Integration of ReM-AM in Smart Environments

GABRIELA SANTIAGO, JOSE AGUILAR
CEMISID, Dpto. de Computación, Facultad de Ingeniería
Universidad de Los Andes
La Hechicera, Mérida Edo. Mérida
VENEZUELA
gabrielas@ula.ve, aguilas@ula.ve

Abstract: - This paper presents the detailed architecture of the Reflective Middleware for Acoustic Management called ReM-AM, which is based on an extension of the AmICL architecture. This extension consists in a new layer, called AML (Audio Management Layer), which is composed of a Collecting Audio Data process (CAD), an Interaction System-User-Agent (ISUA), and a decision-making process (DM). ReM-AM aims for the improvement of the experiences and capabilities offered by the Smart Environments from the acoustic perspective. Additionally, for the definition of this middleware, this paper presents the autonomic cycles of tasks of analysis of Audio Data that will make affordable the acoustic comfort in a smart environment, supported by ReM-AM.

Key-Words: - Acoustic, Autonomic Cycle, Data Analysis, Reflective Middleware, Self-Management, Smart Environment.

1 Introduction

In a smart environment, all the information about what is happening there can be used to improve its effectiveness. From the acoustic perspective, being the sound signals over all the places, it is important to obtain information from acoustic signals to manage the behavior of the environment.

In this work a middleware is extended to use the acoustic information in a smart environment to generate new experiences for the users, taking as a start point the identification of sound interactions, in order to analyze and make decisions that will end up in a different ambient in terms of acoustic comfort.

The Reflective Middleware, called AmICL, uses the principle of iCloud Learning [1, 2, 3] to modify the behavior of smart classrooms, depending on its requirements. In this paper, AmICL is extended with acoustic software and hardware components, in order to modify the behavior of any smart environment, not only smart classrooms, by using the acoustic information and sound interactions. This extension helps to improve the experience of the users of Smart Environments (AmI) by observing, modifying and interacting with acoustic signals.

This extension is called ReM-AM, which is based on an Audio Management Layer (AML) that is aware of the unpredictable situations due to sounds and vibrations in an AmI, and is able to recognize acoustic signals, process them, analyze them and interact with them [4]. Particularly, ReM-AM is composed of a Collecting Audio Data (CAD) component that creates the metadata about the perceived sound information and will categorize every sound event, an Interaction System-User-Agent (ISUA) that identifies and analyses the acoustic signals to determine the interactions that take place in the AmI, and a Decision Making (DM) component that adapts the AmI from the acoustic standpoint.

Additionally, in ReM-AM, a set of autonomic cycles of tasks of Audio Data analysis are implemented, which are carried out by its components, working together to reach collective goals. The concept of "autonomic cycle of data analysis tasks" has been proposed in [5, 6], which is a type of autonomous intelligent supervision that allows reaching strategic objectives around a given problem. The autonomic cycles integrate a set of data analysis tasks, which autonomously and collectively work to achieve the strategic objectives pursued by these cycles [5, 6]. This set of tasks interacts with each other, and they have different roles in the cycle: Observing the process, analyzing and interpreting what happens in it, and making decisions about the process that allow reaching the objective for which the cycle was designed.

ReM-AM has a set of autonomic cycles with the goal of managing the behavior of acoustic waves in an AmI, making an intelligent analysis of the sound events and creating the possibility of artificial perception, in order to change the acoustic atmosphere in an AmI.

In the literature, the works closer to our proposal are: In [7], Wang presents a model for sound

classification and analysis using deep learning, to improve hearing in hearing-impaired people. In [8], the authors present a social machine implemented as a Multiagent System (MAS) to define specialized roles in the creative process for the transformation of a picture into sound. In works as [9] systems for audio recognition are presented, which identify environmental sounds to detect alterations related to cognitive capabilities in the individuals in the environment. Also, Tremblay et al. [10] propose the design of a smart room based on acoustic detection and voice recognition, including the analysis of sound frequencies, being its main benefits its adaptability and the invisibility. On the other hand, [11] proposes an approach to identify random sound events in a room with acoustic sensors. Finally, real-time processing of the sound is analyzed in [12, 13] in the context of the interactions of users and acoustic agents in interactive platforms.
The next section presents the AmICL middleware and the concept of acoustic science. The next section presents our extension to AmICL, called ReM-AM. Section 4 specifies the autonomic cycles involved in the acoustic management in ReM-AM, and finally, the last section presents examples of application of ReM-AM.

2 Theoretical Framework

2.1 AmICL
AmICL is a reflective middleware, which uses self-awareness and self-reference to change the behavior in a smart classroom, in order to follow the requirements and needs of the environment. It is based on an introspective process to observe and reason, and in an intersection process to modify its state or structure, and adapt it to the context. AmICL has two levels:

- The base level: It is the level where the applications/devices are, and where the functionalities and services are executed. At this level, the process of intersection to modify the state and the structure of the environment is developed.
- The meta level: At this level, the reflective capability is located, to observe and reason about the states of the applications and devices, and determine how to adapt them. Also, in the meta level is located the capability to develop computational systems that are sensitive to the ambience.

AmICL is based on the C-Learning paradigm [1, 2]. It uses digital resources from the Internet to improve the learning process in the smart classroom. For that, it uses the adequate tools and services in the cloud in order to adapt a smart classroom. Specifically, AmICL combines educational services available in the cloud with intelligent or non-intelligent objects in the smart classroom, to adapt the learning process to the student's preference.
The integration of objects with educational services in the cloud is a way to adjust the behavior of the objects to the requirements of the users and the context of the AmI. Fig. 1 shows the architecture of AmICL, a Multilayer architecture that includes: a Physical Layer (PL), a MAS Management Layer (MMAL), a Services Management Layer (SML), an AmI Logical Management Layer (ILL) and an AmI Physical Management Layer (IPL). They have been described in detail in [1, 2, 3].

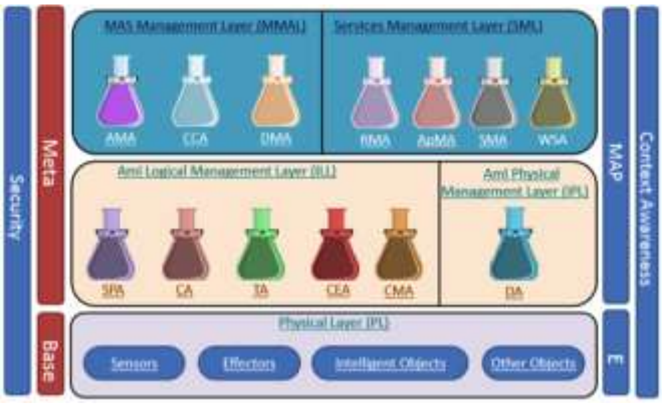

Figure 1. AmICL, proposed in [1]

MMAL defines the MAS for the management of the community of agents in the smart classroom, defined according to the FIPA Standard [14]. The SML defines the connections between the educational services in the cloud [1, 2, 3, 15] and the agents in AmICL. The ILL contains the software components used in the smart classroom, defined as agents. Some of them are the learning resource repository, the virtual learning environment (VLE), among others. The IPL contains the different devices in the smart classroom, defined as agents (The metadata of the physical devices are defined in the agents). Finally, PL deploys the different devices and software used in the smart classroom.

2.2 Acoustic Science
As explained in a previous work [16], the behavior of an acoustic wave depends not only on its own features, but also on the features of the space where it propagates.
There are some acoustic terms that are especially relevant in ReM-AM [16] to understand the behavior of an acoustic signal and the hearing reaction of the

users of an AmI: the *acoustic field* is the distribution of the acoustic pressure in time and space; the *reflection* is the change of direction of a wave when it crashes with a wall. The *reverberation* is the persistence of the sound after it stops.
On the other hand, the *absorption coefficient* describes how much acoustic energy a material absorbs. The *sound pressure level* is a logarithmic expression used to describe the range of sound pressures in the context of the human hearing (see Fig. 2).

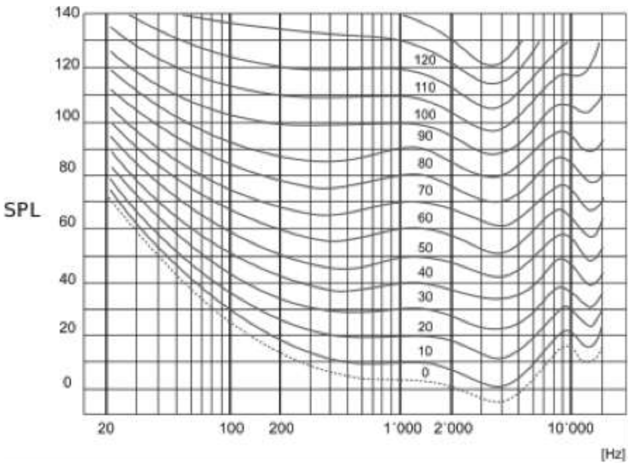

Figure 2. Fletcher-Munson curves, presented in [16]

At the level of the human hearing processing, it is important to define the following terms [16]: *psychoacoustics* is the study of the reactions of the human brain to an acoustic stimulus; *cognitive neuroscience of hearing* is the study of cognitive capabilities using the sound with neurological basis.
These terms are part of the awareness that ReM-AM provides in an AmI.

3 ReM-AM

3.1 Adaptation of AmICL

When ReM-AM is an extension of AmICL, with the same layers of AmICL, but adding some acoustic elements (see Fig. 3). The links to the sound in AmICL are mainly the acoustic sensors in the smart classroom. Theses sensors are deployed in the PL, and can detect the sound in terms of location, sound source, and acoustic parameters.
The SML has a big importance when the acoustic management takes place [1, 2 3], because it allows exploiting the services in the cloud to adapt the acoustic comfort of the AmI to the user's requirements, in order to improve the intelligibility and reduce the noise. In the case of ILL, it contains the software components for the intelligent management of the sound, such as the preprocessing, identification, analysis, interpretation, among other things, of the sound. In general, the algorithms of sound filtering, recognition and learning of acoustic signals, among other mechanisms, required for an intelligent sound management, are part of this layer. One example of software for ReM-AM is the classification algorithm of acoustic signals proposed in [7].
Finally, a new layer is included in AmICL, called Audio Management Layer (AML), specific to ReM-AM. It is located at the meta level of the middleware, next to MMAL and SML, and is described in the next section.

Figure 3. ReM-AM architecture [4]

3.2 AML (Audio Management Layer)

The Audio Management Layer (AML) has three components for acoustic management in AmICL (See Fig. 3). In AML, the components carry out different audio tasks, to react to acoustic events, among other things. Each component in AML has its own behavior, which are integrated together in order to allow the acoustic self- management in AmICL.

- CAD (Collecting Audio Data) component: its aims at obtaining as much information as possible from the sound events that take place in the AmI. It will be in charge of the generation of the audio metadata, working with IPL and ILL for the characterization of the sound objects, and for the definition of their properties. The concrete services that this component will offer are the characterization of sound events and the exploitation of an auditory vocabulary in order to categorize them. The main data structure that will be used for the storage of the sound events is adapted from the work [17] (see Fig.4). This data structure consists of a two-branch hierarchy that separates the sound events in human sources and natural sources. The human sources are human made noises such as speech, machine noises, and also, noises due to the transportation media. The branch of natural sound includes biological and geophysical events, such as the water or wind.

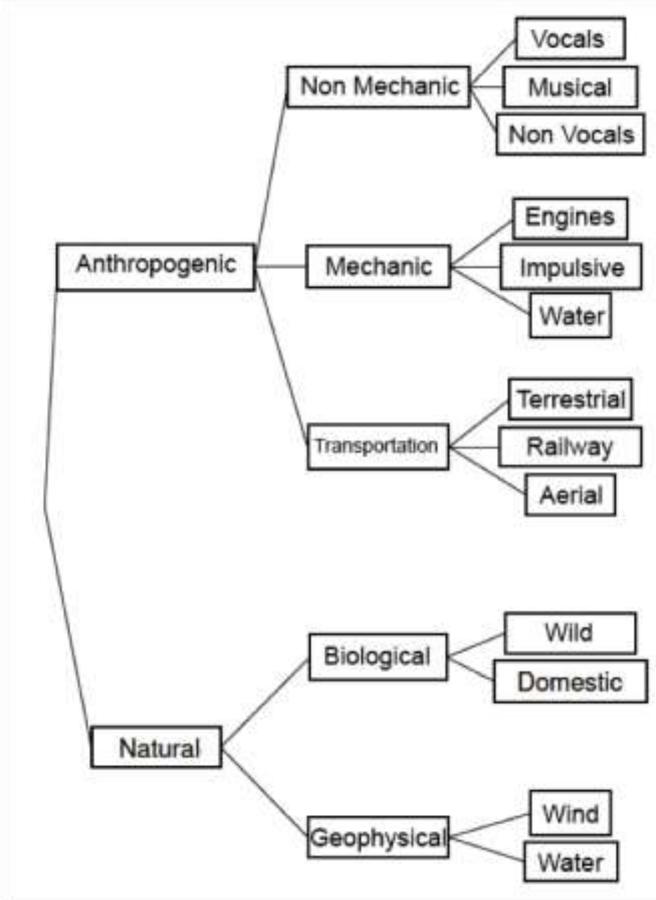

Figure 4. Hierarchical classification structure of sound events adapted from [17]

This data structure is used by the CAD component to identify the sound events, and classify them into those categories. Once a sound event has been classified, its acoustical spectral parameters are defined: loudness, sharpness, roughness, fluctuation strength, speech intelligibility and tonality. At the end, the system will have information about the presumable social-ecological source, and about the event itself.

- ISUA (Interaction System-User-Agent) component: it recognizes the source and defines the tasks according to the acoustic events that take place in the environment. In this way, it identifies specifically the source using the algorithms provided by the cloud, linked to audio filtering and recognition. Particularly, ISUA offers the services of sound pattern recognition and sound smart analysis. In general, the system will be aware of the sound in the AmI due to this component.
- DM (Decision-Making) component: it uses the information obtained by CAD and ISUA, in order to decide the actions to execute in order to acoustically adequate the AmI to the current needs. DM analyses options and decides which one is helpful to complete acoustic optimization of the AmI, which means that its services are related to general acoustic management in terms of absorption, block and cover (ABC Paradigm) [18].

Some of the required services by the components of ReM-AM are of analysis of frequencies, signal recognition, among others.

4 Autonomic Cycles in ReM-AM

As defined in [5, 6], in an autonomic cycle, there are different data analysis tasks that interact with each other, some of them must observe the supervised process, others must analyze what is happening, and others make decisions to improve the supervised process.

Each component in ReM-AM has its own role in an autonomic cycle: The CAD will be in charge of the observation of the AmI; ISUA will be in charge of the general analysis; DM will take the final decision. In general, there are three main autonomic cycles in the ReM-AM.

4.1 General Acoustic Management (GAM)

In this autonomic cycle, the goal is to achieve the comfort of acoustic design following the ABC paradigm [18] (see Fig.5): This paradigm proposes Absorption-Block-Cover as the basis for the general acoustic comfort: the *absorption* of sound waves to control the reverberation of the non-desirable waves, the *block* of the direction that the wave takes in order to control the focalization and the dispersion, and the *cover* of non-desirable noises with noise cancelling systems.

- Observation Phase: in this case, ReM-AM obtains information about shapes, materials, barrier objects [11], absorption coefficients, temperature, air density, quantity of people in the space, among other elements, in order to identify elements that can characterize the acoustic behavior. This phase is carried out by the CAD component, with the help of the elements of PL.
- Analysis phase: in this phase, the information will be classified and the sound sources will be determined. Also, it will be determined the sound to be absorbed, to be blocked and to be covered. This phase can use the linked data paradigm to

enrich this process. This phase is carried out by the CAD and ISUA components.
- Decision-making phase: this phase is carried out by the DM component to improve the actual acoustical situation in terms of undesirable noises. For that, it determines the specific actions to carry out in the AmI.

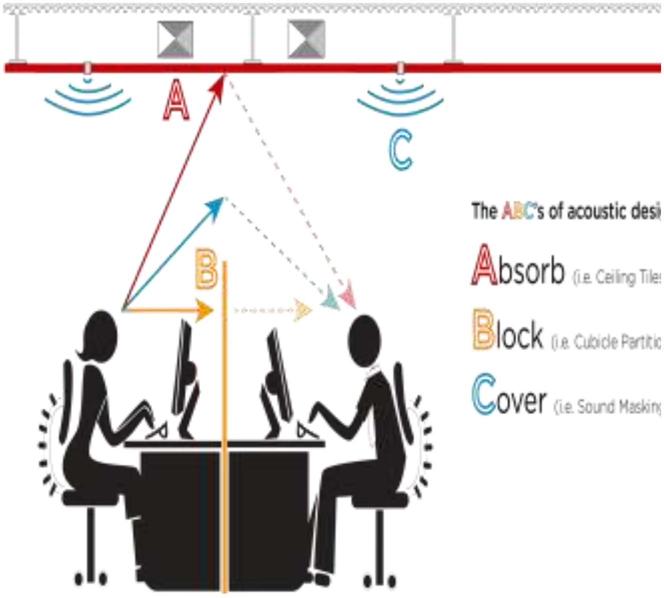

Figure 5. The ABC's of acoustic design [18]

As explained in [18], an optimal acoustic environment should consider a variety of elements to absorb, block and cover the sound; the balance of this treatment reduces unwanted noises and conversational distractions, making the environment aesthetically pleasant. This analysis is made by ISUA. After 'observing' the environment and collecting the information (CAD component), the ISUA component 'analyzes' which is the main source of the acoustic signal and which must be improved. Depending on this, the DM component will determine the different options, such as changing the surfaces of desktop elements, modifying the position of acoustic panels, or changing the frequencies that help with noise cancelling, among other things.

4.2 Intelligent Sound Analysis (ISA)

The goal of this autonomic cycle is to identify the acoustic features of the AmI, and with them, discover the smart environment (a smart classroom, outdoor, an ambient assisted living, an intelligent concert hall, among others) and which possible tasks can be executed in this context.
For that, ReM-AM uses a set of microphones or acoustic sensors in the AmI. The location of microphones will depend on the acoustic features of the space, but must follow the microphone location standard defined in works like [18, 19] (See Fig. 6).

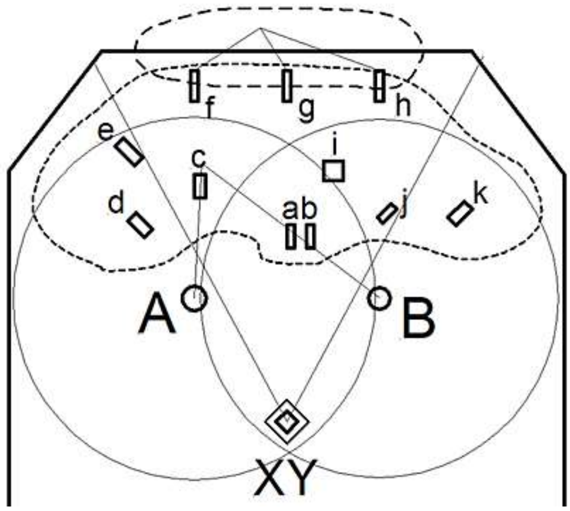

Figure 6. Microphone setup for preserving natural spatial relationships [18]

The 3 phases of the autonomic cycle are:
- Observation phase: the CAD component will use the microphones and acoustic sensors to obtain the sound information from the AmI and its features. It will allow the precise perception of the sound field in the AmI.
- Analysis phase: ISUA component will detect and discriminate sources and users. The detection and discrimination that will possess the system is determined by using recognition algorithms like [7].
- Decision making phase: the DM component will determine the current environment, and additionally, the tasks that can be executed in the current context of this AmI.

4.3 Artificial Sound Perception (ASP)

ReM-AM has an autonomic cycle with the goal of offering an artificial perception of the environment. This autonomic cycle is based on the work presented in [20], but in the inverse way. This work presents a virtual acoustic reality, but instead of generating an artificial acoustic environment, ReM-AM will offer an artificial perception of it. The main contribution will be the knowledge of the behavior of acoustic waves almost in an observable way. It will help with the generation of the sound when it is not in the visual field, or over or under the human hearing threshold.
The 3 phases of the autonomic cycle are:
- Observation phase: the CAD component will locate the sound source to focus on it, and to

identify its features to amplify them, in order to make it possible to hear (Fig. 7).

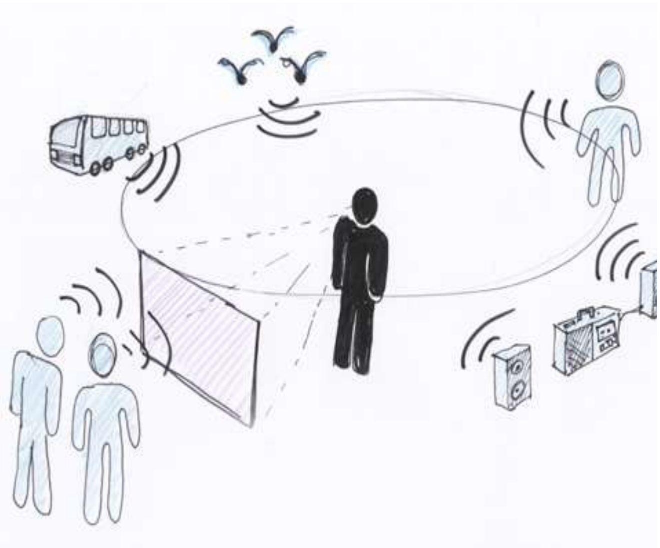

Figure 7. Sound perception and its relation with space [18]

- Analysis phase: the ISUA will determine if the potency of the sound is within human hearing parameters. Were it not to be the case, it will make a deeper scan to determine the parameters that are out of this threshold in order to make them perceptible. In this way, it allows the knowledge of the acoustic features of the sound events.
- Decision-making phase: DM determines the behavior of the AmI in terms of movements, rotations, qualities of its components, to make the sound perceptible.

5 Case Study

To give an example of how to use the autonomic cycles of ReM-AM in an AmI, these are deployed in different contexts: The General Acoustic Management in a Smart Classroom (SaCI [1, 2, 15]), the Intelligent Sound Analysis in a Smart Concert Hall, and the Artificial Sound Perception in an Ambient Assisted Living (AAL).

5.1 GAM in SaCI

Normally, the main problems in SaCI are the internal noise generated by the students and the intelligibility of the teacher's speech. In this AmI, we suppose the presence of a group of students, the teacher, chairs, tables, and different intelligent agents that represent the devices in the smart environment, such as the smartboard, computers, speakers, cameras, microphones. Also, we suppose the presence of acoustic elements, such as panels that can change their ability to reflect or absorb acoustic waves.

With the GAM autonomic cycle, the system obtains information about surface materials (from chairs, tables, walls) through the CAD component (observation phase), to identify which ones could help with acoustic absorption.

Then, the system analyzes, with the ISUA component, which of the remaining frequencies (other than those absorbed) could be blocked using acoustic panels, and which could be masked [21].

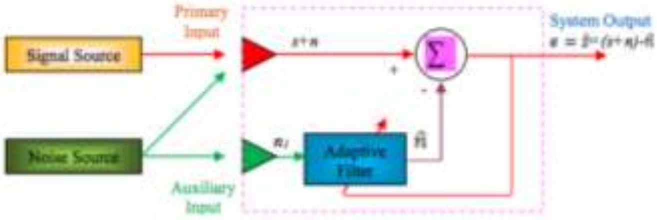

Figure 8. The adaptive noise cancelling concept [22]

In the decision-making phase, with the DM component, the system could select an adaptive noise cancelling technique, like the one presented in the work [22] (See Fig. 8), to get the signal sources in the SaCI, and the noise sources. It uses an adaptive filter that gives an output cover at the remaining noise in the room.

5.2 ISA in Smart Concert Hall (SCH)

In general, in a SCH there are seats covered with an absorbent textile, speakers, microphones, acoustic panels, singers or musicians, music instruments, and the audience. It is also supposed that the SCH has intelligent agents, which represent the component to control the light and temperature. These agents are going to work hand in hand with the acoustic management system.

To make a concert hall more practical during a concert, the ISA autonomic cycle proposes in the observation phase that different microphones located around the hall perceive the acoustic behavior in the room, with the CAD component. The CAD component identifies the sound events. The main sound events are instrument tuning, music being played or singed, and applauses from the audience. Once the system identifies every possible source, in the analysis phase, the ISUA component discriminates every sound event using a classification system like the Hierarchical classification structure found in fig. 4.

Finally, in the decision-making phase, the system (DM component) could use a deep learning algorithm [23] and extract, for example, just the 440Hz (or 432Hz according to the orchestra) tuning frequency from instruments. When the system perceives this frequency, it will send a message to the light actuators to turn off the lights; the signal for the beginning of the concert.

This process could also be used at the end of the concert, but to identify applauses from the audience, in order to turn on the lights.

5.3 ASP in AAL

The ASP will work as an assistant for disable people. Even if the person is in a non-smart environment, the system will be located in an in-ear device, and it will use the CAD component in the observation phase to identify the sound sources of the different sound events around the person.

In the analysis phase, the system will work with the ISUA component to determine if there is a signal that is not easily recognizable by the user. Here, it is possible to consider the critical-band process explained in [24], to solve the cocktail party problem explained in [25]; which consists in the sounds produced by different sources aggregating in the air before entering the ear and requiring the auditory system to infer sound sources of interest from a mixture.

There is a misconception about hearing-loss problems and its relation to sonority levels. Normally, the problem is not the volume, but the frequencies. The system will use the DM component in the decision-making phase to determine if it is necessary to modify the frequencies to make them audible –which it would do on its own –, or if it is just a volume issue and then make it louder or lower.

6 Comparison with previous works

This section presents a comparative analysis with previous works (table 1). We define a set of criteria, in order to compare our works with previous ones. These are defined according to the capabilities of ReM-AM.

The acoustic management system includes acoustic sensors, as presented in [3], to detect the different sound events in an AmI. These sensors can send signals as a direct answer to a command, or can analyze the signals to make decisions in the AmI as in [12].

On the other hand, the emotion recognition as it is presented in [11], will help with the sound adaptation process in the middleware, allowing the anticipation to the necessities of the users.

Another feature is the capability of signal classification and conversion into sound event, as in [26]. This will help to improve the semantic meaning of the event in an AmI. This process can imply contextual awareness for knowledge generation.

To improve the acoustic quality in a room, the middleware will use noise-cancelling techniques, as presented in [7, 10, 22], and will consider the critical bands to solver the cocktail-party effect [25].

The real-time response, as presented in [13], will contribute with acoustic solutions in an AmI when it comes to short-term sound events that have to be immediately addressed.

Work	Acoustic sensors	Emotion recogniti on	Event classificat ion	Knowl edge genera tion	Noise cancelling	Real-time
[3]	X					
[7]		X	X	X		
[10]	X		X		X	
[11]	X	X				
[12]	X		X		X	
[13]			X			X
[22]			X		X	
[25]				X	X	
[26]	X		X		X	
ReM-AM	X	X	X	X	X	X

Table 1. Comparison between previous works and ReM-AM

ReM-AM will use acoustic sensors, with emotion recognition mechanisms and sound event classification mechanisms, noise-cancelling processes, and knowledge generation to give answers in real-time, in order to improve the experience of AmI users.

The system will provide acoustic services to other agents of the AmI, such as acoustic characteristic identification, harmonization of the user's sound perception, among others, and the different agents will use this information to adapt the AmI.

7 Conclusion

This work shows the components of the ReM-AM architecture and its autonomic cycles for acoustic management in smart environments. Additionally, the paper presents the uses of the autonomic cycles in different case studies.

ReM-AM aims at improving the experience of the users of AmIs having as quality criterion the acoustic comfort. Particularly, every autonomic cycle of ReM-AM can satisfy different necessities in different AmIs, but focusing on acoustic improvement. The autonomic cycles are composed by three steps (observe, analyze, make decision), and each step has a ReM-AM component in charge. The autonomic cycles look forward to optimize and enhance the capabilities of an AmI from its acoustical features, considering the acoustic waves as an invisible element that is in constant interaction.

The GAM autonomic cycle is based on the improvement of the user's hearing experience quality. With the autonomic cycle of ISA, the sound events are recognized and classified in order to act in response to them. In the ASP autonomic cycle, a way to make audible the frequencies out of the human threshold is proposed.

Future works in ReM-AM will be about the services required by the autonomic cycles, such as the algorithms for the classification and the analysis of the sound events, among others.

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