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Interoperable neuro-fuzzy services for emotion-aware ambient intelligence

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ABSTRACT

Ambient Intelligence (AmI) carries out a futuristic vision of living environments which are sensitive and responsive to the presence of people and, by taking care of their desires, intelligently respond to their actions improving their comfort and well-being. Typically, AmI frameworks are based on distributed context-aware approaches that, by using collections of invisible and interconnected devices, elicit and analyze environmental knowledge for delivering an appropriate set of services. Emotion-aware AmI (AmE) enhances the conventional idea of intelligent environment by exploiting theories from psychology and social sciences for suitably analyzing human emotional status and achieving a higher users' satisfaction. This work proposes a novel approach of combining emotion-aware idea with a neuro-fuzzy framework to train a collection of intelligent FML-based agents aimed at delivering efficient, personalized and interoperable emotion services in an AmE environment. As will be shown in experimental results, where a usability study and a confirmation of expectations test have been performed, the proposed approach is capable of anticipating user's requirements and improving the performance of a conventional AmI framework.

1. Introduction

Ambient Intelligence (AmI) is an innovative approach to the design of future living environments where technology is aimed at supporting human activities through a smart and non-explicit assistance [1]. AmI scenarios combine concepts of ubiquitous computing, intelligent systems and advanced user interfaces dipping humans in the heart of technological developments. From an implementative point of view, AmI systems use a collection of invisible and interconnected devices for identifying different situations that a human can live in a given environment, and delivering an appropriate set of services for assisting him in such situations. Thanks to these context-awareness capabilities [2,3], AmI is offering new opportunities for a wide number of applications such as education and training, health care, efficient managing of energy resources, leisure and entertainment, and so on. However, last studies prove that an AmI system is more than a simple integration of computational methodologies. The current trend is represented by Emotion-aware AmI (AmE) which exploits concepts from psychology and social sciences to suitably analyze the human being status and to enrich context information. AmE achieves this goal by extending AmI equipment through a collection of enhanced sensors and devices capable of recognizing human emotion starting from facial expressions [4] or human behaviors such as hand gestures, body movement and speech [5,6]. The exploitation of these new emotional context-awareness devices enable systems to deliver a highly personalized and dedicated collection of services aimed at better supporting users' and achieving their satisfaction.

The aim of this paper is to extend the architecture presented in [7] by proposing an innovative AmE system capable of delivering *emotional neuro-fuzzy services*, i.e., adaptive services that continually *morph* in order to respond to new environmental demands and emotional human status and *coordinate* the device network in order to satisfy user's requirements by proactively controlling environment actuators. In order to achieve this objective, our system is based on a combination of theories and methodologies derived from computational intelligence and psychology area. In detail, our proposal exploits an Adaptive Neuro fuzzy Inference System (ANFIS) [8–10] embedded in a multi-agent paradigm for designing a learning algorithm capable of capturing environmental features and human emotion and generate the most appropriate collection of services. This choice is very suitable to deal with high levels of vagueness and imprecision featuring the human–system interactions in AmE context. In order to model emotion concepts, a neural network has been trained according the Russell's emotional model. Moreover, in a such distributed framework, it appears clear that only those who

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succeeded in achieving *hardware interoperability* will be able to furnish innovative solutions and satisfy users' needs. Our system exploits the FML technology to implement the inferred emotional neuro-fuzzy services in an abstract way and, as a consequence, define a collection of interoperable services.

As will be shown in experimental results, where a usability study and a confirmation of expectations test have been performed, the proposed approach is capable of anticipating user's requirements and improving the performance of a conventional AmI framework.

The paper is organized as follows. In Section 2, we present some related works. Section 3 presents the basic concepts and backgrounds necessary to develop our neuro-fuzzy AmE architecture. Our proposal is accurately described in 4. Before concluding in Section 6, the performed experiments are presented in Section 5.

2. Related Works

In literature, there are a lot of research projects aimed at supporting individuals in their lives providing services through the application of computational intelligence techniques embedded in multi-agent systems. In particular, in [11], the authors present an enhanced type-2 fuzzy logic based agent which can be embedded in a multi-occupant smart environment. The agent uses the type-2 fuzzy logic theory in order to deal with several kinds of uncertainty. It learns the collective behavior of the occupants from their individual type-1 profiles and stores this knowledge encoding it in type-2 fuzzy rules and membership functions. The agent uses this information to control the environment on behalf of the users. In [12], the presented project, called MavHome, is aimed at creating a home able to reason about and adapt to its habitants in order to maxime users'comfort and minimize operation cost. In order to achieve these goals, the project designs a multi-agent system where each smart home agent is able to accurately predict mobility and other activities of the inhabitants. Apart from accomplishing the individual goal (e.g. light controlling, multimedia entertainment, etc.), each smart home agent should cooperate with the other ones in order to perform the whole purpose of the system. The objective of the research in [13] is to design software algorithms that recognize and assess the consistency of activities of daily living that individuals perform in their own homes. The designed algorithms automatically learn Markov models for each class of activity so to identify errors and inconsistencies in the performed activity. This research can be strongly used in order to provide valuable health monitoring and assistance technology to help individuals live independent lives in their own homes. In [14], an automatic in-home healthcare monitoring system for several uses is proposed. In detail, it is a multimodal platform with several sensors that can be installed at home and enables us to have a full and tightly controlled universe of data sets. It integrates elderly physiological and behavioral data, the acoustical environment of the elderly, environmental conditions and medical knowledge. A data fusion approach based on fuzzy logic with a set of rules directed by medical recommendations, is used to fuse the various subsystem outputs. This multimodal fusion increases the reliability of the whole system by detecting several distress situations.

In last years, some researches demonstrate that considering human emotional status as context information improves the distribution of personalized services in AmI scenarios. However, human emotions are rarely included in these visions and the majority of the research in this field ignores human emotions [15]. As matter of fact, in the current state of art, only few frameworks considering user's emotional behavior have been designed [16–18].

The aim of this work is reinforced the validity of the innovative emotion-aware systems by proposing a new AmE architecture which exploits multi-agents paradigm, neural network computing and fuzzy logic for delivering the most appropriate services starting from environmental features and user's emotional status. As shown in experiments, our proposal yields performances better than a conventional AmI approach.

3. Background and AmE architectural basic components

This section introduces the basic concepts and backgrounds need to develop our neuro-fuzzy AmE architecture. This intelligent system is mainly based on three methodologies/technologies. In particular, the *Russell's emotional model* is a tool from psychology area supporting our system by providing it with a method for identifying human emotions. The *Adaptive Neuro Fuzzy Inference Engine* (*ANFIS*) represents the architecture component implementing strategies for learning personalized services in our intelligent environment. *Fuzzy Markup Language* (*FML*) provide our system with interoperability, indeed it allows to implement the learned service in hardware independent way.

3.1. The Russell's circumplex approach

Emotion modelling is a broad research field and many theories related to the classification of emotions have been devised over time. In particular, in our work, we follow the Russell's emotional model definition. In detail, Russell's model represents a so-called *dimensional approach*, i.e., it states the existence of a limited number of dimensions on which are based all affective states. In details, the Russell's model, named *the circumplex model of Affect* [19], characterizes the affective space through two-dimensions: pleasure–displeasure (*valence dimension*) and arousal–sleep (*arousal dimension*). Therefore, in his vision, each emotion is depicted as a linear combination of valence and arousal, respectively, the horizontal and vertical axis in Fig. 1. Precisely, Russell views the affective space tracked by eight emotions: pleasure, displeasure, arousal and sleep which represent the ends of the two dimensions and excitement, distress, depression and contentment which only help to define the quadrants of space, but do not form independent dimensions [19].

As consequence, the affective space is represented by a circle (circumplex) built by eight points in the following order: pleasure (0°), excitement (45°), arousal (90°), distress (135°), displeasure (180°), depression (225°), sleepness (270°) and contentment (315°). In a

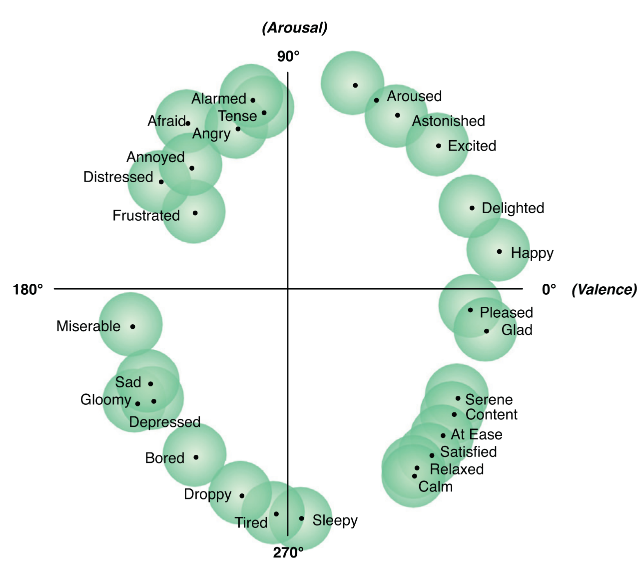

Fig. 1. Russell's emotion model.