NICA Cares for Me! Planning Socially Intelligent Reactions in a Caring Robot

Berardina De Carolis, Irene Mazzotta, Nicole Novielli

Dipartimento di Informatica, Universita' di Bari, Italy

<decarolis,mazzotta,novielli> @di.uniba.it

ABSTRACT

Ambient Intelligence solutions may provide a great opportunity for elderly people to live longer at home. Assistance and care are delegated to the intelligence embedded in the environment. However, besides considering service-oriented response to the user needs, the assistance has to take into account the establishment of social relations that become particularly relevant when media are not boxed in a desktop computer but are integrated pervasively in everyday life environments. We propose the use of a robot NICA (as the name of the project *Natural Interaction with a Caring Agent*) acting as a caring assistant that provides a social interface with the smart home services. In this paper, we introduce the general architecture of the robot's "mind" and then we focus on the need to properly react to affective and socially oriented situations. In doing so, the robot implements a meta-level reasoner able to interpret the situation and to understand when to interrupt the current behavior in order to handle the new situation. To this aim it uses a probabilistic model to revise its beliefs and to trigger high-level goals. According to the selected goal the behavioral plan is computed by choosing the most appropriate set of actions.

Keywords

Socially Intelligent Robots, Ambient Intelligence.

1. INTRODUCTION

The development of Ambient Intelligence (AmI) solutions that provide assistance to elderly people in order to improve their quality of life at home is a very fervid research field [1,2]. In this vision, assistance and care are delegated to the intelligence embedded in the environment. Obviously, technology should not represent a further obstacle in achieving the user goals and therefore, besides providing efficient infrastructures for managing domestic automated services, it is necessary to put the emphasis on human-technology interaction. The environment should provide an easy and natural interface in order to make service fruition effective and adapted to the user needs [3].

In our system we use a robot named NICA (Natural Interaction with a Caring Agent) that aims at increasing the quality of life by acting as a social interface between the user and the home services. NICA, combining the interpretation of the user moves (sentences, actions, etc.) and sensors data, provides proactively and reactively the needed assistance.

The level of assistance, however, has to take into account not only service provision but also the establishment of social relations. Social and affective factors become even more relevant when the system has to be used by elderly people since they need not only service-oriented assistance but also a friendly companion. In our opinion these aspects become even more relevant when media are not boxed in a desktop computer but are integrated pervasively in everyday life environments [4].

In developing the architecture of NICA, besides developing a way to control smart services, we had to consider **social factors**, that are normally an issue when referring to people everyday situations, and **affective factors**, which are proved to enhance the effectiveness and believability of the interaction especially when it happens through a natural dialog with an artificial entity.

In previous projects our research group have faced the problem of modelling user and agent affective state: we have investigated the problem of recognizing the user attitude towards an Embodied Conversational Agent (ECA) by exploiting lexical and acoustic analysis of dialogue turns [5]. Moreover, we have investigated how dialog strategies may be formalized in order to selected the most appropriate one, according to the user state [6]. In particular, we have explore the effectiveness of alternative persuasion strategies that may be used to strengthen the dialog strategies [7], focusing on the role of emotional and non emotional component of persuasion [8] and in a previous phase of this project, we worked at a model for recognizing the user attitude and communicative intent [9]. Moreover, we have developed C@sa a MultiAgent architecture for providing proactive service oriented assistance in a smart home [10].

In this paper we present the general architecture of NICA that, acting as a mediator between the user and the environment, provides a natural interface to C@sa services. However NICA is not acting merely as a microphone and a set of speakers shaped as a robot but it tries to establish a social relation with the user by achieving its persistent long term goals (i.e. keeping the wellness state of the user) and, at the same time, by handling the reaction to changes in the current context in order to infer contingent user goals and needs.

We focus on the integration of a social and affective reactive layer in the robot deliberative architecture.

To test our approach we decided to use LegoMindStorm for embodying NICA and at present we simulate the interaction with the user and the environment using a simulation tool and the robot is acting in a "toy" house. However, in our approach we separate the mind from the body using the same approach we adopted in [11] and therefore we can easily change the body of our robot with another one.

2. APPLICATION SCENARIO

To define and implement feasible behaviours of NICA, we started from real data. To collect them we asked two families in a similar situation to record the experience of two human caregivers about the assistance of two elder women affected by chronic diseases during a period of one month. Both women lived alone, they had a son/daughter living in another town, which could intervene only in case of need and for solving relevant medical and logistic problems. Data have been collected using a diary. Everyday the caregiver had to annotate her paper-diary with two kinds of entries, the schedule of the daily tasks and the relevant events of the day, using a schema like the one reported in Table 1.

Table 1. Two entries from the diary.

time	event	reason	action	affective action
10.45	Maria is worried	medical visit	I go toward Maria and ask about her state.	encourage
11.00	-	medical visit	I call the daughter to remind her.	-

From these data we extracted the knowledge needed to build the reasoning strategies of the robot, to try to make it behave as a human caregiver. In particular, as we did in other projects [], this labelled corpus of about 900 entries was used for i) understanding which were the events and context conditions relevant to goal and action triggering; ii) learning causal relation among data and for determining the possible action plans.

Then, starting from this experience we depicted the following scenario to test our agent framework:

"Maria is an elder woman living alone in her smart house equipped with smart sensors and devices typical of an AmI system. She suffers of a serious form of diabetes and a mild form of heart disease. Her daughter lives in another town and she is quite busy. NICA is a social robot that has the role of taking care of Maria. Since NICA is only a robot, in order to perform its tasks, it takes advantage of the AmI system capabilities. If the smart devices in the house can interact with NICA, it could detect and communicate, for instance an alarming state of affairs so that they can manage such critical state. NICA can ask the AmI system to call immediately a medical specialist, or the daughter [12,13] according to the urgency of the situation".

We work on a simulation of this scenario that let us to abstract from many technological issues, raised by the use of devices that are outside the main scope of this paper. Hence, for our purposes, all the AmI devices are embedded in software agents that are integrated in a multi-agent system, as discussed in [10]. Instead in this scenario we want to outline the importance of integrating the social aspects of taking care of a person with service oriented assistance. We will consider the described scenario and the entries of the diary in Table 1 as a running example for our simulation Scenario:

"One day Maria has to go to the doctor in order to discuss the results of blood tests. NICA's selected plan is made up of the following actions: to remember Maria about the appointment, to suggest about the dressing according to the weather situation, and to call her daughter to remember to go to get Maria to the doctor. After these actions, NICA has to ask to the smart phone to send a remind message to the daughter. Suddenly Maria, sitting on a chair waiting for her daughter, starts whispering and moaning. NICA approaches the woman and asks about her complaints, encouraging with appropriate sentences."

3. NICA'S ARCHITECTURE OVERVIEW

The architecture of NICA is based on the BDI model [11] and the goal processing cycle is a simplification of the model presented in Castelfranchi and Paglieri [12].

NICA implements a life cycle based on the following steps (Figure 1):

- PERCEPTION,
- INTERPRETATION,
- GOAL ACTIVATION,
- EVALUATION and CHECKING,
- PLANNING and EXECUTION .

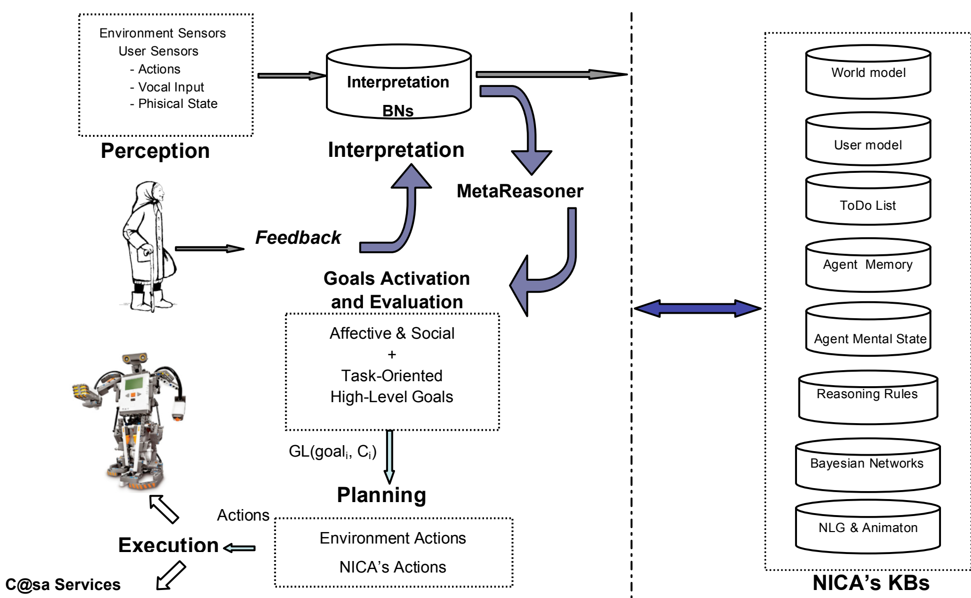

Figure 1. NICA's Architecture.

For reasoning on the situation, NICA's mental state uses and stores different types knowledge:

- the **World Model** that represents a set of relevant beliefs about the current environment context.
- the **User Model** that contains the representation of beliefs about the user of various type. In particular, for our aims, long terms factors concern user stable data (i.e. sex, age, chronicle diseases, allergies, main personality traits, interests, etc.) and short term factors concerns belief regarding the current user situation, the physical state, affective state, health conditions, recognized goals etc.
- the **ToDoList** that represents the agenda of scheduled daily activities that should be performed by the user. For instance: at 11.00 a.m. Maria must go to the doctor. This agenda is planned everyday and it is revised when new events have to be scheduled (i.e. an appointment is postponed, etc.
- the **Agent Social Memory** stores structured information about feelings associated with an event. It holds not only information about when, what and how an event happened, but also an `arousal' tag and a `valence' tag. It is used to learn relations about events and the user affective state. The importance of this feature at the aim of establishing empathy with the elder person was outlined several times by the human caregivers during the data collection phase.

As the agent reasons and updates beliefs, infers goals, plans actions and executes them, it keeps an image of this process in its mental state.

3.1 Mental State Representation

Let's denote with N NICA and with U the User. Let's denote variables in small letters, a constant (in capitals) or a function (initiating with a capital) denoting a fact about the user or the world:

a. ***Actions***: we need representing two types of actions:

- *domain actions*: Act-Name(N x) where x is the object of the action; For example: Administer(N drug);
- *communicative actions*: (Act-Name N U x); for example: (Remind N U Take(drug))

b. ***Facts***:

- *properties of objects or states*: Property(y) where y is an object or a state; for instance: Normal(healthstate);
- *predicates*: Predicate(U,z) where z is a value or a fact; for instance Feel(U,sad);

c. ***Beliefs, Intentions and Goals***:

Since uncertainty is typical of this domain (data can be incomplete and/or rough data have to be interpreted at a higher level of abstraction in order to be represented as beliefs), we indicate in the representation of beliefs, intentions and goals their probability to be true.

-`Beliefs: (BEL N u p)`, where u is a mental attitude or a fact and p is the probability that the belief is true.

- Intentions: (`Int-To-Do N z p`) should be intepreted as: 'NICA intends to perform the action z with a probability of p', where z is a domain action.

-Goals: (`GOAL N v p`), v is a mental attitude and p is the probability of the goal. In particular we indicate with `(P-GOAL N v)` the agent's persistent goals that are certain.

3.2 Perception and Interpretation

The PERCEPTION phase allows collecting data from sensors present in the environment and to handle the user input (speech or actions in the environment). Sensors are controlled, as in C@sa architecture, by simple agents that send messages to the INTERPRETATION Metareasoner. This module evaluates changes in the world and user state that are relevant to the robot reasoning. The received messages are then transformed into a set of beliefs that are evaluated and stored in the agent's mental state.

In order to handle the goal processing steps, these beliefs are classified into the agent mental state as:

- **Maintenance Beliefs**: in this set are stored beliefs supporting P-GOALs. These beliefs must be kept true with a high level of certainty in order to support the mission and motivations of the agent. In our application scenario we have identified the followings beliefs that can be inferred starting from a set of perceptions about the user and context state or trough a dialog with the user:
`(BEL N (Feel(U,comfort))0.75)`: "NICA has to belief that the user is in a quite comfortable situation".
`(BEL N (Has(U,normal(health_state)))0.75)`: "NICA has to belief with a good degree of certainty that the user is in a normal health condition", i.e. the value of the diabetes, blood pressure and heart beats are in a normal range.
`(BEL N NOT(Is(U, Negative(affective_state)) 0.75)`:"NICA has to belief that the user is not in a negative affective state".

Figure 2 shows an example of belief network (BN) in which low level beliefs deriving from perceptions can be used to infer beliefs about the negative, neutral or positive affective state of the user.

This model is dynamic and allows to take into account also the influence of the previous affective state by expressing this temporal link as a function between the *Bel(AffSate)* variable at time t_i and the same variable at time t_{i+1} (Dynamic BN, [16]).

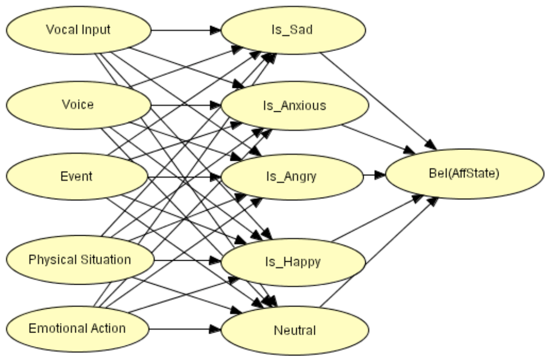

Figure 2. User affective state belief network.

In order to handle complexity, modularity and flexibility of the model, root nodes in the BN structure can recursively represent elementary BNs that are used to reason on the particular belief described by that node. The nested network will have a single leaf node that will correspond to the root node of the main complex network [7,17]. For instance, on the node Voice in Figure 2 will be nested a BN that allows to determine the probability that the utterance spoken by the user denotes a negative, positive or neutral attitude by analysing speech prosodic features (see [5] for more details).

- **Triggers Beliefs**: this set stores beliefs that denote changes in the world, after the belief revision, that may trigger new contingent goals.
- **Preference Beliefs**: in this set are stored beliefs that indicate a preference about a certain action over another one.
- **Cost Beliefs**: represents costs in terms of time, resources, etc. useful for the estimation of the utility of goals or plans.

3.3 Agent's Goals

The *agent's mental state* stores also the Agent Persistent Goals (P-GOALs) and the Contingent Goals.

The *persistent goals* never change because denotes the agent's nature, its mission, and guide its reasoning (i.e. keep the wellness of the user). Their achievement is then interleaved with the achievement of contingent *goals* that are triggered by the situation. The current goals to achieve are saved into the Goals Stack that is update according to the evolution of the situation.

Table 2. Persistent goals considered in the scenario

persistent goal	Maintance beliefs supporting goals

keep the wellness of the user	`(P-GOAL N (BEL N (Feel(U,comfort))))`
	`(P-GOAL N (BEL N (Has(U,normal(health_state))))`
	`(P-GOAL N (BEL N NOT(Is(U,Negative(affective_state))))`

schedule daily ToDoList	`(P-GOAL N (Int-To-Do N Plan(N ToDoList)))`
execute actions in ToDoList	`FORALL z element of ToDoList:` `(P-GOAL N (Intend-To_Do N z))`

In the considered scenario we set the persistent goals shown in Table 2. These goals are the ones that human caregivers indicated as important in their daily assistance.

3.4 Goal Triggering and Planning

The reasoning of the agent is constituted by different steps. The first one is Goal ACTIVATION. In this phase, goals are triggered on the bases of the current beliefs and these can be then pursued after the EVALUATION step.
Indeed this phase uses a reasoning model that allows to relate beliefs stored in the agent's mental state with the activation of the goals. Possible goals belong to two categories: service-oriented task execution and socio-emotional related goals.

This step is based upon a mixed model: starting from the beliefs about the current state and from the agent's persistent goals, using a set of reasoning rules the model selects the influence diagrams describing the possible contingent goals in the current context.

Influence Diagrams (ID) [16] have been selected as modelling formalism since the agent has to reason on the utility of pursuing a goal in the current context. In particular it models the relation between goals, random uncertain quantities (e.g. context situation) and values (e.g. utility of the goal).

Figure 3 shows the high-level diagram used for deciding the utility of the possible affective goals triggered by the situation. In particular, the ***square box*** denotes the decision about selecting a goal G at time t_i; the ***round nodes*** are chance variables like in a BN and they denote the situation before (t_i;) deciding to achieve one of the goals and after (t_{i+1}); the ***rhombus nodes*** represents the utility value deriving from an improvement in the user affective state when G is selected and the correspondent plan will be executed.

Each activated goal will have an utility, that defines how much it is worth to be pursued. Then, the Evaluation Phase decides whether or not active goals can in principle be pursued, according

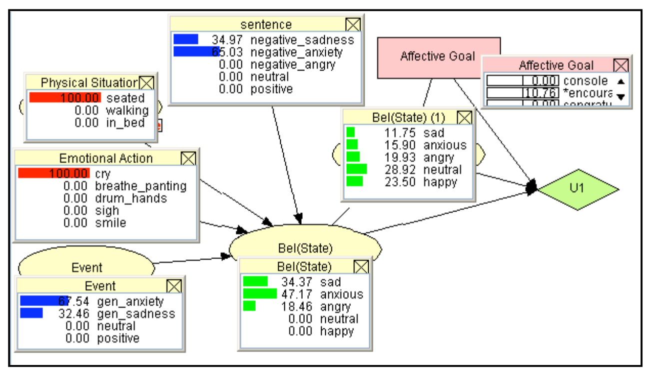

Figure 3. An example of goal activation.

to the beliefs in the mental state of the user. For example conflicts, resources etc, are checked. After this checking, goals with the maximum utility are selected. When there are goals of the same type, it is possible to use preferences or priority rules.

The example shown in Figure 3 describes how the goal triggering model works in the scenario described previously:

Maria is crying and the event "going to the doctor" generates anxiety and sadness in Maria. Moreover, the linguistic and prosodic features of the spoken sentence denotes a high level anxiety and a bit of sadness.

In this case, NICA chooses to activate the "encourage" goal, because it is the one with the higher utility since it let to raise the wellness level of the affective state of the user, leading to a probable lowering of the probability of being sad and anxious and to a raising of the probability of being in a normal state.

Once a goal has been selected, actions are planned selecting the plan from a library.

The planning of the service-oriented actions, actually related to the ToDoList, is made using plans that allow calling the services provided by the smart home.

The planning of the social and affective actions is made using plans that actually drive the communicative behaviour of the robot.

In both cases a plan is described as follows:

- *precondition*s: the conditions that have to be true to select the plan;

- *effect*: the goal that the plan achieves.

- *body*: the set of conditional actions that constitute the plan.

The following is an example of a portion of instantiated plan:

```
<Plan Name="Encourage">
<SelectCond> <Cond var="affective_goal" value="encourage"\>
<Body>
   <Act name="Move" to="Maria" />
<Cond var="know_reason" p-down="0" p-up="0,49">
   <Act name="Ask" to="Maria" var="Why(Maria,anxious)"/>
</Cond>
<Cond var="know_reason" p-down="0,5" p-up="1">
   <Act name="Inform" to="Maria" var="Understand(NICA,MARIA)"/>
</Cond>
   <Act name="Express" to="Maria" var="Encourage(NICA,MARIA)"/>
   <Act name="Inform" to="Maria" var="WhatToDo(MARIA)"/>
...
```

The tag <Cond> allows selecting actions on the basis of the current situation. For instance, the action "Ask Why" will be performed only if the agent does not know with a certainty higher than 0.5 why the user is in the current state. Moreover, if the action is complex, then how it is decomposed into elementary robot behaviors is specified in a subplan. Plans have been created and optimized combining actions on the basis of pragmatic rules that were derived from the corpus dataset.

After the execution of each action, the correspondent effect is written as belief in the agent's mental state.

4. AN EXAMPLE

In the proposed scenario we suppose that the user, called Maria, is sitting down moaning; this is considered as a triggering belief and it is stored in the agent mental state as:

(BEL NICA Feel(MARIA,anxious)).

According to the BN in Figure 2 this belief influences the belief on the user affective state that is inferred as being negative with a high probability. This fact threaten one of the maintance beliefs for the persistent goal:

GOAL-P N (BEL N NOT(Is(U,Negative (affective_state))))

This fact is added to the list of triggers beliefs and then the agent considers if a reaction is needed to restore the belief. In the first phase the rules to select the influence diagram modelling reasoning about this influence sphere are applied. To this aim, IDs are enriched with information about the influence sphere they allow to manage.

In this example, the ID in Figure 3 is selected and as explained previously the "encourage" goal is selected and the correspondent plan actions are inserted in the Action list. Then the execution begins.

Figure 4 shows the robot monitor interface when the goal is triggered and the plan is executed. The plan includes the following actions since NICA does not know why the user is anxious and a bit sad it will ask the user about it:

MoveTo(NICA,MARIA)
Ask(N, MARIA, Why(MARIA,anxious))
Express(N, MARIA, encouragement)
Inform(N,MARIA, WhatToDo)

When the user answers, his/her move is evaluated using the method explained above. If the current goal keeps its validity than the current plan execution proceeds, otherwise the goal is dropped, actions in the list are cancelled and a new plan is selected.
The new beliefs related to the affective and social sphere that are acquired by the agent during the interaction with the user are stored in the Social Memory. In this way, NICA will remember that the event "going to the doctor" is associated to "being anxious and the next time will try to prevent this state.

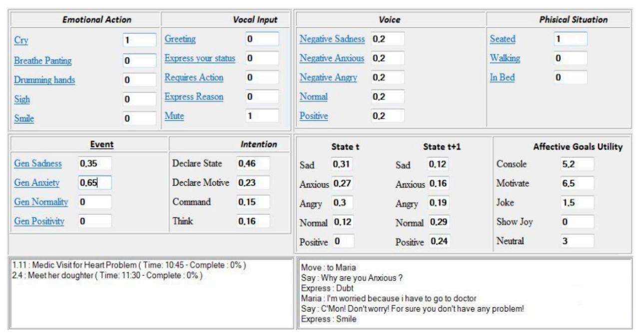

Figure 4. Screenshot of NICA monitor window.

5. CONCLUSIONS AND FUTURE WORK

The research presented in this paper has been developed in the context of the NICA project. NICA is a social robot acting as a caring assistant for elderly people living in a smart home.

Besides performing service-oriented tasks, the robot has to establish a social long term relation with the user so as to enforce trust and confidence. In this phase of the project we have developed the service-oriented infrastructure [10], the feedback interpretation module [9], the daily activity scheduler. In this paper we have presented an approach to planning social and affective reactions in the robot behaviour. This approach is based on the integration of logical rules, probabilistic models and conditional plans.

The first results are encouraging, however we did not have yet the possibility to evaluate the system with real users. In this phase of the project we performed a quantitative evaluation of the decisions and plans executed by the agent compared to the behaviours of the human caregivers collected in the initial phase of the project.

Results of the evaluation indicate that the system performance is quite good since the percentage of matching between robot and human actions in the dataset is 79.

At the moment we are testing and refining the reasoning strategies of the robot in order to improve its performance.

6. ACKNOWLEDGMENTS

Our thanks to VINCENZO DESARIO for developing the prototype of the system.

REFERENCES

[1] T. McFadden, J. Indulska, Context-aware Environments for Independent Living, Proceedings of 3rd National Conference of Emerging Researchers in Ageing (ERA 2004), Australia, 2004.

[2] S. Consolvo, P. Roessler, and B. E. Shelton, “The CareNet display: Lessons learned from an in home evaluation of an ambient display,” in LNCS - UbiComp 2004: Proceedings of 6th International Conference on Ubiquitous Computing, vol. 3205.Springer, 2004

[3] N. Shadbolt, Ambient Intelligence. IEEE Intelligent Systems. (Vol.18, No.4) July/August 2003.

[4] B. Reeves, C. Nass, The media equation: how people treat computers, television, and new media like real people and places, Cambridge University Press, New York, NY, 1996.

[5] F. de Rosis, A. Batliner, N. Novielli and S. Steidl. 'You are sooo cool Valentina!'. Recognizing social attitude in speech-based dialogues with an ECA, Proceedings of ACII 2007, 179-190.

[6] F. de Rosis, N. Novielli, V. Carofiglio, A. Cavalluzzi, and B. De Carolis. User Modeling And Adaptation In Health Promotion Dialogs With An Animated Character. Int. Journal of Biomedical Informatics, pages 514-531, 2006.

[7] I.Mazzotta, F.de Rosis and V.Carofiglio. A User-Adapted persuasion system in the healthy eating domain. IEEE Intelligent Systems, 22, 6, 2007.

[8] I. Mazzotta, V. Silvestri, and F. de Rosis. Emotional And Non Emotional Persuasion Strength. Proceedings of AISB08, Symposium on ‘Persuasive Technology’, 14-21, 2008.

[9] G. Cozzolongo, B. De Carolis, S. Pizzutilo: Social robots as mediators between users and smart environments. Proceedings of the 12th international Conference on intelligent User interfaces (Hawaii, USA, 2007). IUI '07.ACM Press, New York, 353-356.

[10] B. De Carolis, G. Cozzolongo, S. Pizzutilo, V. L. Plantamura: Agent-Based Home Simulation and Control. ISMIS 2005: 404-412.

[11] de Rosis, F De Carolis, B Carofiglio V, Pizzutilo S: (2003). Shallow and inner forms of emotional intelligence in advisory dialog simulation. In H Prendinger and M Ishizuka (Eds): "Life-like Characters. Tools, Affective Functions and Applications". Springer, 2003.

[12] H. H. Asada, P. Shaltis, A. Reisner, S. Ree, and R. C. Hutchinson, “Mobile monitoring with wearable photopletismographic biosensors,”IEEE Eng. Med. Biol. Mag., vol. 22, no. 3, pp. 28–40, 2003.

[13] I. Korhonen, J. Parkka, and M. V. Gils, “Health Monitoring in the Home of the Future,” IEEE Eng. Med. Biol. Mag., vol. 22, no. 3, 2003.

[14] M. Rao, M. Georgeff, BDI Agents from Theory to Practice, Technical Note 56, AAII, April 1995.

[15] C. Castelfranchi, C., Paglieri, F. (2007). "The role of beliefs in goal dynamics: Prolegomena to a constructive theory of intentions". Synthese 155, pp. 237-263.

[16] F.V. Jensen. Bayesian Networks and Decision Graphs. Statistics for engineering and information.

[17] E. Gyftodimos and P. A. Flach. Hierarchical bayesian networks: A probabilistic reasoning model for structured domains. In Edwin de Jong and Tim Oates, editors, Proceedings of the ICML-2002 Workshop on Development of Representations. University of New South Wales, 2002.