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AN INVESTIGATION OF SOUND SOURCES IN SMART HOUSES FOR IMPROVED MACHINE-TO-HUMAN COMMUNICATION

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ABSTRACT

This study aims to investigate the ever-evolving indoor soundscapes of smart houses by classification of the sounds emitted from smart devices. Nowadays, communication is no longer limited to person-to-person. Smart devices frequently communicate with users by verbal or tonal notifications. Therefore, acoustic characteristics of smart houses, especially reverberation time and background noise levels, have increased importance in achieving improved and lossless signal transfer and speech intelligibility. It is hypothesized that most houses are unsuitable for effective tonal and verbal communication with smart devices regarding acoustical conditions. Within the scope of the study, the devices found in the smart technology market were investigated. The sounds emitted from the identified devices were then classified according to their communicative nature (verbal/tonal), designability, customizability, and cause (i.e., intentional or consequential). The acoustic requirements for effective communication with the individual smart devices were analyzed in addition to the resulting holistic indoor soundscape of the smart houses The results of the study will help architects, interior architects, and other environmental designers to improve the quality of communication while guiding future research to understand indoor soundscapes of smart houses.

Keywords: indoor soundscape, smart house, speech intelligibility, communication

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1. INTRODUCTION

Smart houses became popular in recent years, adding more devices in households, leading to an increase in the variety of sound sources as well. Sounds emitted in traditional households can be categorized generally as bi-product noises such as electronic devices, media, verbal and non-verbal human voices, alarms/notifications, musical instruments, sonic ornamentation, pets, house noises, external sounds, and neighbours' noises [1]. Devices such as smart speakers, thermostats, and smart alarms are essential for smart house functions to occur. These devices emit a variety of sounds to communicate with the users. Therefore, this paper aims to investigate what smart devices appear in smart houses and classify the sounds they emit according to their functions. Since sounds in spaces affect the emotion, behaviour, and health of users [2], proper acoustical design is essential for users to have a better overall experience. This study is the initial step of the research project on the effects of smart technology on machine-to-human communication by providing design guidelines on the acoustical requirements of smart houses for designers. To proceed with the following steps of the project, it is first required to understand the current soundscapes of households and the influence of smart technologies.

2. SMART TECHNOLOGY AND SMART SPEAKERS

Smart houses include Internet of Things technology IOT [3], which refers to devices that are connected to the internet or with each other and accomplish tasks at the house without the need for human interaction [4]. Some general and most common smart device examples are sensors, machines, drones, and cameras [5].

Smart houses consist of four main functions; (1) Alerting, which enables the house to sense the environment and provide users with alerts on different levels, drawing the attention of users for urgent situations as the main need of the function or for some important changes the user needs to react to; (2) Monitoring, is the most important function, connecting with sensors as well, the smart house is able to give information about different activities going on in the household, monitoring provides the user with the ability to decisions making while having better awareness about the house situation; (3) Controlling, in smart houses, it is easier for users to have control on more activities with higher automation options, this function can occur with different methods such as voice control, remotely controlling, or through phone applications; (4) Intelligence, or House Intelligence which is the most iconic function of a smart house since it addresses its' behaviour, this function relates to the decisions made automatically by machines and artificial intelligence in a household. The level of automation in a household can represent the level of intelligence of the smart system applied [6]. These four smart house functions will be an essential classification criterion for the current study.

Smart speakers are considered the heart of smart houses. They evaluate the level of automation in smart houses and control the devices in a household. Smart speakers have had a major impact on controlling smart houses and automating them, and they can provide real-time information [7]. Smart speakers rely mainly on the concept of Machine-to-Human communication. Machine-to-Human communication is both a concept and an area of study, it refers to giving meaning between humans and machines [8].

3. METHODS

To determine the most used smart devices in smart houses, the Statista database was used. Statista is a statistical data source found in the literature [9]. The top three most owned smart speakers' brands were searched to collect their sound files. Only sound files for Amazon Echo were found on developer pages [10] [11], and sound files for Apple HomePod were found on unofficial sites [12].

The collected sound files were categorized according to their type (verbal/tonal), other factors such as duration, designability, and customizability were considered to find possible patterns in these sounds. After collecting and sorting smart speaker sounds, the sounds were classified under the four main smart house functions. The results were compared to discuss the relationship between smart house functions and machine-to-human communication with its acoustical needs in smart houses.

4. EVALUATION OF MACHINE-TO-HUMAN COMMUNICATION

Smart speakers are the main focus of this paper for being the most owned smart device type in smart houses and the huge impact it has on the acoustical condition with direct Machine-to-Human communication. The current information on smart device usage in houses is presented in Figure 1. The most owned smart device in smart houses is smart speakers, with 131.4 million owned devices worldwide in 2022 and an estimated number of 353.3 million devices in 2027 [13].

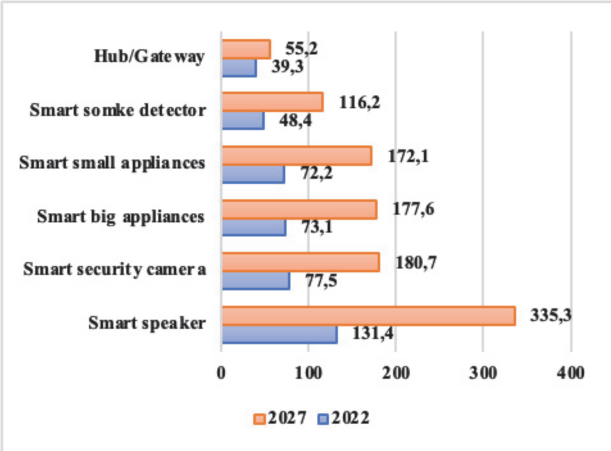

Figure 1. Number of households having different smart devices in millions [13].

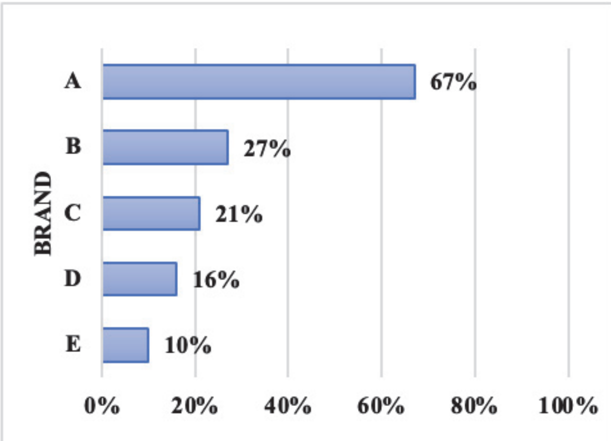

Figure 2. Most owned smart speaker in the US in 2022 [14].

Since the paper is not financed, the author decided to rely on unpaid data only, thus the most recent statistical data were according to the U.S. in 2022, as shown in Figure 2, the results highlight that Brand A "Amazon Echo" highly dominates the market, with a market coverage of 67%. Brand B, "Google Home", and Brand C "Apple HomePod" follows Brand A, with 27% and 21% of market coverage, respectively. Thus, Brand A, Brand B, and Brand C were initially selected for the study. However, data were available only for Brand A and Brand C.

The data were collected, sorted, and classified. Table 1 shows the *designability*, which refers to the ability for the sounds to be intentionally designed, and *customizability*, referring to whether users have the capability of modifying the sounds or not, the table informs that verbal sounds are less flexible in terms of *customizability.*

Table 1. The *designability* and *customizability* of sounds emitted from the two brands.

Brand	Type	Total Number	Designability		Customizability	
			yes	no	yes	no
A	Verbal	316	316	0	0	316
	Tonal	14	14	0	14	0
C	Verbal	55	55	0	0	55
	Tonal	17	17	0	17	0

Sounds were classified under the four main smart house functions: *alerting, monitoring, controlling,* and *intelligence*. As shown in Table 2, for the Brand A "Amazon Echo" *alerting* is a shared function between verbal (68.4%) and tonal (31.6%) sounds, for *monitoring* (97.3%) and *intelligence* (98.3%) verbal sounds are highly dominant, however for *controlling* 100% of the emitted sounds are tonal. For Brand C "Apple HomePod", 100% of the sounds used in *alerting* and *controlling* functions are tonal, for *monitoring,* 35% are tonal as well, but only 2.8% of tonal sounds are identified for *intelligence* function.

The data shows a significant number of verbal notifications; this type of notification has a better capability in delivering the information to users, they require good language skills to achieve efficient results, personal language differences must be taken into consideration while using verbal notifications since there are no identical languages in either symbols or the way a language sounds [15].

Table 2. Classification of sounds emitted according to smart house Function.

Brand	Type	Total Number	Alerting		Monitoring		Controlling		Intelligence	
			Count	Percentage	Count	Percentage	Count	Percentage	Count	Percentage
A	Verbal	316	13	68.4	73	97.3	0	0.0	230	98.3
	Tonal	14	6	31.6	2	2.7	2	100.0	4	1.7
C	Verbal	55	0	0.0	20	64.5	0	0.0	35	97.2
	Tonal	17	3	100.0	11	35.5	2	100.0	1	2.8

5. CONCLUSION

It was observed that sounds emitted from smart speakers are mostly verbal, and most of them are used in *intelligence* functions with a low ratio of tonal sounds for that function. However, all the sounds emitted for Controlling functions were tonal in both cases. Lastly, *monitoring* and *alerting* functions show the differences between the two brands in the ratio of relying on either verbal or tonal sounds for these functions. This results in a more efficient information delivery from Machine-to-Human since it is less reliable on the personal differences in perceiving information. However, relying on verbal notifications requires higher speech intelligibility in households, higher language skills, and a better understanding of the acoustical needs of space. Smart technology in smart houses relies more on Verbal voices to notify the users. All emitted voices for *controlling* function are Tonal in both cases, *alerting* and *monitoring* functions show variation in the type of used voices, while verbal voices are dominant for the *intelligence* function.

Smart devices and smart speakers especially, are advancing in understanding human speech more clearly by improving the technology of used microphones and including artificial intelligence and machine learning mechanism. However, for users to understand machines, and smart speakers, in this case, room acoustics are the main factor in improving the user's experience of understanding the device clearly from the first time. Thus, the main project aims to measure the acoustical changes in houses since they became smart, study the effect of these changes on users' perception of space, and determine the acoustical requirements for designing smart houses. This paper is the first step of the main project, it determines the smart devices that appear in smart houses and classify the sounds they emit according to the main functions of smart houses, which is important for having base knowledge about the current acoustical condition of smart houses for the main project.

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