

# Accessible Smart Home System for the Deaf and Hard-of-Hearing

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## ABSTRACT

Currently, smart home systems are not accessible to deaf and hard-of-hearing (DHH) residents. The purpose is to build an accessible system that can be integrated with smart home systems. It will allow DHH people to be notified when appliances produce sounds in a home environment. The Internet of Things (IoT) platform is used to provide engineers a development environment, which allows them to develop a cost effective and customizable application for different possible accessibility solutions that will benefit the DHH community. Consumer demand is driving the adoption of IoT as the new technology to improve home, energy savings, and safety that will create new things that have not been envisioned yet. The IoT is based on a powerful embedded controller with Bluetooth and Wi-Fi technologies. These technologies can ultimately be used to improve access to a wide variety of electronic and communication devices. Because of on-going development of specific solutions for accessibility needs, it reduces the development cycle by creating a common platform as a base for most solutions. The emergence of widely available accessible smart devices on the market is due to the low cost, small physical footprint, and the ability to move from research to commercialization.

## Categories and Subject Descriptors

K.4.2 [Computing Milieux]: Social Issues – *Assistive Technologies for Persons with Disabilities*

## General Terms

Documentation, Human Factors, Standardization.

## Keywords

Deaf, Hard-of-Hearing, DHH, Accessibility, Smart Homes, Home Automation

## 1. INTRODUCTION

A Smart Home is a home that provides a resident security, lighting control, energy efficiency, convenience, and entertainment through wireless technology. In a smart home, necessities such as lighting, air conditioning/heating systems, TVs, and appliances are capable of communicating with one another. Other devices having such capabilities include computers, entertainment audio & video

systems, security, and camera systems. Those devices can be controlled remotely from any room in the home as well as from any location in the world by smartphone or internet [18]. With home automation, manual activations are minimized as the different smart appliances are controlled by a computer database. The system of home devices connected to the Internet, which is also called the Internet of Things (IoT), becomes an integrated environmental awareness that is both safe and secure in a smart home [13].

The ability to talk with a smart home gives the homeowner a sense of control. The different actions to be taken at the smart house can be controlled by a touch of a button, the register of the resident's voice, or a time schedule [14]. This home can be secured, for example, by setting up a camera, a motion sensor, and a siren strobe alarm. This security system can be configured to both emit a loud siren and send text messages when a potential danger is detected.

Typically, a smart home requires an internet connection, a hub, and a mobile device. An internet connection is necessary for hubs to communicate with smart devices. Hubs assist in the communication between internet-enabled devices. Mobile devices are used to control smart devices and receive notifications from hubs from anywhere in the world.

Disability is a term used to describe any restrictions that personal and/or environmental factors have on an individual with a health condition [5]. The disability statistics provided by the World Bank organization presents that 15 percent of the world's population is living with some kind of disability and facing barriers daily such as "inaccessible buildings, transport, information, and communication technology...[6]." People with hearing, sight, and intellectual challenges and physical restrictions, to name a few, fall into the disability category.

In the next section, related work is discussed. A brief background and challenges faced by DHH people are detailed in Section 3. Sections 4 and 5 explain the gaps and the potential solutions to fill them in respectively. Finally, discussion and conclusion are presented in the final section.

## 2. RELATED WORK

In June 2015, a wounded veteran and his wife moved into a new smart home that met his needs. The wide entrance and hallways, lowered cabinets and surfaces along with a tablet controlled lights and appliances made the home more accessible for the man who uses both prosthetic legs and a wheelchair [20].

SmartThings has a mobile app, SmartApp, which is friendly for the elderly. The app incorporates both the Daily Routine and Slip & Fall features. The first feature allows the caretaker of the elderly to be notified of any anomaly in the elderly's daily routine. Family members or loved ones are notified any time their aging relatives

have slipped and fallen in their bedroom or bathroom by the second feature of the SmartApp [16].

Visually impaired individuals have the advantage of using a smart voice control speaker to interact with their smart homes. For example, by verbally asking the Amazon Echo to turn on the light, the device will trigger the preferred lights to turn on.

Upon more research, works related to the creation of accessible smart homes for DHH residents are not found. This pushes the need to explain the homeowners' background and the type of challenges they have to face daily to stress the importance of an inclusive smart home for people with hearing loss.

### 3. A BRIEF DHH BACKGROUND

In domestic environments (homes, apartment, dormitory), individuals are typically exposed to what may be described as a domestic of sounds generated by a wide variety of sources. Being able to selectively discern the presence and origin of a particular sound enables an individual to distinguish important information. The common distinct sounds that are normally heard include running water from a faucet, arrival of an individual at the doorbell, or notification of a timed event (washer/dryer).

In short, individuals frequently find themselves in an environment that are electronically noisy or where the sounds of interest are of a very low level, which prevents them from effectively interfacing with their surroundings. This situation can be significantly exacerbated for individuals with any degree of hearing loss. For those individuals, there are varieties of devices that can be utilized to address a range of deficits. Personal Sound Amplification Products (PSAPs) [10], hearing aids, and cochlear implants are examples of such technologies. Their levels of sophistication and regulation are designed to provide and enhance auditory information of all normally perceived sound sources.

However, in general, they are not designed to detect, selectively pass, or discriminate specific sound sources [7], let alone their location. Detection or selective amplification of specific sound sources would enable enhanced notification capabilities that could, in turn, enhance the user's ability for attention, decision making and navigation.

This situation represents a multi-dimensional challenge. There is a wide variety of sounds that individuals are exposed to, the circumstances and attention requirements in the residential area (e.g. paying attention to a break-in, waiting for a friend, and waiting for the microwave to finish cooking a frozen dinner) and the degree and type of hearing deficit of an individual or multiple individuals. Any cost effective and consumer friendly solution would need to be adapted or easily adjusted for these unique circumstances that fall under the general category of sound identification and notification.

It would also be essential that some degree of assurance of reliability and confidence of performance would need to be incorporated directly into such solutions. It would be either that or be easily available to provide such assessment for the individuals concerned.

## 4. GAPS

### 4.1 Overview

Even though the number of people in the world with hearing loss is significant, 36% of the estimated 1 billion people with disabilities [4], those people do not appear to be inclusive in the already

accessible smart homes for wheelchair users, the elderly, and people with visual challenges [8].

While it is fortunate that DHH people are able to take advantage of some smart devices used for common issues faced by hearing people, gaps continue to exist. Break-ins and potential danger from smoke and carbon monoxide, to name a few, are the issues faced by homeowners. However, the common issues faced by homeowners that are acoustic based have not been incorporated in the design of smart homes. The home automation companies took this action based on the assumption that their customers will respond to them automatically. Unfortunately, this is not true for DHH customers since they rely heavily on visual alerts. For instance, a beeping noise that goes off when the oven timer ends often goes unheard by those with hearing loss. As a result, the food in the oven gets over-baked and burnt which would then trigger the smoke detector to go off. This creates chaos in the house. All of this could be avoided if there was a device that would alert the DHH people that the timer is going off. An oven is one of the several acoustic devices that needs to be kept in mind when designing cost effective smart products.

The previous example explained is one of the numerous incidents that may occur due to the diversified degree of hearing loss. Another good example would be hot water being left unattended. The longer the heated water is running, the higher the water and gas/electricity bills get.



Figure 1. Gaps in Current Homes

Figure 1 illustrates several common sound-based household components and products in today's homes. The dishwasher, oven, and washer/dryer all produce beeping noises upon completion. Humming sounds are often generated by both garbage disposal and stove fan hood when they are on. During the times that the water is running or leaking, a sound is created as well. As it shows, sounds are constantly being formed in a standard home.

Those residents without hearing loss have the advantage of hearing those audible sounds without the need of assistance from smart products. On the other hand, this creates an enormous gap in the accessibility of a home for those with hearing loss.

## 4.2 Common Incidents and Issues

The following table is a short list of the common household incidents. Each one of them is examined to see whether home automation companies address them. To conduct this examination, the companies' products were reviewed and then concluded whether or not they can be used as solutions to the incidents.

**Table 1. Gaps in the Home Automation System**

Common Incidents	Incorporated in Smart Homes?
Knocking on the Door	X
Opened Refrigerator	X
Opened Garage Door	X
Break Ins	X
Smoke Detector	X
Broken Sump Pump	X
Water Leaking	Internal
	External
Oven Done Baking	
Alarm Clock Going Off	
Ventilation Fan Left On	
Garbage Disposal Left On	
Stove Hood Fan Spinning	
Completed Microwave	
Completed Washer/Dryer	
Completed Dishwasher	
Completed Appliances	
Broken HVAC	

Again, the information was gathered from several companies that design and develop smart products such as SmartThings [15], Wink [3], Insteon [2], and WeMo [17]. By observation, only 39% of the incidents are resolved by smart devices. The remaining 61% end up being overlooked by DHH homeowners. It is either this or those homeowners will have to take additional actions to ensure the remaining 11 issues are detected in their houses. This may require for the homeowners to hard-wire devices or purchase separate appliances that are not integrated into the home automation system.

The other issue faced by DHH people is the various smart products provided by different home automation companies. DHH customers may purchase a specific set of devices from one company and a different set from another company. The favor of the various products depends on both cost and efficiency as well as the degree it aids the DHH customer. By having devices from multiple companies, the number of mobile apps necessary to manage the customer's smart home increases. As a result, this defeats the purpose of a smart home in terms of convenience and ease of use.

Those issues become even bigger when the DHH residents go to bed for the night. The alerting text messages from smart devices and/or hubs become useless. This is where visual and haptic notifications come in. While some hubs have the capability of receiving information from one device and using that to trigger

another device such as a light into action, others do not [19]. With that, DHH people will be visually and haptically alerted not for all but some smart devices.

It appears that the Whirlpool Corporation has a smart washer and dryer pair that would notify the customers their clothes have been washed and dried for around \$3,400 [12]. June, another modern appliance company, has a smart oven that is coming out in Spring 2016 for \$1,495. This oven comes with a June app that incorporates recipes, alerts, live video monitoring, and meal planning [9].

Those new smart devices may be something that DHH people can take advantage of but again, it adds to the list of apps they will have to maintain. In addition, by having to purchase expensive washers, dryers, and ovens, the smart home becomes less cost effective.

## 5. POTENTIAL APPROACHES

There are five potential approaches to solve the aforementioned issues DHH face in their current houses. They are explained in the following subsections.

### 5.1 Design New Smart Products

One way to solve the issue of missing acoustic smart appliances is to assemble new smart household products such as a smart alarm clock, a smart ventilation fan, and a smart stove hood fan. As mentioned earlier, there are some existing smart appliances such as a smart washer, dryer, and oven. Since the evolution of technology is moving rapidly, it is expected for the costs of Whirlpool's smart washer and dryer pair as well as June's smart oven to decrease and become cost effective in the near future. This gives the DHH homeowners the option of replacing their current home appliances that produce sounds with "smarter" ones.

### 5.2 The Band-Aid Solution

The second approach, a band-aid solution, is to develop a sound sensor for the different sounds that notifies and/or alerts the homeowners of the current circumstances. The resulting device could be something similar to Samsung SmartThings' Water Leak Sensor. This wireless sensor is placed in areas in the house that are prone to leaking such as in a basement or under an old water pipe. Once an excessive moisture is detected, either an immediate alert is sent on the smartphone or a light is triggered [11]. The designed sound sensor could be placed near existing acoustic based appliances and whenever a sound has been detected for a certain period of time, the sensor could send a notification and flash a light. This may enforce the goal of maintaining the cost effectiveness of a smart home in the meantime.

### 5.3 An Integrated App

The probable answer to the multiple mobile app issues is to develop an integrated app. The resident should be able to control several hubs and devices, all from one app. This app should support most, if not all, existing hubs and their corresponding devices. This will minimize the number of apps running in the background on smartphones and/or tablets.

### 5.4 A Hub Supporting All Wireless Protocols

One way to solve the nighttime issue is to develop a single hub or controller that allows the communication between all smart products to happen. To make this possible, it may be necessary to set a standard such as one that supports all wireless protocols, Wi-Fi, Bluetooth LE, ZigBee, Z-Wave, and Insteon. This would allow the compatibility of all devices to a single hub. With this, homeowners can easily connect the smart devices to any visual

and/or haptic internet-enabled devices so that they will be alerted anytime a potential danger is detected throughout the night.

## 5.5 IFTTT

For the current hubs that do not support the passing of the information from one smart device to another to trigger an action, the If This, Then That (IFTTT) web-based service may be a workaround solution. IFTTT allows the mobile device user to be creative with how products and apps work together and comes with two “recipes,” IF and DO [1]. The IF recipe is an applicable solution to this issue. It runs in the background and will execute the “then” portion anytime the “if” occurs in the “if this, then that” statement. IFTTT users may create a recipe, “if I receive a notification from one smart device, then trigger the other device such as a light (or vibration) to turn on” to assure they will be notified when they go to bed.

## 6. DISCUSSION AND CONCLUSION

Home automation appears to be a good solution to DHH people’s needs in their homes. In spite of that, it is still missing several smart products that would create a more accessible smart home for those with hearing loss. With that, there are many gaps that need to be filled in by smart home companies. Sounds are being produced everywhere every day which makes it understandable for people to assume it is not necessary to create solutions for them in homes. However, based on the statistics, 5% of the world population is living with hearing loss, which is a big number. Thus, their needs ought to be addressed.

As per Table 1, there are 18 identified problems with five discussed probable solutions. DHH homeowners’ current sound producing devices can be used with the band-aid solution of creating a separate sound sensor or replaced with smart ones. For an ease of use, all apps can be integrated into one. The other approach is to create a single hub that is interoperable with existing smart devices. Lastly, but not least, IFTTT can be used as a workaround solution.

Although the solutions are concise, they have the ability to grow in length as they can be detailed even further. While today’s smart homes are not DHH friendly, it is expected that the circumstances will change within a couple of years as technology is constantly evolving. All in all, it is important to ensure the DHH people are guaranteed the opportunity to experience the same comfort of living in their smart homes as those without hearing loss.

## 7. ACKNOWLEDGMENTS

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