use the touch modality. Although we believe that the loud shower sound may be one reason why the speech modality is not utilized in the bathroom, it may be used when the users are bathing or getting ready. It can be convenient for users to control bathroom appliances without having to move around. In the bathroom, users may use the speech modality to manage their environment, such as sending and receiving messages, changing the lights, and playing music.

The speech modality can be utilized to operate bathroom equipment

We assume that the speech modality may also be useful in other settings of the home. Users might use speech to manage household appliances, receive health feedback, secure the home, and stay educated. When instructed, interfaces aimed towards the users' health, for example, might provide the users with an overview of their health state and development. We anticipate that, users will be able to find out about their health condition more quickly and easily since they will be able to accomplish other tasks while listening to their health status and progress. The speech modality might be an excellent method for learning a new language. It is evident that individuals learn better by doing, thus while learning a new language, it is essential for the person to speak it and, of course, hear it in order to get more comfortable with it. This may be achieved with a tabletop interface that uses the speech modality and artificial intelligence that can converse with the user in that language while also assisting them in learning it.

The speech modality might be utilized to control domestic appliances, get health input, protect the house, and study

In terms of touch interaction, as previously said, notwithstanding the purpose and setting of these interfaces, the majority of the researched interfaces employ it as an interaction style. While the categorization of the interfaces revealed a range of modalities used for different purposes, in private settings, touch was the most used interaction modality utilized for entertainment (e.g. [31, 47, 46, 21], and [45]). Since all of the investigated interfaces in that category are situated in the bathroom, touch is the only form of interaction we found. We believe another reason why the

For interfaces in the bathroom, touch was the only modality found interfaces solely utilized touch as a modality is due to the constant movement of the users. Utilizing speech as a modality may pose issues as mentioned, and using mid-air gesture as a modality can result in unintended input when showering or bathing, which may be irritating. We believe that users can still benefit from mid-air gestures, which will be discussed in further detail in the following paragraphs.

Touch is used in a variety of ways in wearable interfaces

Other touch-based interfaces include wearable interfaces that serve a variety of functions. While the *DB-hand* by Caporusso [2008] and the *Lorm Glove* by Gollner et al. [2012] use touch to enable communication for people with disabilities, the *Belt* [Dobbelstein et al., 2015] and *Smart Sleeve* [Parzer et al., 2017] use it to make a wearable item interactive, *PocketTouch* [Saponas et al., 2011], and *Nail Display* [Su et al., 2013] use it for hands-free interaction with a mobile phone or other devices, and *Zippro* [Ku et al., 2020] and *switchback* [Hughes et al., 2014] use it to make textile objects interactive. We think users are already accustomed with touch due to smart phones and other devices, making dealing with new interfaces simpler than interacting with a modality they are unfamiliar with. Touch input can be extremely beneficial for persons with impairments, particularly for interfaces built and developed exclusively for deaf-blind people, such as the *DB-hand* and the *Lorm Glove*. Due to the fact that deaf-blind people cannot communicate through speech, interacting with interfaces through touch is one solution that is used by the interfaces we investigated. Wearable glove interfaces can be inconvenient for users since they can't use the hand that the glove is on, as discussed in Section 4.1.1. We think that the system of these interfaces may be integrated into furniture, such as a couch, which is one of the reasons why they are included in this taxonomy. For example, the *Lorm Glove*'s system may be placed on the sofa armrest, allowing users to compose messages using the buttons on the armrest. This integration at home has the benefit of removing the need for persons with disabilities to wear the glove at home. Gollner et al. [2012] expressed worry about the glove's thickness, which may be unpleasant for users at home. Also users are unable to use the hand that the glove is on for anything else, as stated in Section 4.1.1. Users will not have these issues if the glove system is incorporated

Deaf-blind persons benefit from touch modality

Wearable interfaces for deaf-blind individuals can be integrated into furniture into the sofa, for example, and will be able to converse with friends and family while at home.

Touch is employed as a modality in the majority of interactive tabletop interfaces

Most tabletop interfaces, such as *ChemicAble* [Agrawal et al., 2013], *Read-It* [Sluis et al., 2004], *CounterActive* [Ju et al., 2001], *CRISTAL* [Seifried et al., 2009], etc., utilize touch as modality as well, despite the fact that the purpose they aim for are distinct. Due to the ubiquitous usage of smart gadgets like smart phones nowadays, people are already acquainted with touch interfaces on flat surfaces, making them easier to use. The touch modality on tabletop has the benefit of being effective, especially for tabletop interfaces that are designed with the user's education in mind [Agrawal et al., 2013]. According to Agrawal et al. [2013], and Khandelwal and Mazalek [2007] there is convincing evidence that children learn and absorb information considerably more quickly when it is presented to them in a physical, manipulative, interactive, and assessing style than when it is presented to them in a written one. Which is why we believe that these interfaces make the learning process more enjoyable, and encourages the students to study more frequently.

Because of the mid-air gesture modality, users may accidentally trigger the system

Tabletop interfaces also leverage mid-air gestures as an interaction method. *Gesture Desk* [Hermann et al., 2004], a tabletop interface that does not employ touch, uses mid-air gestures to enhance the functionality of traditional input devices like the mouse and keyboard. We suspect accidental triggering of the interface may be an issue that can occur while using the *Gesture Desk* [Hermann et al., 2004], since users may move even if they don't wish to activate the system. For example, when users reach for their coffee cup, write notes, or stretch, the interface may be triggered.

Interfaces employ mid-air gestures to operate appliances

Interfaces projected on the wall employ mid-air gestures as modality as well, such as the *Information Wall* [Mäkelä et al., 2014], *Ambient Wall* [Kim et al., 2011], and the interface presented by Shoemaker et al. [2010]. Users may utilize these interfaces to operate appliances, watch movies, play games, and much more. Ha and Byun [2012] presented a wearable interface, that leverages mid-air motions. These interfaces differ not simply in terms of their purposes and settings, but also in terms of the approaches they employ. The homecare system by Ha and Byun [2012] makes use of a wearable device to operate household appliances, whereas the other mentioned interfaces do not require a controller. Unlike the *Information* and *Ambient Wall*, Shoemaker et al. [2010]'s interface can be manipulated with the entire body, not just the hands. The ability to manage appliances, read information, and monitor the house without the need of a remote control is a benefit for consumers, unintentional interaction with the interface may be drawback in certain instances. When utilizing the ambient wall, for example, users may mistakenly control home appliances due to their movements. Even though the interface is only activated when users point to a blank ceiling or wall, the system can be activated by accident while users are dancing, working out, or moving their hands while talking. Another issue that users have is the inability to learn, recall, and precisely perform gestures [Attwenger, 2017]. The interface designers should provide a system that properly recognizes these motions, as well as a guide that enables for rapid and easy learning of these movements.

Interaction with the interface by accident is the disadvantage

Users need to learn, recall, and execute motions exactly

Although we consider unintentional system activation to be a drawback of the interaction modality mid-air gestures, it may be useful in other situations, such as the kitchen. *CounterActive* by Ju et al. [2001] projects recipes on the kitchen counter and can be managed with touch, but we believe that mid-air gestures may also be a valuable modality for this interface. When users' hands are filthy and they want to engage with the interface, mid-air gestures might be quicker, faster, and more pleasant than washing and drying hands in the middle of a cooking session to interact with the interface.

Mid-air gestures might be useful in some situations at home

Even though the interfaces we examined in the private setting that aim for entertainment did not leverage mid-air gestures, the interaction modality can be advantageous for users. Mid-air gestures, like the suggested activities for the speech modality, can be utilized to operate bathroom appliances. The system must be designed in such a manner that it is not activated by every single movement made by the users, and they must be able to switch it off and on whenever they choose.

In private settings, users may benefit from mid-air gestures

We believe that a wall interface that can be controlled with speech and mid-air gestures might be created in the future for entertainment in the bathroom. The interface, similar to the *Ambient Wall* [Kim et al., 2011], projects the display on the wall and may be connected to the users' mobile phone, allowing them to view videos on YouTube, watch their favorite TV series on Netflix, or even text family and friends while in the bathroom.

Pressure is used to monitor and manage the health of users and equipment

Another interaction that the interfaces employ is pressure. Pressure is used by certain interfaces, such as *Exerseat* [Braun et al., 2015c], to monitor the user's health, while others, such as *CapCouch* [Pohl et al., 2015], couch Rus et al. [2017], and cushion [Suzuki et al., 2020], utilize it to operate household appliances. The application of pressure on furniture to control appliances can be comfortable for users at home, however we believe the difficulties that arise when putting pressure on furniture to control appliances include unintentional and unwanted contact. Unlike touch, pressure may be engaged with the entire body, not just the hands. These interfaces also employ a range of pressure patterns, for example the cushion by Suzuki et al. [2020] differentiates between push and long push, however users may have difficulty comprehending and distinguishing these patterns from one another, resulting in undesired appliance control, as the authors of the interface also mentioned. A solution to this problem would be to avoid comparable pressure patterns, such as only utilizing push or long push. This technique reduces the number of pressure patterns that may be employed, but consumers will have no trouble distinguishing between them.

When utilizing pressure as a modality, unintentional and undesired contact is conceivable

Gaze is being utilized as a form of interaction to help people with impairments

Gaze is also a modality used by a few interfaces (4%) to interact with them, which is particularly beneficial to people with disabilities. The interfaces presented by Bissoli et al. [2019] and Gautam et al. [2014] utilize the sight to operate appliances and wheelchairs, respectively. Both take into account the wide range of infirmities and the fact that persons with severe disabilities are unable to utilize many interfaces, which is why the interaction is done with the eyes. Accidental triggering of the system is feasible with the gaze, just as it is with the modalities mid-air gesture and pressure. This may create a lot of problems, especially when operating the wheelchair. Even

The drawback is that the system might be accidentally triggered though we believe that interfaces can be triggered by accident, the gaze modality can be useful in some aspects of a home. For example, the interactive cookbook *eyeCOOK* by Bradbury et al. [2003] allows users to interact with it via gaze or touch, allowing them to manage it even when they are not in close proximity or when their hands are dirty. This eliminates the need for users to walk back and forth while cooking to engage with *eyeCOOK*; instead, they can just use their gaze. The gaze modality may also be utilized in other areas of the house, such as controlling the TV to change stations or dimming the lights. We presume that combining the gaze modality with another modality, such as speech, will increase user satisfaction. Users can manage the channels with their sight and increase the volume with their voice, and after they've found the channel they want, they can switch off the gaze recognition system by commanding it.

Users may find the gaze modality valuable when combined with other modalities

When it comes to interface interaction the setting of the interfaces did not demonstrate a clear separation. This discovery suggests that there is no need to choose a single interaction modality for a particular setting. Interfaces in both scenarios employed the aforementioned interactions. The only discernible distinction is the interaction utilized for entertainment in a public setting versus the interaction used for entertainment in both public and private settings. As previously stated, touch was the sole modality employed by the investigated interfaces intended for entertainment in just public settings. However, alternative modalities, such as mid-air gestures, were discovered in the entertainment category for both public and private settings. The interface modalities touch and pressure may be found in both private and public settings, however no interface that utilized speech as a sole interaction was discovered throughout the research of these interfaces. As previously said, this might be attributed to the fact that customers are already utilizing speech interfaces at home.

There is no apparent separation of interface interaction dependent on setting

The examined interfaces did not use the speech modality in either the public or private setting

According to the findings of this section, the aspect of interface interaction was critical in the design and development of interfaces. The way people engage with an interface has a major influence on how they perceive it as a whole. Users may be dissatisfied with a modality if it is not chosen appropriately and fully tested. Touch tends to be the most often used interaction across all categories by most interfaces due to its familiarity and low risk. While mid-air gestures, gaze, and pressure might be beneficial in specific scenarios at home, the system's unintentional and undesired activation is a drawback. As previously stated, we feel that interfaces that leverage several modalities for interaction are more advantageous to users since they provide them with a variety of engagement options. However, real-world user testing over a long period of time is essential to ensure that the interface interactions are effective and efficient.

Chapter 7

Conclusion

We propose a new taxonomy for the description and classification of indoor home interfaces in this paper. Indoor home interface design and development has progressed from smart home to interactive furniture, as discussed in Section 1. Most existing taxonomies on home interfaces are device- or task-focused rather than concentrating on the interfaces' purpose, and hence are likely to become obsolete as technology advances. This taxonomy categorizes and examines indoor home interfaces based on their intended purpose and setting.

A new taxonomy for home interfaces is presented, based on the setting and purpose

When categorizing interfaces, we consider the private setting, the public setting, and both settings at the same time. In addition, each setting is separated into purposes that we defined in Section 2.1. The private setting is subdivided into entertainment, health, and security, while the public setting is divided into education and communication, and the private and public setting is categorized into comfort, entertainment, and sustainability.

There are three types of settings: private, public, and private & public, each of which is further split into purpose

We discovered that most interfaces are created for the users' comfort and that while there are entertainment interfaces designed for private settings alone, we identified no interfaces designed for the users' pleasure in public settings. An interface that may be designed, for example, is a tabletop interface that is only utilized during game evenings. We also found no interfaces designed specifically for people with chronic conditions, as well as no interfaces for intentional, unintentional threads or malfunctions at home. When it comes to home sustainability, extra aspects, such as energy management, should be addressed that were not taken into account by the discovered interfaces.

The interface interaction was also discussed

We also discuss the investigated interfaces in terms of interaction that was used, and make recommendations for future indoor home interface development. A variety of interfaces utilized the modalities touch, mid-air gestures, and pressure, whereas the speech interface was not widely used. Touch was discovered to be the most often utilized interface interaction, followed by mid-air gestures, and pressure. Even though speech was not utilized as the sole interaction modality, we suspect it can be beneficial to users at home. Additionally, using various modalities to interact with the interface may be preferable to using only one. The taxonomy is meant to be a resource for other Human-Computer interaction (HCI) researchers, but it might also serve as a starting point for newcomers looking for an overview of indoor home interfaces. Also, the goal of this classification is to identify potential gaps in the development of home interfaces that may be solved.

Touch, pressure, gaze, and mid-air gesture were used

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