# On Interfacing with an Ubiquitous Robotic System

**Donatella Guarino**[1] and **Alessandro Saffiotti**[2]

**Abstract.** The emerging field of ubiquitous robotics presents new challenges for human-robot interface. In this note, we introduce the concept of a *common interface point* using an *expression-based semantics* as a way to address some of these challenges. We illustrate this concept in the framework of the PEIS-Ecology approach to ubiquitous robotics.

## 1 Introduction

There is a marked tendency toward the embedding of many ubiquitous, intelligent, networked robotic devices in our homes and offices. This tendency is witnessed by the growing interest in the fields of ambient intelligence and smart homes, as well as by the new emerging field of ubiquitous robotics [1, 3]. The development of these ubiquitous systems is often motivated by the desire to improve the quality of life of citizens in general, and of elderly people in particular. In this context, it is essential that this development is accompanied by the development of suitable *interfaces* that ensure the usability and acceptability of these systems.

The problem of interfacing with an ubiquitous system is different from, and more complex than, the conventional human-computer and human-robot interface problems. First, although the system consists of a collection of many inter-connected devices, the user should perceive it as one system, and interact with all the devices in it through *one and the same* interface. Second, the interaction between the user and (the different devices in) the system should be based on a *uniform model*, hiding the heterogeneity of the devices. Note that this interaction should be *two-way*, that is, the user should be able both to control the system and to get information from it.

In this note, we study how an ubiquitous robotic system can provide a human user with information which is unobtrusive, intuitive and relevant. We introduce two concepts that address the two challenges above: the concept of *common interface point*, which collects and summarizes the relevant information about the status of the system; and the concept of *expression-based semantics*, which provides a uniform semantics to talk about status information, and an intuitive way to convey this information to the user. In order to illustrate these concepts, we consider a specific concrete approach to ubiquitous robotics: the PEIS-Ecology approach.

## 2 The PEIS-Ecology Approach

The concept of PEIS-Ecology [3] puts together insights from the fields of autonomous robotics and ambient intelligence to generate a radically new approach to building assistive, personal, and service robots. The main constituent of a PEIS-Ecology is a *physically embedded intelligent system*, or PEIS. This is any computerized system interacting with the environment through sensors and/or actuators and including some degree of "intelligence". A PEIS can be as simple as a smart toaster and as complex as a humanoid robot. Notice that PEIS are *physically embedded systems*, not just software agents.

Individual PEIS in a PEIS-Ecology can cooperate by *linking functional components*: each PEIS can use functionalities from other PEIS in the ecology in order to compensate or to complement its own. The power of the PEIS-Ecology does not come from the individual power of its constituent PEIS, but it emerges from their ability to interact and cooperate. In a sense, the PEIS-Ecology approach redefines the very notion of a *robot* to encompass the entire environment.

Consider the example in figure 1. By itself, the simple autonomous cleaner can only use basic reactive cleaning strategies. If the home is equipped with an overhead tracking system, though, the robot can use it to know its own position in the house and hence use smarter cleaning strategies. Suppose then that the cleaner encounters a plant, and that the plant is equipped with a micro-PEIS (e.g., a mote) able to communicate its properties (size, wheel-support, humidity, temperature, etc) to the robot. Then, the robot can decide if it can push the plant away and clean under it.

## 3 The Common Interface Point

In a PEIS-Ecology, the single robot servant assumed in most literature on human-robot interface is replaced by a network of devices distributed all around the environment. Correspondingly, the notion of a single-robot interface should be replaced by a multitude of PEIS-specific interfaces, which are distributed all over the environment.

However, asking the user to interact with a large number of devices using a correspondingly large number of specialized and possibly different interfaces is clearly a bad idea. We therefore envision one single main *interface point* that integrates all the information from the different PEIS in the ecology, and dispatches all the com-

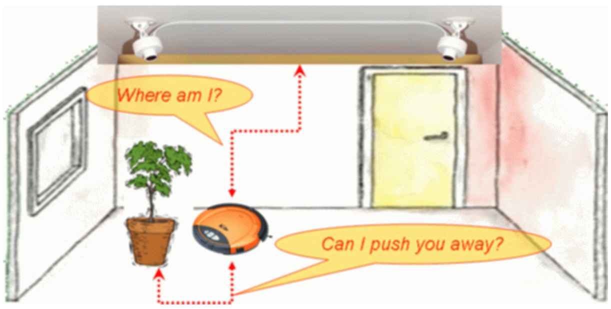


**Figure 1.** A simple PEIS-Ecology consisting of three PEIS.

[1] ICAR, National Council of Research. Viale delle Scienze, Palermo, Italy. Email: dony@pa.icar.cnr.it
[2] Center for Applied Autonomous Sensor Systems. University of Örebro, Sweden. Email: alessandro.saffiotti@aass.oru.se.

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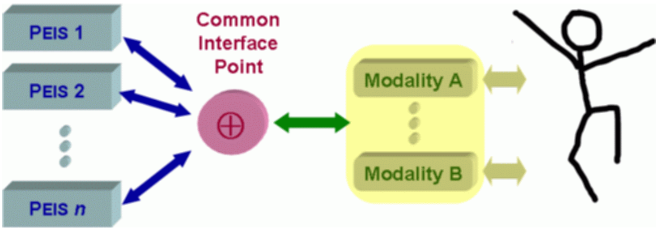


**Figure 2.** The common interface point for a PEIS-Ecology.

mands to them. This interface point may communicate with the user by a number of different modalities (e.g., speech, gestures, expressions), including remote ones (e.g., a mobile phone). The interface point, however, should be perceived as a single interface toward the whole ecology, as well as toward each individual PEIS. This concept is illustrated in figure 2.

In our work, we explore the realization of the common interface point in the system-user direction to convey status information. For the above schema to work, four problems must be solved: (1) how to encode status information from each PEIS, endowed with a *common semantics*; (2) how to *combine* status information coming from different PEIS, so as to reflect the status of the entire PEIS-Ecology (or parts of it); (3) how to *present* the status information to the user; and (4) how to *generate* this status information inside each PEIS. In the next section, we outline our solution to the first three problems; the fourth one is part of our current research.

## 4 Expression-Based Semantics

In many cases, a PEIS has an internal status from which we can distinguish "normal" and "abnormal" conditions. Different PEIS, however, have different ways to represent their status, and different measures to be used to detect a normal or abnormal condition. For instance, in the above scenario, the plant may need watering, or the cleaning robot may be running out of batteries: the relevant measures are the ground humidity or the battery voltage, respectively.

In order to provide a uniform way to treat these conditions we consider an abstract notion of "satisfaction". Each PEIS represents its internal satisfaction status in a succinct way as an *expression*, ranging from "sad" to "happy", and encoded by a real number in the $[0, 1]$ interval. These numbers are combined into a joint measure of the degree of satisfaction of the whole PEIS-Ecology, through some combination operator $\oplus$. Intermediate combination steps may be performed if the PEIS-Ecology is partitioned into sub-ecologies.

The satisfaction status is shown to the user in the form of a human understandable expression, which gives an immediate impression about the overall status of the PEIS-Ecology. Figure 3 shows some realizations of these expressions in our test implementation.

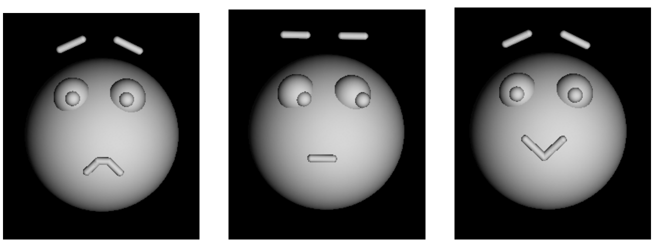

**Figure 3.** Visualization of the satisfaction status for three different values: 0.2 (very sad, left); 0.6 (rather worried, middle); 1.0 (quite happy, right).

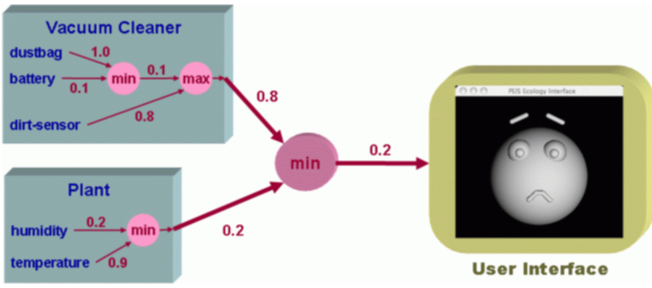


**Figure 4.** The overall satisfaction status of a simple PEIS-Ecology is computed, and it is conveyed to the user by a corresponding expression.

In general, the satisfaction state of each individual PEIS may depend on the combination of a number of different factors. For example, the state of the autonomous vacuum cleaner will be "happy" if the batteries are not empty and its dust-bag is not full. However, if the room is already clean, its state will be "happy" even if the batteries are empty, since no more cleaning is needed. This example shows that the behavior of the $\oplus$ operator may need to be fairly complex, and that we may need different operators inside each PEIS, and between different subsets of PEIS.

To allow this, we combine satisfaction states using the mechanisms of fuzzy logic. Fuzzy logic has been given semantics in terms of desirability values [2]. These semantics are compatible with the expression semantics adopted here, by stipulating that the degree of satisfaction of a PEIS in a given state corresponds to the degree by which that state is *desirable* for that PEIS. Fuzzy logic provides mechanisms to write and evaluate logical combinations of $[0, 1]$ desirability values. For example, the following formula in (propositional) fuzzy logic could express the combined desirability for the vacuum cleaner example above:

$$\text{cleaner-happy} \Leftrightarrow \text{clean-floor} \vee (\text{full-battery} \wedge \text{empty-dustbag}) .$$

The degree of happiness of the cleaner PEIS, then, is obtained by computing the truth value of the above formula using the rules of fuzzy logic. Figure 4 shows an example of computation of the overall state of a simple two-PEIS ecology. In this example, the vacuum-cleaner is fine but the plant needs attention.

## 5 Next Steps

The study of expression-based semantics for ubiquitous systems has just started, and very many issues remain to be investigated. Among these: How can each PEIS generate its satisfaction value? How can we weight these values to take into account the user's needs and preferences? How can we extend the expression-based semantics to other types of states, like danger or surprise? How can we convey "expressions" using other modalities, like sound or color? How can we help the user to pinpoint the cause of a "sad" status?

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