Design of an Intelligent Robotic Audio System for Smart Home Environment

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ABSTRACT

We are not far from having everything in our homes automated including a smart audio system. As we explore the possibilities for smart audio systems, the findings will not only enhance a listener's listening experience but also push Home Audio Systems to the next level of development. More specifically, the issue with the present Home Audio Systems is that they are static and are not capable of directing sound towards the listener's location.

In pursuit of a solution to this issue we propose an inexpensive yet efficient approach. The Smart Audio System triangulates the listener's location and adjusts the angle of focus of the speaker to point towards the related position of the listener. In order to accomplish this we will be adopting popular indoor location detection techniques. Furthermore, a sensor will be located in the room collecting the location and the distance of the listener.

In the future work we are expecting to incorporate further advancements of the prototype such as the capabilities to interconnect with other systems of the home automation system using the location of the user.

Keywords

Smart Home, Intelligent Robotic Audio System

1. INTRODUCTION

Advancement in modern technology has sophisticated every facet of day-to-day living. With the development of home automation, consumers have high demands to automate the functionality of common household appliances. Home automation is a system to program, automate, and control a variety of home appliances for enhanced functionality.

Home automation has existed since the 1980's with the aim of providing security, convenience, and personal comfort. Earlier devices like Life Alert [3] introduced in the year 1990, entailed the user wearing a pendant around the neck to allow the user to conveniently alert a central response center when he/she experiences an emergency.

Home automation using sophisticated sensors has seen a huge growth after the introduction of Life Alert. Other examples of home automation systems include; automated light fixtures, automated air-conditioning systems, and automated garages.

As for a brief outline of this paper, the order will include: State of art, System architecture, Implementation, Discussion, and then the paper will conclude.

2. STATE OF ART

Over the years both the audio equipment and home automation companies have strived to make a considerable impact to the listener's overall experience. With all the advancements in these two fields this paper focuses on the shortcomings that both industries have yet to explore.

From our research on the audio equipment industry, we found that a tremendous amount of effort has been focused on delivering sound to a specific "static" location. Our team wants to keep the extraordinary sound delivery techniques and address an unexplored issue. The issue to be addressed is to deliver the optimum listening experience to the listener on the move in the room.

When discussing the advancements in the home automation industry, we noticed a great deal of research has been done to locating a users' specific position in a room. Even though studies have come a long way there is not much focus towards pinpointing the exact location of the moving "dynamic" person in the room. We have researched many different techniques to discover a person's location. However, as the person changes locations we have not found enough research that is capable of tracking the users movements. The next paragraph will go into details regarding the audio equipment industry and then the paragraph following will discuss the home automation industry shortcomings.

There is a need in today's audio equipment industry; with the current static state of sound delivery, we noticed that a user deserves to hear extraordinary quality of sound at any location in the room. One example of a company who has been known for setting the industry-standard is Dolby Digital [2]. Dolby surround sound audio codec is designed to deliver multiple channels of audio to many popular forms of entertainment including DVDs; Blu-ray Discs; cable, broadcast, and satellite TV programming; PCs; and even video games. Seeing as how Dolby has been one of the greatest things to happen to the sound delivery industry; still, there is a missing element. This element includes delivering optimal sound to a listener who is constantly moving in one room. As for another example in recent years the company Bose has been known for their ground breaking research and producing superb quality audio speakers. Bose Corporation recently introduced their "phase guide" and "room match" technologies. [5] Essentially the "phase guide" technology is using Parametric Arrays to direct sound to a specific portion of the room. [6] The "room match" technology requires the speakers to be installed in precise location according to the dimensions of the room, which in turn delivers absolute greatness. Although both technologies create an exhilarating listening experience the technologies still falls a step short from actually identifying where the moving listener is located in the room.

Automating the functions of everyday home devices is the sole reason of home automation systems. Inventor Deok-Jae Lee has

produced a home automation system that is capable of controlling the temperature, flow rate, and air conditioner delivery [4]. This is achievable by the system using multipoint sensors to divide the targeted area into individual zones. Once the user is found in a zone the controller is capable of altering the temperature for that specific zone. This technique allows for users to be identified by a zone in the room, it does not focus on the precise location of the user. Another example of recent home automation user location technology, Patient US6912429 [1], includes occupancy sensors. These occupancy sensors use an exit/entry strategy for detecting movements through the doorways as well as a spot sensor strategy for detecting the specific locations within a room central controller communicates with both sensor strategies over a communication network. These sensing strategies have not been extended to home audio systems. The exit/entry strategy would prove to be useful and only limited to when determining when a user has walked through a doorway. As for the spot sensor strategy, it is limited as well in the audio equipment industry considering the fact that the user has to stand in a specific spot in a room when the challenge is keeping track of the user moving around the room. The last paragraph of this section will conclude.

In conclusion, as you can see in the above review of literature, both older and recent technologies developed to optimize audio systems and home automation is lacking a key component to further advance the user's experience. Overall the ultimate goal of our research is to explore the possibilities of both adjusting the volume and rotating a speaker to create an excellent automated listening experience.

3. SYSTEM ARCHTECTURE

3.1 System Overview

In Figure 1, the home automation system is a system that functions alongside many other subsystems to provide various automated functionalities, thereby making the home conditions sophisticated with automated features.

In figure 1, the system controllers control the subsystems controller that is connected to the main system. The subsystem controllers control its specific subsystem. The specific system controller controls those specific functions of that system. In this case we see the system controller controls the audio system controller that controls the functions of the audio system.

As the subsystems in figure 1 require communication to the main system, we find there is a need to look into the architecture of the main system. We need to send the information back and forth from the main system to the device to make the functions automated. The main system functions like the brain, which controls all other functions of the system. To communicate with the main system we need an interface. We use Wi-Fi to connect subsystems to main system over the network.

The network controlling component as in the figure 1 diagram of the main home automation system controls the communications to the subsystem over the network.

The device controlling components control the functioning of the smart devices that need to correspond to the functions from the main system.

The intelligent component analyzes the data and justifies the action to be taken and delivers it to the smart components to allow the user to feel it is automated. The intelligent component of this system takes the information from the devices of the subsystems and analyzes the data and justifies the action to be taken according to the conditions set up and delivers it to the smart devices to allow the person to feel it is automated. The cased based part and the reasoning part of this intelligent component makes the function act accordingly, e.g. the brain acting to a situation.

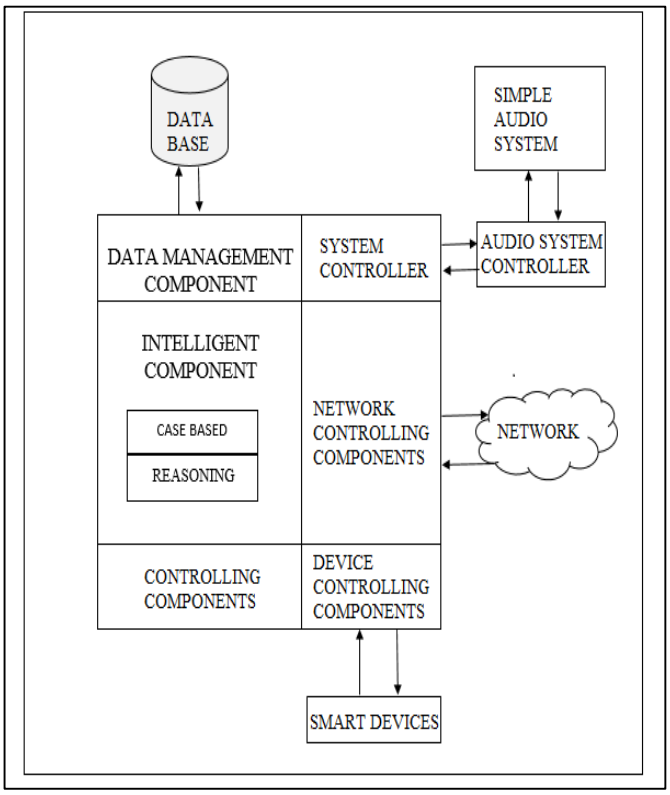

Figure. 1 Main Home Automation System Architecture

The Data Management component allows the system to manage the data that has to been placed in the databases for various functions. When data is needed the component manages to call for the data and also maintains the data in the database.

The controlling component controls the functioning of the main system. This component allows to combine the information passed along the different components in the main system and responds accordingly making the main system control to function efficiently. Thus the main home automation system controls all other systems of the house acting like the central main control.

3.2 Electrical Architecture

Now as we look into the smaller picture, the home audio system of the main system. In this simple audio system, which is a subsystem of the main home automation system, we see there are many electrical components that are used to play music. We need to set up connections from the audio system to the main system. Once the main system activates the audio system the control is passed onto the controller of the audio system by using Wi-Fi; communicates to sub system.

The Simple Smart Robo Audio System (SSRAS) has the following physical electrical components that are visible to the user: speakers, sensors, and servomotors.

As you can see in figure 2 the speaker is attached to the digital amplifier that amplifies the signal received from both the Pulse

Width Modulator PWM (Φ) and the digital to analog convertor. The PWM (Φ) is used to synthesize sound (music) controlling the sound (pitch) that adds to provide a rich sound effect. The Digital to analog converter converts the digital signal to sound signal and makes it audible to the listener. The speaker gives out the amplified sound signal of the PWM (Φ) and the digital to analog converter.

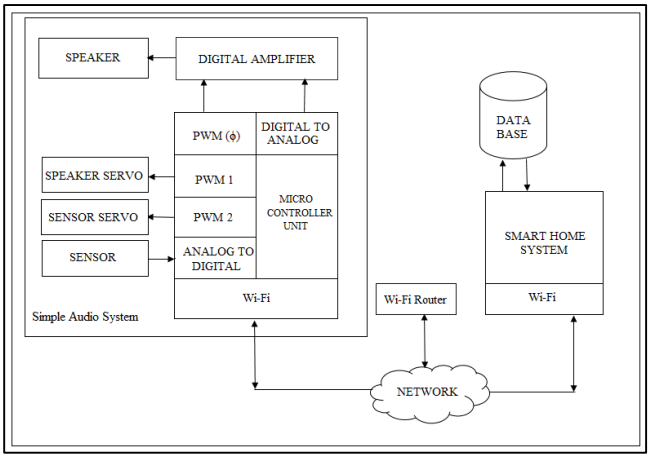

Figure. 2 Electrical Architecture of Simple Smart Robo Audio System

The servomotors on which the speaker and sensor are mounted are attached to the Pulse Width Modulators PWM1 and PWM2 respectively.

The Pulse width modulators are used to allow the controlled flow of power supplied to electrical devices. In this case we use the pulse width modulators to allow the controlled flow of power supply to both servomotors. The pulse width modulator PWM 1 serves the motor on which the speaker is placed. The PWM 2 serves the motor on which the sensor is mounted.

In figure 2 the sensor is connected to an analog to digital converter to send its sensed information in the form of a digital signal to the controlling unit for further action to be taken corresponding to the sensing information received.

The micro controller controls all the pulse width modulators, the digital to analog, and analog to digital converters. This then establishes a connection with the system controller of the Main Home automation system over the Wi-Fi interface.

3.3 System Process Architecture

Figure 3 shows how the home automation system is the central system that controls various subsystems e.g. audio system, air conditioning system, temperature control system, and etc. The system controllers help in controlling the subsystems thereby allowing the functions of the home devices to be automated according to the desired conditions. For example the air conditioning in the room is maintained by sensing the person in the room and depending on the temperature detected it adjusts the air conditioning of the room either to hot or cool depending on the conditions set up. The subsystems interact with the main systems through interfaces and act in response to the conditions that are set up at the central main control. The system controller collects and processes data through the intelligent component of the main system.

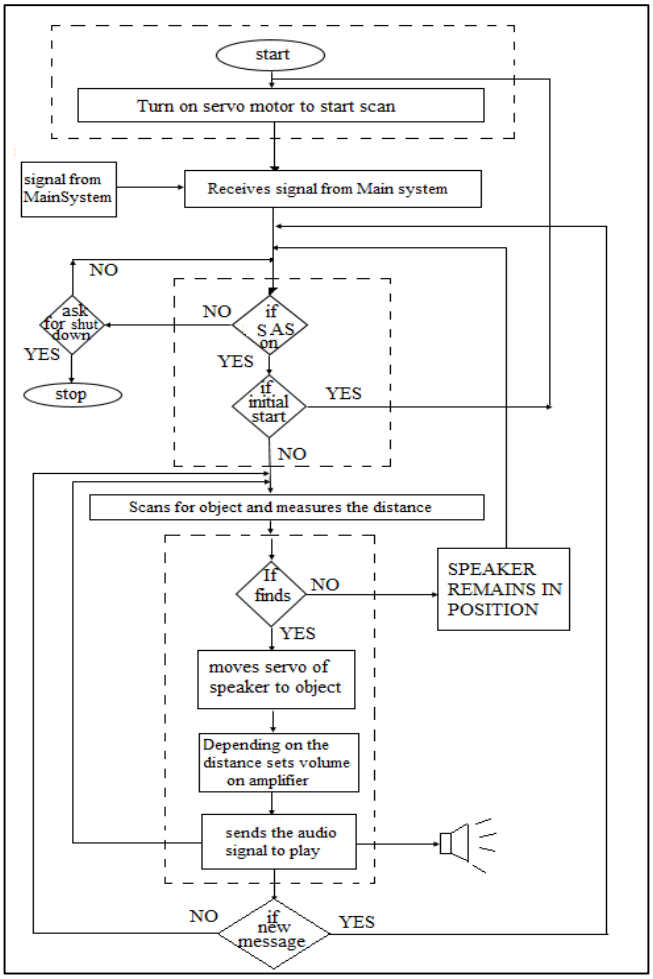

Figure 3 System Process Architecture

In this paper we talk about a subsystem; the Simple Smart Robo Audio System that interacts with the main system and responds in accordance to the position of the person in the room. It detects the position of the person and directs the speaker towards the listener. The person at home who desires to listens to music can move around the house and still feel the rich sound in any part of the room and even in any room while the person is moving. When the person turns on the audio system, the main home automation system notifies the audio system to be turned on. On receiving the notification from the main automation system, the simple smart audio system checks if it is the initial start or if it has started previously. If it is the initial start this system observes the initial conditions and activates the servomotor on which the sensor is mounted and as well the sensor starts sensing. The rotation movement of the servomotor allows the sensor to sweep and scan all over the room for the exact position of the listener.

When the sensor detects the listener's position in the room it instigates the servomotor on which the speaker is placed directing the speaker to the position of the person; thereby enabling the listener to have the best and desirable rich sound clarity. This scenario is extended as the listener moves to whichever room. By doing so we allow the system to track the position of the listener and the speaker on the servomotor follows the listener.

The servomotor on which the speaker is placed notices the detected condition of the sensor and its position and moves it to the position of the servomotor on which the sensor is mounted. The speaker stays in that position until the sensor detects another position to which the listener has moved. A check is then carried out to find out if there is any change in position of the user.

When the sensor that is sweeping through the room finds the new position of the listener, the speaker is directed to the listener. If the position of the listener is not found in the room, the speaker remains in the previous position and checks if the smart audio system is still turned on by the main system.

If the audio system is still turned on it continues the whole process once again. From the start it checks for the position of the listener and if it finds, it directs the speaker to the listener. However, if the audio system is turned off by the main system, it then shuts down.

4. IMPLEMENTATION

In this paper, we are focusing on proof of key concepts through this prototyping of Smart Robo Audio System. Thus we implement our system on miniature sized of testbed room (80cm x 80cm).

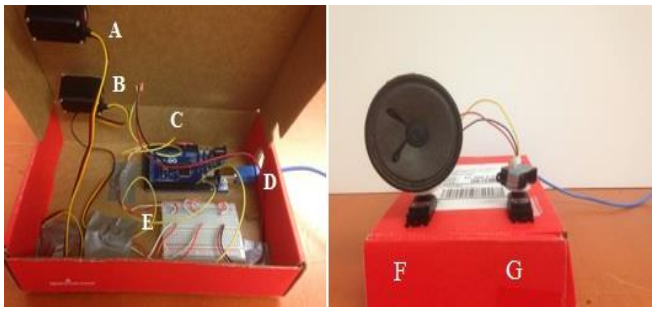

Figure 4 Smart Robo Audio Prototype

In this prototype, we used six major components, Analog servomotors, IR sensor, Arduino Mega 2560, breadboard, and fake speaker shown in figure 4. Two servomotors (A, B) are connected to the Arduino board (C). The USB cable (D) is used to supply power to the Arduino and the breadboard (E) is used to extend the positive and negative connections. The IR sensor (G) is connected to the servomotor (A). The speaker (F) is mounted on servomotor (B).

In our prototype to detect the position of the listener in the room we require a sensor. The IR Sensor we used is capable of sensing only a certain range (80cm), which can cover a miniature room. In order to cover a wider region we mounted the sensor on top of a servomotor (HS-422) that rotates allowing the sensor to sweep and sense the whole room. The IR sensor scans 180 degree with 1 degree unit. As shown in figure 5. we see that the IR sensor is in different direction. 5a shows the IR sensor sensing in the leftmost region, 5b shows it sensing in the middle region and 5c shows it sensing in the rightmost region. During this scanning procedure, the system updates the map of the scanned area for detecting user's location.

The scanning function is to gather the sensed information and passes the analog signal of the IR sensor to the analog to digital converter of the Arduino. On receiving the information from the IR sensor the Arduino performs two main functions. First, it calculates the distance and position of the listener. Secondly, checks for the preset conditions in the program. During this scanning procedure, the system updates the map of the scanned area for detecting user's location.

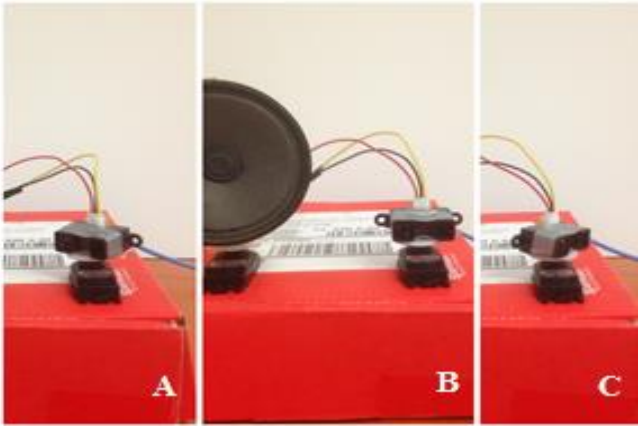

Figure 5 Scanning for localization of user position

Based on the distance from the listener, the volume is estimated. For the volume to be sent out of the speaker it is passed over to the digital amplifier to reach the speaker. Based on the position of the listener in the room, the Arduino responds by altering the direction of the speaker towards the listener as it is programmed in the Arduino.

In our small-scale demonstration of the scenario we use small robot acting like the presence of the listener in the room as shown in figure 6. When the listener is detected, the speaker's direction is autonomously changed for the listener by rotating the speaker servomotor. As shown in figure 6a we see that the robot is in the extreme left position and the speaker is directed towards it, and in figure 6b we can see that when the robot is moved to the middle of the room, the speaker head to the position of the robot. And lastly the speaker is directed to the robot at extreme right position

This scanning procedure is continued for updating the user's location and giving out the volume based on the distance from the speaker.

In this demonstration we prove the Simple Smart Robo Audio system can detect the user's location and directing the speaker and adjusting the volume so that the user can receive a rich and same quality of music in smart environment.

Figure 6 Demonstration of Smart Robo Audio

5. DISCUSSION

We look into the smaller picture of the home automation system, which is the smart audio system. We consider the sensor to scan the position of the listener to direct the music. We are acknowledging

that we can improve the detection with better methods of sensing using better sensing devices, the Xbox Kinect has advanced sensing capabilities and can be used to gather more accurate data about the users location.

We consider a single listener is in the room and still plan to investigate complications and functioning of multiple listeners. We need to take into consideration, multiple speakers and how we can implement this concept.

We can complicate this concept with the use of the artificial intelligence and permitting this system to interact with the other subsystems of the home automation system.

We also plan to implement automated volume control. Since we did not implement a working speaker we were unable to demonstrate increased or decreased volume depending on the distance of the user.

6. CONCLUSION

Home automation is drawing more attention. The smart audio system works to allow a better functioning of the existing audio system by focusing the sound directly to the listener rather than just improving the quality of the sound and making it have good and rich effects. We have proven a working concept by implementing techniques to show a good impact of sound to the listener. For future work, using this concept we can extend the technology to a clarity sophisticated condition where we can utilize the artificial intelligence to direct which song to be played depending on the mood of the user.

7. ACKNOWLEDGMENTS

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