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IoT 센서를 이용한 국산 RV차량 음향시스템의 음향특성에 관한 분석

IoT Based Performance Measurement of Car Audio Systems in Korean Recreation Vehicles

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요 약

오늘날 자동차 제조회사들은 차량의 기능과 성능을 향상시키는 기술에 주안을 두는 것은 기본이고, 시장성의 극대화 및 고객 만족도를 높이기 위해 고품질 오디오 장치 구축에도 투자를 아끼지 않고 있다. 특히 고가의 차량일수록 일반 청음실에서 느낄 수 있는 높은 수준의 음향 시설을 갖추려고 한다. 이러한 현상은 차량의 모델에 국한되지 않는다. 요즘 인기가 많은 RV차량에서도 고객들이 수준 높은 음질을 만끽할 수 있도록 제조사들은 고품질의 음향 시스템을 탑재하는 움직임을 발견할 수 있다. 그러나 고품질 음향시스템은 대부분 고가의 부품을 필요로 하는 관계로, 이는 필연적으로 자동차 판매가의 증대를 야기한다. 따라서 비교적 저가의 음향 시스템을 이용하더라도 고객이 만족해 할 수 있는 음질을 구현하는 차량 내 음향 시스템 구축의 필요성이 대두되었다. 즉, 인간의 청각적 특성이 고려된 객관적인 자동차 '오디오 시스템 성능 측정 지표' 및 튜닝 방법에 관한 연구가 필요하다. 본 논문에서는 RV차량의 오디오 시스템의 성능을 평가하고 개선하기 위해 인간의 청각적 특성이 고려된 오디오 신호의 특성을 사물인터넷(IoT) 센서를 이용해 측정하고 분석하였다. 분석 결과 사람에게 민감한 대역의 높은 에너지가 있는 점은 인지에 대한 비중을 높일 수 있으나, 해당 대역만 강조된 경우에는 성가심을 유발할 수 있는 것으로 나타났다. 그리고 왜곡된 주파수 평탄도는 음질에 나쁜 영향을 줄 수 있어 주파수 응답의 평탄화를 필요로 한다는 점을 발견할 수 있었다.

☞ 주제어 : 청각특성, 음장, 차량 오디오, 청력손실, IoT센서

ABSTRACT

Recent automobile manufacturing technology has improved not only the function and performance of cars, but also the audio systems in cars so as to increase their marketability. Automobile manufacturers always have the option of simply installing an expensive acoustic system to help customers enjoy a high-level sound quality car audio system. However, this also tends to increase the MSRP (Manufacturer's Suggested Retail Price) of the car. Therefore, it is desirable, where possible, to enhance the sound quality of plainer, less expensive audio devices to help customers feel as if they have a high-quality and expensive audio device in their car. In order to make this happen, the manufacturer must develop an optimal interior environment and audio system at a relatively lower cost. To this end, features of the car audio system can be enhanced by analyzing audio frequency response and using performance metrics to figure out the characteristics of the human auditory system. This study analyzed the sound field of Korean Recreation Vehicles (RVs) using the Internet of Things (IoT) sensor for the measurement of car audio system. As a result, high energy of sensitive bandwidth, one of the human auditory characteristics often makes annoying sound. This study also found that increasing the frequency response flatness is required by taking human auditory field into account when designing the car audio system for the future.

☞ keyword : Characteristics of hearing, Sound field, Vehicle Audio, Hearing loss, IoT sensor

1. Introduction

Along with developments in machine-civilization and changes in people's living standards, people have become less physically active. Cars have become the most popular means of transportation, and many people use cars to move even short distances due to their convenience. In addition, different environments are being created for cars such as auto

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camping fields, drive-in theatres, and car sharing. The main contemporary functions of cars are to carry people from one point to another, and transport loads that cannot be carried by people. The design of vehicles is continually being upgraded in order to provide both drivers and passengers with more convenience and comfort. In order to satisfy consumers, automobile manufacturers have been trying to produce a vehicle which is quiet, vibrates less, fast, and comfortable. Meanwhile, manufacturers have been also trying to upgrade car audio systems which can entertain both the driver and passengers [1]. Recently, smart cars have become a major element of the expanding Internet of Things (IoT). It is expected that one in five vehicles will have some sort of wireless network connection by 2020 [2]

People do a range of things while they are inside a car. While drivers operate the vehicle, passengers can take a nap, chat with the driver, or chat with other passengers, amongst other things. People often listen to music or the radio through the car audio system, which is installed inside the car, to ward off sleepiness or boredom. Some people may wish to upgrade the default audio system in their car to a higher quality one if they are not satisfied with the sound quality of their existing audio system .A lot of noise is created while driving from different sources, such as the engine, wiper blades, wind, etc. These noises may disturb passengers while they listen to music, and even reduce the sound quality of the audio systems in the car. However, from a manufacturer's point of view, it is not easy to invest a large amount of money solely into a high quality audio system in a car to satisfy consumers who are very sensitive to sound quality. Their major concern should be in regards to the main functions of the vehicle, namely as a transportation tool [3-5].

From the passenger's perspective though, a lack of controllable devices or tools that can adjust the basic features of the car audio system, such as volume, equalizer, balance of left/right speakers, switching from radio to usb inputs etc, [6], may be an inconvenience.

In terms of car audio systems, it is obvious that manufacturers can build high quality audio systems if they use expensive amplifiers and speakers. The systems would be improved even further if manufacturers considered additional factors such as the location in which to install the speakers, interior materials used, echo range, or interior shape. However, the selling price is another important issue for the manufacturer. Greatly increasing the price is almost impossible for manufacturers if they are targeting ordinary consumers. Therefore, it is necessary that extra work on developing the optimal interior environment and audio systems can be completed at a reasonable price, and the car audio system can be enhanced by analyzing audio frequency response and using performance metrics in order to figure out the characteristics of human auditory system [7].

A manufacturer also has an ethical duty to consider hearing loss from a poorly implemented audio system. Hearing is very hard to recover once it is damaged. Thus, extreme caution to make sure that a car audio system is safe is a critical factor for a manufacturer. In order to protect passengers from hearing loss, this study examined existing literature on hearing impairment. Further, it also evaluated the features of sound fields in cars to investigate how they may cause hearing impairment, and any possible solutions to this [8-11].

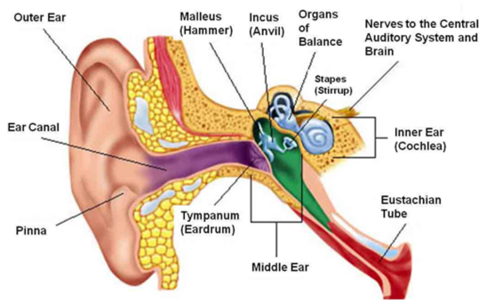
Currently, a good deal of research is being undertaken dealing with automatic controllable technology using internet sensors. It is generally better if the sound quality of an audio system in a car can be measured and controlled by IoT sensor networks.

In this research, firstly, we performed an evaluation of a car audio system's sound quality. In particular, we focused on the low sound field which the human hearing system is very sensitive to. The low sound field is the main sound interval which is produced for human conversation, and the frequency band that can be best heard by people. In Chapter 2, we discuss human hearing features and human noise hearing impairment. The experiment and it's results are demonstrated in Chapter 3. The conclusion of this study follows in Chapter 4.

2. Human auditory characteristics

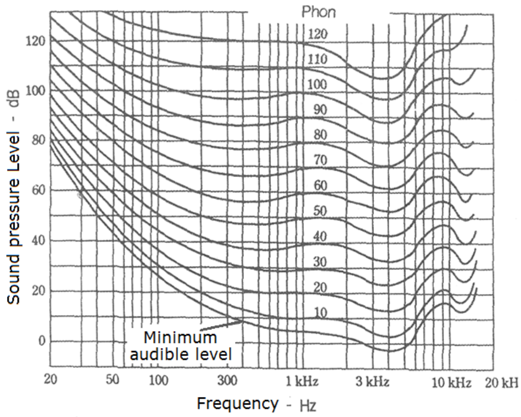
2.1 Ear structure and characteristics

The Ear is the organ responsible for hearing. The ear can be anatomically divided into the inner ear, middle ear, and outer ear. The ear corresponds to a transducer that converts a very small amount of energy sound into an electrical signal through the auditory nerve [10]. In addition, the human ear evaluates external acoustic signals, and is the basic sensory organ that grasps and judges the type and characteristics of the sound generated in a person's surroundings, and transmits this information to the brain [9]. In addition, these factors provide a basis for evaluating sound by subjective standards as well as grasping information through the objective sound of this sense. . The external ear consists of the pinna, the ear canal, and the eardrum. The middle ear includes the ossicles and the eustachian tubes, consisting of the hammer bones, ankle and torso. It is the innermost part of the cochlea where the wah has a cortical organ and is fluid and spiraling. Detailed structures, illustrations and explanations have been provided in [8][10]. The process by which humans recognize sound starts when [10], the sound source is transmitted through the air as a wave and is then transmitted from the ear canal to the brain through the nervous system. The transmitted acoustic signal is recognized in the human brain and basically determines the information of the perceived sound. For example, in the case of voices, it is a basic function to interpret linguistic information and communicate meaning or knowledge. Further, when you listen to music or sound, the ear evaluates the quality and whether a sound is perceived as good or bad. In addition, objective and subjective evaluations of the sounds heard in our ears produce good indicators of sound [8-11].



(Figure 1) Structure of Ear[10]

Our hearing has several characteristics. First, there is a logarithmic scale increase in frequency and magnitude. Even when a person hearing a sound recognizes the frequency, the low frequency is sensitive and the high frequency is insensitive. In recognition of the size, there is a characteristic of recognizing that it increases linearly when it increases logarithmically. This is known as the equal-loudness contour as shown in Figure1 2 [8]. In the time and frequency domains, there is a masking effect that causes loud noises to drown out neighboring sounds. As a result, when people talk in a noisy environment or hear a sound, this device will be activated and this will damage human hearing. It is generally accepted that hearing damage begins to occur from 80 dB in human hearing [10].



(Figure 2) Equal-loudness contour[8]

2.3 Hearing loss

Hearing loss is not easily recognized compared to other disorders. Even if hearing damage is severe, it can be overshadowed. Healthy people have an audible frequency range of 20 ~ 20,000 Hz, but limits on the range of sounds that can be heard increase with aging. In addition, as the aging process progresses, the audible spectrum decreases and the audible range gradually decreases from the high frequency end [11].

Hearing loss is classified into various types according to cause and phenomenon. In this paper, we investigate hearing loss caused by car audio equipment. If hearing loss is caused by a loud noise, it corresponds to noise-induced hearing loss, which is one of the sensory nerve impairments. Sensory neural deafness is the result of damage to the inner ear or the cochlea, and is caused by such factors as aging, continuous noise, or drugs, and even if the cause is removed, the damaged to the cochlea and inner ear is not easily restored [12].

Noise-induced hearing loss occurs when a person is exposed to large sound pressure for a long time, and the hair cells inside the cochlea are damaged, resulting in hearing ability being lowered. Noise-induced damage of hair cells affects the outermost hair cells near the fenestra ovalis of the cochlea, and sound gradually becomes inaudible from the high frequency to the speech band (250~8,000 Hz) [12].

The auditory hair cells are capable of regenerating, so that temporary damage can be recovered, in part, within 24 hours and overall within 72 hours.. However, permanent hearing loss i may occur when the ability to regenerate hair cells significantly decreases, as when transient hearing loss is repeated frequently. Table 1 shows the allowable listening times per day according to the sound pressure levels specified in the Occupational Safety and Health Administration (OSHA). Exceeding the times allowed for sound pressure levels can damage hair cells and cause loss of hearing [9].

(Table 1) Allowed Hearing Time by Sound Pressure Level [9]

Sound Pressure level	85dB	90dB	95dB	100dB	105dB	110dB
Aloud time	16H	8H	4H	2H	1H	0.5H

3. Measuring of car audio sound and result

3.1 Noise measuring environment and measuring method

This experiment was performed on 3 different Recreation Vehicle(RV) models, all of which were made in Korea, with average ambience noise of less than 30dB. The temperature both inside and outside the car was set to 15~17℃, and the humidity was set to 40%. IoT (Internet of Things) sensors were placed onto 5 different headrests on seats in the car prior to measuring the sound quality of the audio system. They were positioned to be similar to the position of people in a car's ears. The low frequency sound field was analyzed around 22 KHz sampling and 16 bit/sample. White sound was used for the input of the audio system.

The function of the acoustic IoT sensor used in this study is to capture sound generated in the vicinity of the device and convert the sound information into electric signal form. The controller determines the quality, shape, and sound field formation of the received acoustic signal and prepares for active control. Then, the controller and the sound equipment of the vehicle respectively reproduce the necessary sound pressure for each part. At this time, the range of the sound that can be collected should be 20 Hz-20 kHz, which is beyond the range of general human auditory characteristics [11]. However, the measurement and control range in this study is 200Hz – 11kHz. This range is used to control the amount of data to be processed and computed as the number of sensors increases while the number of sensors used for general sound control is two. In addition, when considering the human auditory sense , the control is performed at the sensitive portion of the auditory sense characteristic for performance improvement.

In this study, by improving frequency flatness by analyzing the frequency response, it is possible to ameliorate the negative effects arising when energy is concentrated only in the specific frequency band when the sound is heard by the corresponding equipment. This is known as a sound device [12]. In addition, the frequency flattening of the acoustic equipment using the IoT sensor performed by the present invention can improve not only the performance of the acoustic device by considering human auditory characteristics, but also the performance of smart systems for preventing hearing damage and reducing the influence of the noise caused by vehicle operation. It is fundamental research.

In order to receive the sound signals of the audio system, an IoT sensor, which was developed by the Sori Sound Engineering Research Institute at Soongsil University, was used. The IoT sensor is a sound data acquisition device, which was designed to function both online and offline. The sensors can be both calibrated with a monitor speaker, and synchronized with the sound of peak and pulse.

Calibration and input for the car audio system used in the experiment was prepared in order to measure its frequency response by using white sound. The prepared sound sources were played at 25%, 50%, and 75% of the maximum sound capacity of the car audio system. Lastly, the sound pressure level was measured by both the IoT sensors and noise-measuring-device, which was developed by N company.

3.2 Measuring the result based on sound pressure level

The data obtained from the measurements of sound pressure level were as follows:

1) Measurement of signal to noise ratio (SNR) by comparing the sources of sound and noise.
2) Identifying whether it creates potential noise hearing impairment by measuring the volume of the sound pressure level.
3) Finding the minimum necessary SNR for both smooth communication and listening to music, and estimating the sound pressure level that can be generated from the car audio system.

The experiment was performed in a parked car. Also, the SNR of the car audio system was measured with the ignition switched on and off, respectively. The potentiality of passenger’s noise hearing impairment was determined through the measurement of the sound pressure level both inside and outside of the car.

The average sound pressure generated from the ignited engine was +35㏈. Sound generated from the engine was delivered to both the inside and outside of the car through the engine room. About +18㏈ was delivered inside the car, and the rest of the sound pressure, which was generated from the engine, was diminished by either sound absorption/ insulation materials inside the engine room or inside the vehicle. The measured value for this was -17dB. In other words cognitive SNR becomes 18㏈ while the car is ignited. If the SNR falls below 18dB, it influences the passenger with noise from the engine. As a consequence, it lowers passenger’s cognitive abilities.

Based on the measurement results and masking theory, one of the auditory features of humans, it is possible to calculate the amount of noise generated from the engine. The audio sound that is additionally required in order to avoid passenger’s cognitive ability decrease can also be calculated. The minimum SNR for this is 15㏈. This implies that when calculating noise and the amount of sound pressure, the influence of noise can be ignored above this SNR level in terms of auditory features. Based on this, the minimum sound pressure level of a car audio system with ignition and without ignition can be determined. That is, to make an SNR of 15dB, ambient noise of 30dB was added by influence of noise inside the vehicle from the engine noise of 18dB. Thus, the car audio system should play at at least 50dB sound pressure level. Apart from the SNR ratio, a factor that needs to be examined is the basic dynamic range of the music and the voice. In the case of a sound source with a wide dynamic range, the biggest disadvantage of a car audio system is that sounds that reach a high volume range become very annoying to listen to, and they have a s high possibility of causing noise hearing impairment.

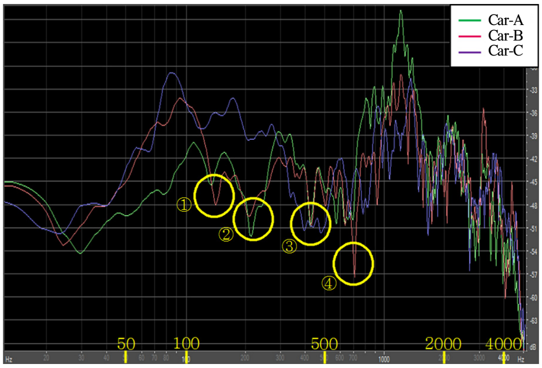
Table 2 shows average sound pressures which were generated from the audio systems in car-A and car-B. The sound source used in this experiment was white noise. For 75% of the maximum sound level, car-A had 86dB and car-B had 92dB. Based on OSHA regulations, 92dB size is analyzed as a loud sound where noise hearing impairment appears abruptly when played between 4 to 8 hours.

(Table 2) Average sound pressure level from car audio

CAR	Car A		Car B	
Engine condition	without ignition	ignition	without ignition	ignition
background noise	35	54	37	55
Vol. 25%	64	68	71	71
Vol. 50%	74	78	83	84
Vol. 75%	84	86	91	92

3.3 Frequency analysis using white sound

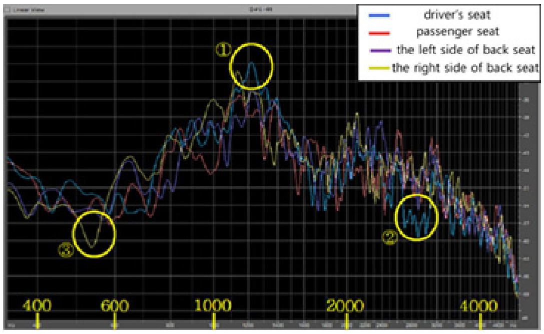
Frequency analysis of sound pressure helps in clarifying the frequency flatness features of audio devices [11]. The main feature of frequency flatness is checking whether the input sound of the device, or the intended voice of a person is represented linearly without any sound distortion [11]. If the intended frequency range for a certain purpose is not set, frequency flatness becomes high. However, a good audio system should be able to play sound sources smoothly across all the frequency fields. The sound source used in this experiment is white noise which has the same energy distribution across all the fields [11].



(Figure 3) Frequency response of Driver's seat

To identify the frequency response of each car audio system, white sound is played and average frequency distribution which was measured from each car analyzed. Figure 3 the frequency responses from the driver's seat in car-A, car-B, and car-C. Car-B had a low response in 150Hz and both car-A and car-B had a low response in 220Hz. As 150Hz and 220Hz fields are the fundamental frequency bands for the human voice, if a low frequency response is shown in these bands, it means that sound recognition is also very low. Car-C had a low response in the 450Hz range. This range is the fundamental frequency band for young children. This means that if the voice of a young child is generated in this range, sound recognition decreases. In terms of car-B, the frequency response in 700Hz dropped rapidly. The 700Hz range is the first formant for /a/ pronunciation and thus, when an /a/ sound is generated, there is a problem of this sound potentially being heard differently.

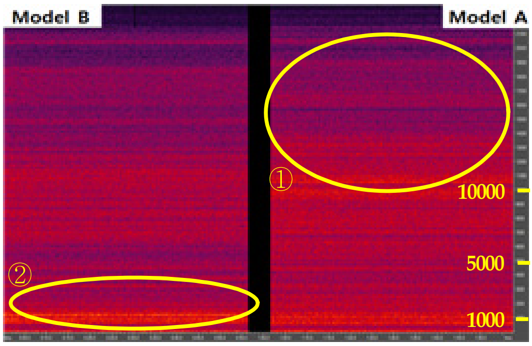
Based on a frequency analysis from the 3 different cars, average acoustics by seat in car A was analyzed. The data was collected from 5 different positions in a 5 passenger car. The middle seat in the second row was excluded from the experiment since people generally prefer not to sit there. The data for 5 different positions were collected from two seats in the first row - both the driver and the passenger side, and three seats in the second row. Figure 4 shows frequency response by each seat in car A. The driver's seat has noticeable energy in the 1200Hz range. This range is highly sensitive to the human ear but if sound in this range is amplified abnormally compared to the other ranges it might be annoying to the ear.



(Figure 4) Frequency response of Each seat

On the other hand, a low response is observed in the 2700~3000Hz range, and this range is more sensitive than the 1200Hz range. The difference can be identified from the fine perturbation and distortion between the frequencies. If the frequency response is low in this range, sound might not be heard clearly. Also, in general, if frequency response is flat in the low frequency sound field, the quality of sound increases. In the case of the right-side seat in the second row, the energy response is shown as low in 527Hz, which is the basic frequency range for young children's voices. If a child's voice is heard from the audio system, a passenger sitting in this seat may have trouble in recognizing the sounds clearly.

Analysis by different cars and different seats were carried out along with a spectrogram examination. Spectrogram analysis was performed for cars A and B. Figure 5 shows a spectrogram analysis between these two cars. Car A has a relatively more even distribution of sound pressure than that of car B in high frequency over 10,000Hz. Car B, excluding the relatively strong energy factors in the120Hz band, has a flat frequency response across all the frequency ranges in general. Car A has a rich sound volume in general, and is better for listening to music since the spectrogram shows less decreases in its high frequencies.



(Figure 5) Spectrogram compare between A and B

4. Conclusion

Technological improvement in automobile manufacturing changed the function of vehicles from simple transportation tools to cozy and happy places for mobility. Consumers prefer cars which are quiet, vibrate less, fast, comfortable, and entertaining. Apart from the basic function of the vehicle, which is a transportation tool, people have started to place various demands on car entertainment systems such as built in audio systems, or DMB. In response to this, automobile manufacturers are trying to incorporate their demands into the products. Among these various demands, the sound characteristics of car audio systems is one of the most important factors for measuring the functions and consumer's satisfaction levels with cars.

Instead of incorporating car audio systems with high priced amplifiers and speakers, providing high quality sound at a reasonable price by analyzing hearing features and frequencies would help to satisfy a great number of consumers.

Based on the analysis of three different RVs (Recreation Vehicles), it was found that the characteristics of frequency response were not flat and stable. In other words, some high and low frequency responses were found.

A low frequency response in the low frequency band field of a car audio system negatively influences voice recognition because it includes fundamental frequency and formant frequency range.

Thus, increasing frequency response flatness by taking the human auditory field into account is required when designing a car audio system for the future.

In addition, it is necessary that studies are undertaken on the measurement of sound fields using IoT sensors, and automation of audio sound quality enhancement. Detailed information about consumers including their preferences, hearing health, age groups, gender, etc. are also needed. Further studies investigating adopting human being's equal loudness contour and tuning technology on audio devices are also recommended.

Furthermore, both numerical adjustment in time and frequency hybrid domain, and emotional evaluation has to be performed to reflect high quality sound.

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