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Ontology Driven Architecture for Acoustic Management

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ABSTRACT

The Reflective Middleware for Acoustic Management (ReM-AM) aims to improve the interaction between users and agents in intelligent environments, using acoustic services in a context modeled with multiagent systems. The middleware allows observing, analyzing, modifying and interacting in every state of an intelligent environment from the acoustics. Its architecture is an extension of the AmICL middleware for Cloud Learning Environments, in order to consider the unpredictable situations due to the sounds and vibrations; this work presents an ontology driven architecture (ODA) for acoustic management. This architecture defines the different domains of knowledge requires for the management of the sounds in smart environment, which are modeled using ontologies. There are ontologies in the domain of the acoustic sciences, contextual ontologies, and ontologies that describe the middleware, among others, which are naturally integrated in the ODA for the acoustic management. Finally, the paper presents several case studies in the context of Smart Classrooms and Smart Concert Halls.

Keywords: Acoustic Management, Intelligent Environments, Multiagent Systems
I-INCE Classification of Subject Number: 30

1. INTRODUCTION

In intelligent environments, all the information that can be obtained from the ambient can be used to enhance the behavior of the system and provide services to the users. In this work the Middleware AmICL is extended to use acoustic information to generate new experiences, identifying sound interactions, in order to analyze them and make decisions that will end up in a different atmosphere from the acoustic comfort.
AmICL uses the principle of iCloud Learning [1, 2] to modify the behavior of smart classrooms, but when extended with acoustic software and hardware components, it modifies the behavior of any smart environment by using the acoustic information and sound interactions. This extension is called ReM-AM, and it 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 [3]. It has a Collecting Audio Data (CAD)

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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.

ReM-AM has a set of autonomic cycles that interact with each other 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 this work it is explained the architecture of ReM-AM, its autonomic cycles and the Ontology Driven Architecture for acoustic management in intelligent environments, follow by case study to understand its deployment.

2. THEORETHICAL 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 introspection 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. In this level the process of intersection to modify the state and structure of the environment is developed.
- The meta level: In 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. Specifically, it 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), a AmI Logical Management Layer (ILL) and a AmI Physical Management Layer (IPL). They have been described in detail in [1, 2].

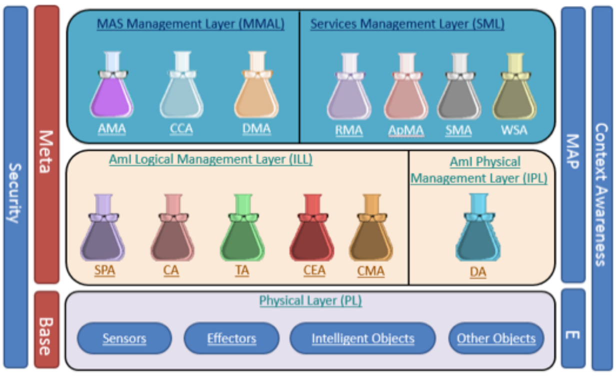

Figure 1. AmICL, proposed in [1]

MMAL defines the MAS for the management of the community of agents in the smart classroom, defined according to the FIPA Standard [4]. The SML defines the connections between the educational services in the cloud [1, 2, 5] 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 resources 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, in PL are deployed the different devices and software used in the smart classroom.

2.2 ReM-AM

ReM-AM is an extension of AmICL, with the same layers of AmICL, but adding some acoustic elements (see Fig. 2). The links with 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], 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 others 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 [6].

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.

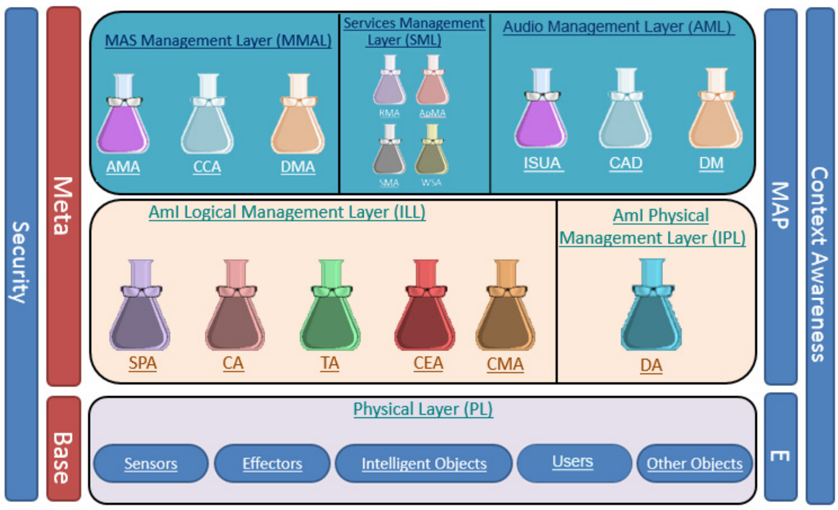

Figure 2. ReM-AM architecture [3]

The Audio Management Layer (AML) has three components for acoustic management in AmICL. In AML, the components carry out different audio tasks, to react to acoustics 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 vocabularies in order to categorize them.

- ISUA (Interaction System-User-Agent): 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 thanks to this component.

- DM (Decision-Making): 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) [7].

2.3 Autonomic Cycles

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:

2.3.1 General Acoustic Management (GAM): In this autonomic cycle, the goal is to achieve the comfort of acoustic design following the ABC paradigm [7], which 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, 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.

As explained in [7], 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.

2.3.2 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 [7]. 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 [6].

-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.

2.3.3 Artificial Sound Perception (ASP): ReM-AM has an autonomic cycle with the goal of offering an artificial perception of it. This autonomic cycle is based on the work presented in [8], 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.

-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.

2.4 ODA Paradigm

Ontology in informatics is the specification of a conceptualization in a machine-readable way [9]. It defines a common vocabulary for data transmission in an specific domain. The components of an ontology are class or type, relations, instances, properties and axioms.

Based on a three-layer approach, the ontology driven architecture provides [10]:

-The Computation Independent Model (CIM) where a system is described from the computation-independent perspective, addressing structural aspects of the system. It is typically a domain model.

-The Platform Independent Model (PIM) defines a system in terms of a technology-neutral virtual machine or a computational abstraction.

-The Platform Specific Model (PSM) is a platform model that captures the technical concepts and services that make up the platform and an implementation-specific model geared towards the concrete implementation technique.

For ReM-AM the approaching will be in CIM and PIM layers.

3. ODA FOR ReM-AM

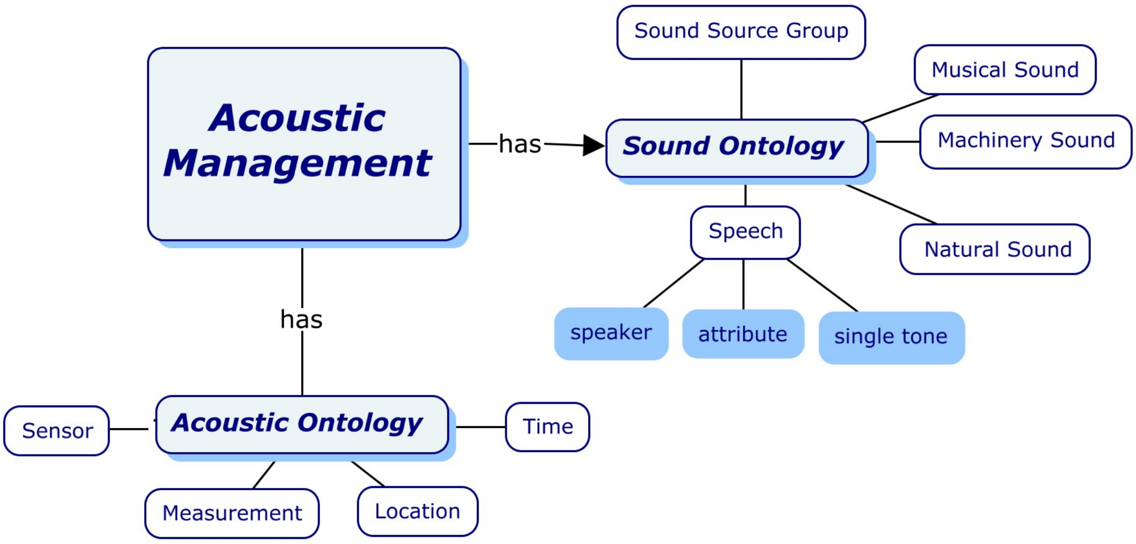

Figure 3. CIM layer for ReM-AM

The CIM layer for ReM-AM (Fig. 3) is composed by the Sound Ontology presented in [11], and the acoustic vocabulary developed in [12]. In the first one, there is proposed a terminology for sound representation and for integration various sound stream segregation systems. It is composed of sound classes, definitions of individual sound attributes, and their relationships. It has two hierarchies: *part-of*, based on the inclusion relation in sound; it-a, based on the abstraction level in sound. In the CIM layer is extended just the *part-of* hierarchy.

In the acoustic vocabulary there are four modules: sensor, allows controlling the acoustic data collecting; measurement, controls the properties of the sensor measurements; time, allows representing the intervals and instants when the measurements were made; location allows representing the geographical positioning.

The PIM layer (Fig. 4) presents the ontologies that are already liked to the middleware: web services, data analytics and autonomic computing.

The Web Services ontology is presented in [13], explaining the types generation, the methods (assembly and order) and the variables (ontology, reasoning and fixing). The Data Analytics is described in [14], where each big data has a set of parameters and criteria that determine the methods and technologies for further analysis.

The Autonomic Computing ontology is extended in [15], where the server contains concepts, properties and rules that are characteristic of all servers, the application and database are included through the transitivity of the ontology inclusion relationship.

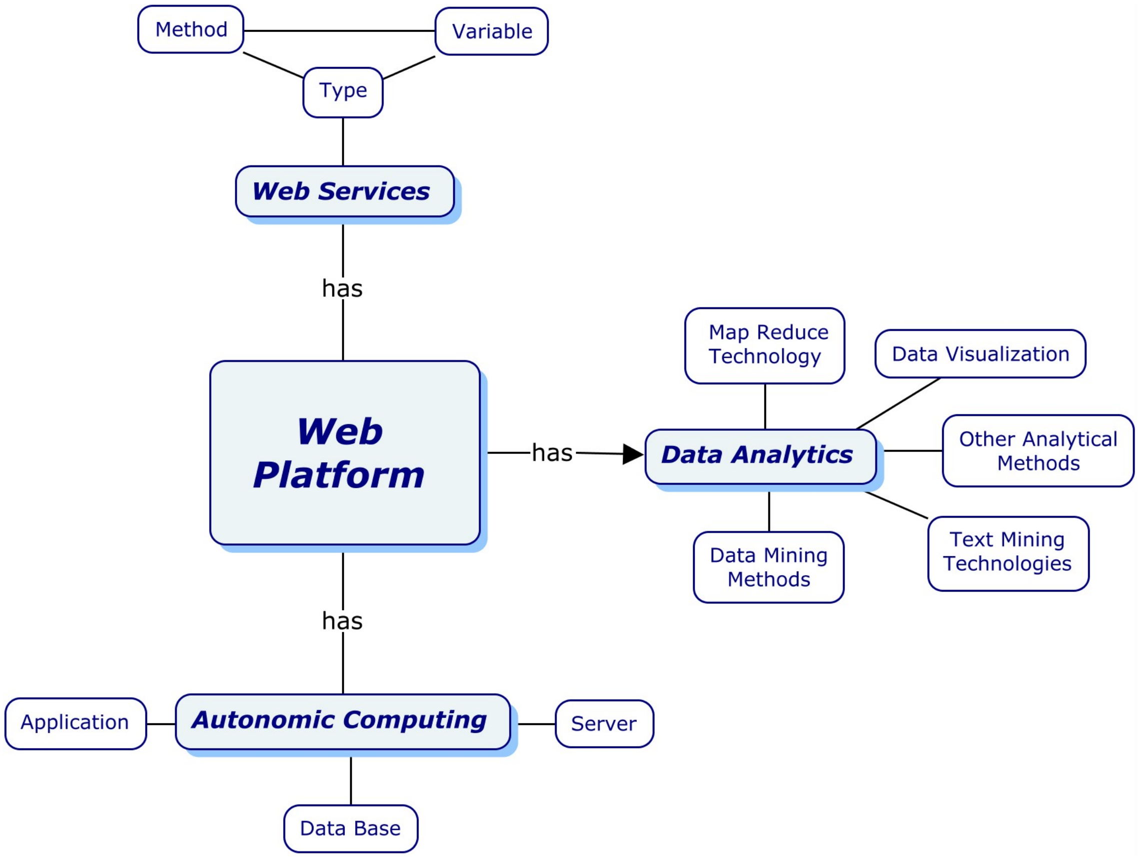

Figure 4. PIM layer for ReM-AM

4. STUDY CASES

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

-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 [16].

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 [17], 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.

-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.

Finally, in the decision-making phase, the system (DM component) could use a deep learning algorithm [18] 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.

-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 [19], to solve the cocktail party problem.

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.

5. CONCLUSIONS

This work shows the components of the ReM-AM architecture, its autonomic cycles for acoustic management in smart environments and the ontologies that are being used. Additionally, it 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 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 layers for ODA are describe: the CIM layer for acoustic management contains a sound ontology and an acoustic ontology; the PIM layer contains the Web Services ontology, the Data Analytics ontology and the Autonomic Computing ontology.

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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