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# Integrating a Humanoid Robot into ECHONET-based Smart Home Environments

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**Abstract.** This paper presents a novel approach to integrating a humanoid robot into the ECHONET-based smart home environment toward the use of elder-care robots therein. We envision a socially assistive humanoid robot companion as a smart care home interface that will support independent living of the disabled and elderly. Especially, universAAL, which is an open platform for Ambient Assisted Living (AAL) solution, is employed to connect components in the proposed software framework. The ECHONET-based smart home environment, iHouse, with the extended AAL solution provides an efficient way to improve the quality of life of smart home residents. We have confirmed that a humanoid robot companion can gain access to the iHouse network and provide user-requested data and services through verbal interaction with the support of a natural language processing tool.

**Keywords:** Human-Robot Interaction, universAAL, ECHONET, Smart Home, Natural Language Processing

## 1 Introduction

Recent advances in integrated sensing and computation technologies are used to help solve many problems in autonomous robots capable of helping humans with daily household chores [8, 15]. However, one of the most challenging questions is how to make robots more human-friendly when they are interacting with their surrounding environments and humans. Toward the use of elder-care robots in smart homes, we aim to enhance the robot's interaction performance, leading to more intuitive, natural ways of human-robot interaction (HRI) for elderly people [10].

The potential benefits of Ambient Assisted Living (AAL) solutions are already clearly recognized [9, 14]. They are receiving substantial attention as a technology to support independent living of elderly people living alone [13]. There have been many efforts based on advanced information and communication technologies (ICT) to develop a software framework and middleware for AAL such as universAAL, OpenRemote, openHAB, etc. They are all utilizing ICT to provide the runtime support for the execution of AAL services in smart home environments which is essential for the development of the AAL. Among these solutions, universAAL (uAAL) seems to be the most holistic platform which benefits end-users by an affordable, easy to configure, personalize, and deploy solution, as well as service providers by making it easier and cheaper to create new AAL services or adapt existing ones. uAAL also supports various home and building automation standards which have been well known in Europe by integrating KNX, Zigbee, and Z-wave (partial) into its middleware [11].

In this paper, we aim to present an innovative software framework to integrate a humanoid robot companion into ECHONET-based smart home environments. This smart home environment can provide AAL services by designing and implementing the integration of uAAL and ECHONET standards. We also apply a natural language processing (NLP) tool to help the robot communicate with humans in a natural way. This work is to provide an integrated networked infrastructure for a newly launched Horizon 2020 EU-Japan project "Culture-Aware Robots and Environmental Sensor Systems for Elderly Support" (CARESSES) [1].

## 2 Research Background

### 2.1 Humanoid Robot: Pepper Robot [3] and NAOqi Framework [6]

Nowadays, various types of humanoid robots are being developed for people who need help with their daily tasks. The Pepper robot, which debuted in 2014 in Japan, is a humanoid robot designed as a social companion robot by Softbank Robotics [5]. Using on-board sensors and processors, it is able to communicate with humans through verbal and nonverbal ways. Specifically, Pepper is equipped with four microphones on top of the head, one HD camera in the mouth, one HD camera in the forehead, and one 3D depth sensor in both eyes. Pepper can also manipulate objects with two hands, each of which has five fingers with touch sensors. The mobile base is equipped with such sensors as lasers, sonars, and gyroscope that allows Pepper to localize itself and navigate autonomously in an unknown environment. In this work, it is demonstrated that Pepper communicates with a user and responds to his/her request, serving as an interface between the user and the smart home environment (Fig. 1).

Softbank Robotics also provides developers with a programming framework to program Pepper which is called NAOqi framework. The architecture of NAOqi framework is illustrated in Fig. 2. Basically, this framework contains two main parts: NAOqi Application Programming Interface (API) and NAOqi Software Development Kit (SDK). The NAOqi API is a library that is able to control the robot's hardware. With the NAOqi SDK, developers can implement applications using the NAOqi API in C++ and Python. Users control the robot through local applications and remote applications. The local applications run on the robot and access directly to the NAOqi API. The remote applications run on the external devices and call the NAOqi API using Ethernet or wireless connections.

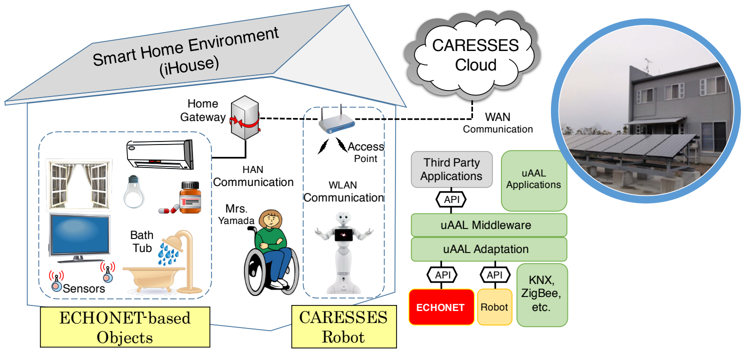



Fig. 1: Integrating a Pepper into iHouse

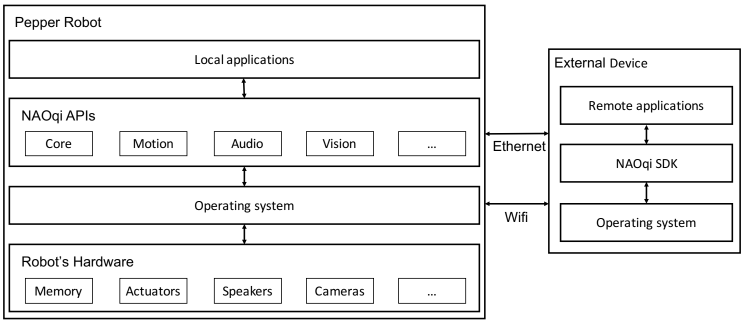



Fig. 2: NAOqi Framework Architecture

### 2.2 ECHONET-based Smart Home Environment: iHouse

The ECHONET-based smart home environment iHouse is located at Nomi City, Ishikawa Prefecture, Japan. iHouse was named as such because it implies **i**shikawa, **i**nternetted, **i**nspiring, and **i**ntelligent House which was the outcome of a research project funded by the Japanese Ministry of Internal Affairs and Communications. It is an advanced experimental environment for Japan's future smart homes equipped with more than 300 sensors and actuators utilizing ECHONET Lite version 1.1 and ECHONET version 3.6.

ECHONET [12], which has became a *de jure* home network standard certified by ICE and ISO, stands for Energy Conservation and Homecare Network. However, the ECHONET protocol did not attain widespread adoption due to two major factors. Firstly, the specification requires a more complicated system configuration for multiple controllers and devices. Another factor was the overall complexity of the protocol, leading to only a few compliant implementations. Therefore, in 2011, it was redesigned to be simpler and easier to use, which is the ECHONET Lite protocol. An overview of these two protocols is shown in Fig. 3.

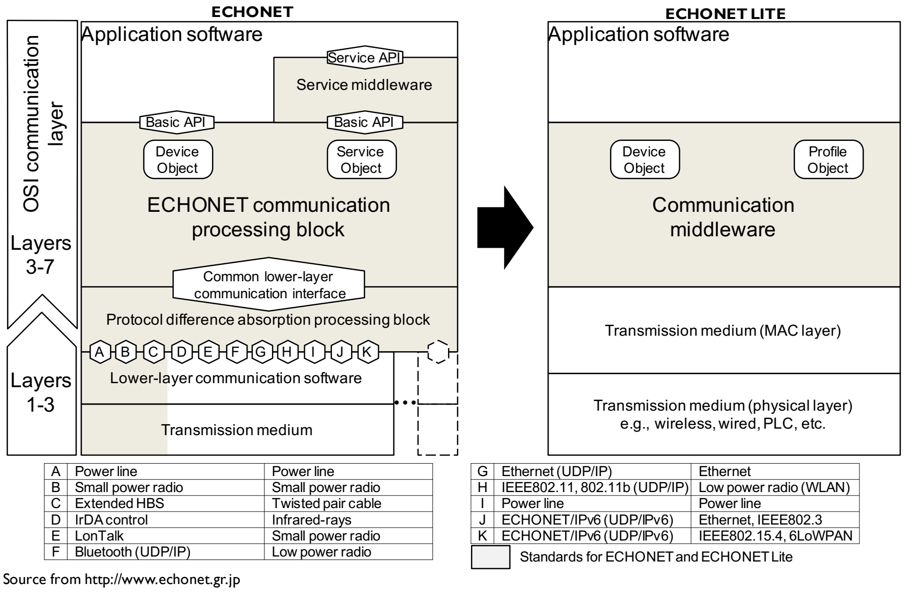



Fig. 3: ECHONET and ECHONET Lite Standard Overview

### 2.3 universAAL(uAAL) [7]

universAAL stands for universal open platform and reference specification for Ambient Assisted Living derived from the European Union funded project to produce an open platform for AAL. uAAL allows the seamless integration of heterogeneous devices within a network environment through two basic concepts: i) the usage of three communication buses for topic-based communication among components, namely, a Context Bus, a Service Bus, and a User Interface Bus provided by the uAAL Middleware; ii) the usage of ontologies for information and services shared between components. The overview of uAAL platform is depicted in Fig. 4.

The uAAL Middleware (MW) is the core component of the uAAL platform which contains the communication infrastructure of the platform, and all devices that run the MW are nodes which can share knowledge and functionalities with other nodes in the form of ontology. The heart of MW is formed by the three buses and all the communication happens via one of the three buses:

- Context Bus (CB) is an event-based communication channel to allow nodes to publish context events to the CB without taking into account the existence of recipients. Recipients are context subscribers whose interested events are registered in the CB, enabling them to receive specific pieces of information.
- Service Bus (SB) is a call-based communication channel to allow nodes to request services from other nodes. Service providers, *a.k.a.* service callees, announce themselves by registering a service profile to describe their capa-

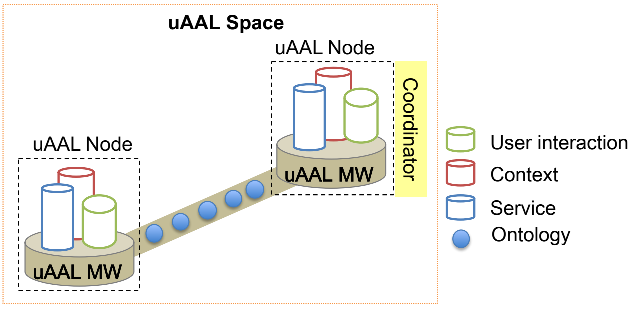



Fig. 4: universAAL Platform Overview

bilities to the SB. The counterpart of service callees are service caller which sends a specific service request to SB.
- User Interface Bus (UI Bus) is used for delivering messages related to user interactions.

### 2.4 Natural Language Processing Tool: Api.ai [2]

NLP is an important domain of computer science and artificial intelligence. In this research, Api.ai library is used as an NLP tool. With Api.ai, a natural language understanding platform, we can easily design and integrate intelligent and sophisticated conversational user interfaces into mobile apps, web applications, devices, and bots. Hence, the robot is able to process human speech patterns, and extract key words such as intents and contexts therein.

## 3 System Integration

### 3.1 Overview

We designed a system in order to integrate the Pepper robot into the iHouse. Figure 5 shows the overall system architecture. The most important part in this work is to get Pepper to understand the user's voice request in natural language. The NAOqi framework and the NLP library Api.ai are employed to solve this task. The robot's application uses the NAOqi framework to transform the user's free speech to text. Then, the NLP library Api.ai converts this text data into a structured form that can be easily recognized by the proposed system.

In this approach, we need an open platform that is able to provide a seamless integration of robots, devices, heterogeneous sensors, home appliances, and user interfaces. This platform is also required to run on different operating systems, and to support several communication protocols within the same framework. Among many feasible platforms, we use the uAAL platform, where each module, *i.e.*, the Robot Controller, the Home Gateway (HGW), and the Cloud Server, has to install a uAAL MW module.

Since the robot needs to interact with devices inside the iHouse via the uAAL platform, we must enable the iHouse to function as a uAAL node. To this end, the integration between the uAAL and ECHONET standards has been done by embedding the uAAL platform into the HGW of the iHouse. The HGW includes:

- ECHONET Interface is responsible for interacting, managing, and controlling ECHONET-based devices.
- uAAL Adaptation is responsible for translating the ECHONET-based frames into ontologies usable by the uAAL MW, as well as translating commands received from the uAAL MW into ECHONET-based frames suitable for ECHONET-based devices.
- uAAL MW is responsible for establishing communication channels with other nodes in the uAAL space.

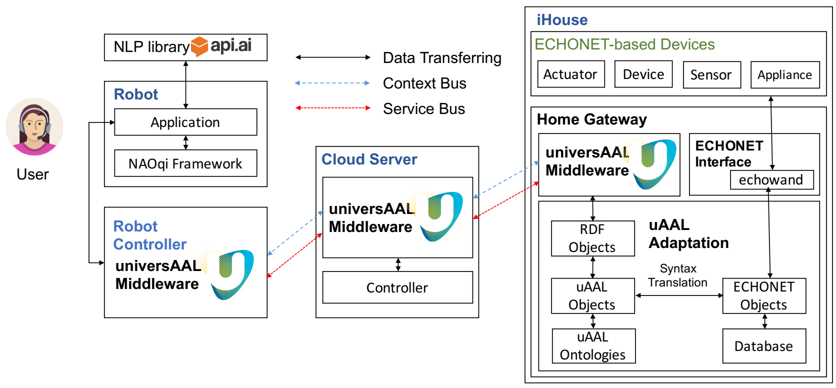


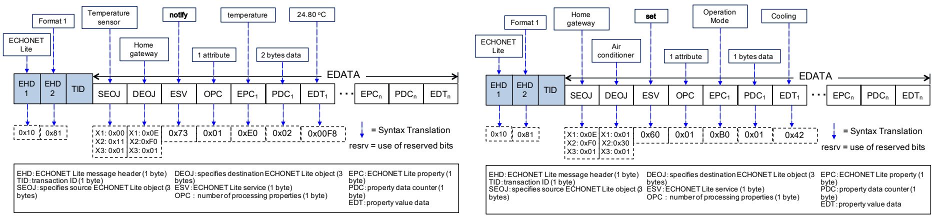

Fig. 5: System Architecture

## 3.2 Integrating universAAL and ECHONET Standard

In this section, the implementation of two main components in the HGW, which are ECHONET interface and uAAL Adaptation, respectively, will be discussed.

**ECHONET interface** The ECHONET interface translates ECHONET frames into ECHONET Objects and vice versa. The details of the frame's translation are described in Fig. 6.

**uAAL Adaptation** Because information can be shared between uAAL nodes in the form of ontology, the main mission of the uAAL adaptation is to map the ECHONET objects into uAAL ontologies. However, the uAAL ontologies can not support all attributes of the ECHONET standard. There is an alternative




(a) Temperature Sensor Sends Data to Home Gateway Frame

(b) Home Gateway Sets Operation Mode of Air-conditioner Frame

Fig. 6: Sample ECHONET Frames

ontology model called SAREF [4] introduced by oneM2M working group that can cover all attributes of ECHONET standard, but it is not compatible with uAAL ontologies. To cope with this, an ontology model based on oneM2M ECHONET ontology was defined and implemented as shown in Fig. 7 which is compatible with uAAL ontologies.

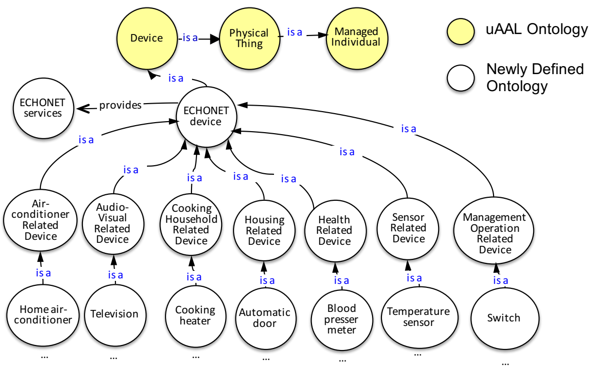



Fig. 7: uAAL-Compatible Ontology Model Extended from SAREF

The uAAL adaptation takes ECHONET objects passing via the ECHONET interface as inputs and translates them into uAAL resources (ontologies, objects) directly usable by the uAAL MW and vice versa.

### 3.3 Experiment

To verify the validity of the proposed system, we create a simple experiment, where a user is talking with the robot about the temperature in the smart home. In this experiment, the user asks the robot a question(s): "What is the temperature?". Then our system performs natural language processing to enable the robot to answer the question using the proposed framework: "The temperature in the living room is 20 degrees.". Figure 8 illustrates the sequence diagram of this demonstration.

Firstly, the Robot Application uses the NAOqi Framework to handle the user's question in natural language, converting his/her speech to a text data. This text data is sent to the NLP tool Api.ai. This library processes the text data to return a structured data. In this step, with the supporting of Api.ai, the meaning of the question can be fully understood by Pepper. For example, "What is the temperature?", "Is it hot in the living room?", "Can you tell me the temperature in living room?", etc, are all recognized as the same question, implying that the user wants to know the temperature of the living room. From this information, the Robot Application creates a request and calls the Robot Controller.

Secondly, the Robot Controller, which is a uAAL MW module, uses the Service Bus of the uAAL platform to communicate with other uAAL MW modules that are the Cloud Server and the HGW. The request about the temperature of the living room is broadcasted to the Cloud Server. This server transfers the request to the HGW of the iHouse.

Finally, the HGW collects data from ECHONET-based devices in the iHouse to build the response. The uAAL Adaptation translates this information to uAAL ontologies. Following the returning flow of the system, the Robot Application receives the temperature data in the living room. Once an answer is constructed, then the robot talks to the user using the NAOqi Framework.

Figure 9 is a screen shot of our system demonstration, where the Pepper robot communicates through natural language to gain access to the user requested temperature in various areas of the iHouse and provide the user with the temperature data therein.

## 4 Conclusion

We provided a new approach to connect a human and a socially assistive robot Pepper within the ECHONET-based smart home environment. Specifically, we presented a method to integrate the robot into the uAAL platform and ECHONET standard. Moreover, the robot could communicate with a user in an intuitive way by employing a free natural language API. We have confirmed that the proposed speech-activated interface enables the robot to gain access to the iHouse network and provide user-requested data and services accordingly.

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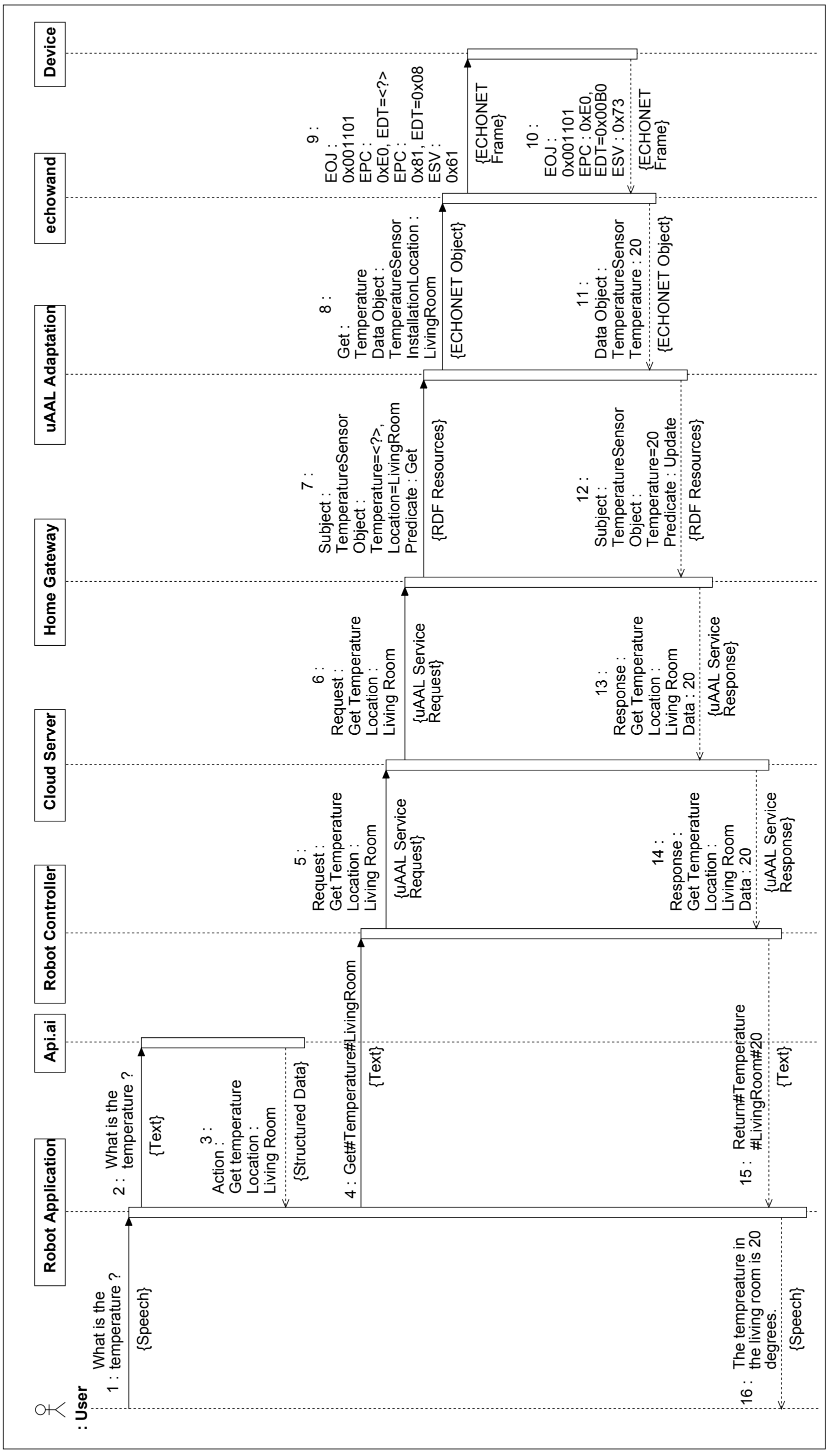


Fig. 8: Sequence Diagram of Experiment


Fig. 9: Testing Proposed Integration Framework

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