An implementation of a symbiotic ecology with self*-properties in an eHealth scenario

Athanasios G. Ouzounis[2], Ioannis D. Zaharakis[1,3] and Achilles D. Kameas[1, 2]
[1] Computer Technology Institute, Patras, Hellas
[2] Hellenic Open University, Patras, Hellas
[3] Technological Educational Institute, Patras, Hellas
athouzgr@hotmail.com, {jzaharak, kameas}@cti.gr

Abstract: This paper presents an implementation of a symbiotic ecology with self*-properties in an eHealth scenario. In addition, presents the architecture of a swarm which consists of a small number of artefacts that operate in the symbiotic ecology. The aim of this work is to study the emergence of self*-properties and particularly the influence of the environment on the timely achievement of the objectives of the swarm. A series of experiments are presented, focusing at the observation of self*-properties and the response times of the swarm. All experiments are performed with the use of a simulator.

I. Introduction

Our daily working or living spaces consisting of Ubiquitous Computing services and Ambient Intelligence artefacts are examples of symbiotic ecologies. Such environments contain many heterogeneous objects which implement different skills and services. All these objects and services can be considered as basic building blocks of such ecologies [9]. Each block has an internal part, which includes the internal structure and function, and an external part, which expresses skills and affects the environment. Moreover, each basic building block has several predefined functions called basic behaviours. Some of these are reactions to external events and mimic the reflective action of living organisms, while others seek to be accomplished and mimic the preservation instincts. The interdependencies among the main structural units and the environment form an ecology. In such ecologies artificial entities and people coexist harmoniously and perform collaborative works [6].

The integration of calculation in everyday objects leads to the development of smart artefacts which are the structural blocks for the vision of Ambient Intelligence. Our approach is that all the artefacts form a heterogeneous swarm of reactive agents, leading to many potential benefits including flexibility and adaptability to the environment, robustness to failures, etc. Reactive agents do not have an internal representation of the world in order to reason about, but their behaviour is based on a stimulus response philosophy to the current state of their environment. In addition, the adoption of subsumption architecture, which first R. Brooks [2] presented, enhances the simplicity, economy, computational tractability, robustness against failure and elegance. Furthermore, the fact that the swarm provides several services contributes to the general capabilities of the system given that the services are as simple as possible. As the number of the artefacts increases, we consider that simple services can be combined with each other and compose new services using swarm intelligence [1]. In this composition several self*-properties emerge, contributing to desirable operations of any autonomous and self-managing system. According to [8] these are:

Self-configuration: every new agent doesn't have to go through a special process, since it is being incorporated automatically into the swarm.

Self-optimization: the system distributes the primary and secondary goals to various agents automatically in the most efficient way.

Self-protection: the system detects and is being protected from damages, originated from accidents.

Self-healing: the system detects and identifies any occurring damage and resuscitates from it.

Due to the instability of the correlation of basic and emerging behaviours, the best known way to strengthen or weaken an emerging property is the extensive experimentation and the continuous observation.

II. Case Study

The study focuses on self*-properties that occur in the symbiotic ecology. Our main objectives are:

a) The modelling of entities, the basic behaviours and the environment inhabit;
b) The encoding of basic behaviours and their integration into a suitable architectural schema in order to solve the given problem;
c) The design and the implementation of a simulation environment;
d) The definition of scenarios for the emergence of self*-properties of the ecology; and
e) The performance of a series of experiments that evaluate the collective behaviour of the ecology.

In this context, we deal with a problem of the real world as a test case. We place a swarm of artefacts in a living space of a patient with permanent respiratory problems, loss of support and partial paralysis in order to provide sufficient oxygen in critical situations. To identify and treat the patient's respiratory insufficiency, we place a finger oximeter, a portable oxygen bottle and an oxygen condenser. To deal with the partial paralysis and the inability of support we place a wheelchair and a patient's bed. We have also implemented a charger and a PDA to support the whole system. The goal achievement is based on the composition of services provided by artefacts. Predefined tasks cannot be completely accomplished by individual services and artefacts. Finally, the patient's inability to serve himself led us to a slightly unorthodox decision. When the patient presents a symptom of respiratory insufficiency, we remove the artefact's control from the patient and adapt it to the system, which is considered to be more reliable.

In our modelling approach, artefacts are reactive agents and they form a heterogeneous swarm. Every reactive agent has several basic behaviours which combine each other and emerge collective behaviours. From the combination of basic and collective behaviours emerge self*-properties.

Healthcare today remains one of the most information intensive and least automated of all industries. European Commission through its eEurope 2005 Action Plan has drawn some specific innovative guidelines and objectives for advancing the current eHealth situation. These include the creation and dissemination of electronic health cards, the set up of European-wide information networks of public health data and the provision of online personalized health services through intelligent information systems to the citizens.

Our goal is to develop a scalable, adaptive system so that they can be modularly integrated into an intelligent home environment to enhance the individual's autonomy. The system has been designed to assist the user through monitoring and mobility help. Thus, we plan to contribute to the development of the next generation of assistive devices for people with disabilities so that they can be self-dependent as long as possible. We focus on compatibility with existing technologies in order to achieve an easier integration into existing systems. Scalability is meant to include or remove devices from the system in a simple, intuitive way.

A multi-agent swarm with self*-properties are adaptable to the environment. As self-configuration emerges it is easy to include or remove new agents, strengthening the scalability. The combination of self-protection and self-healing provides robustness to failures and self-optimization provides also flexibility to the whole system. In addition, the indirect communication eliminates the negotiations between agents.

III. ARCHITECTURE

We provide every reactive agent with a perception system, a set of basic behaviours structured in subsumption architecture, a small memory and a system of actuators. The subsumption architecture suggests that one action takes place at any given time, according to the stimuli.

A. Communication

Our basic communication approach is based on a wireless system being able to transmit and receive radio signals. Each signal is transmitted to a specific frequency and simulates a pheromone of a specific chemical composition. This method allows us to create a variety of digital pheromones. Furthermore, we exploit the environment as a temporary memory, a main component of stigmergy (indirect communication). The signals, which are transmitted into the environment and simulate the pheromones, are (LO) for lack of oxygen, (PO) to provide oxygen and (PP) to provide power. Any agent which is capable of transmitting signals, can only transmit a signal from the (LO), (PO) and (PP). Each signal is a group of concentric circles centred on the agent. Each cycle has a specific intensity, which is strong in the centre, being weakened as it spreads. The duration of the signal is very small, almost instantaneous.

B. Behaviours

We analyzed and encoded basic behaviours and arranged them in a subsumption architecture scheme. These behaviours are:

Move to Target: allows agents to move to a point within a range. There are several behaviours "move to target", depending on the internal situation of the agent which are "move to power supply unit", "move to oxygen supply unit" and "move to patient".

Avoid Obstacles: allows agents to avoid collisions with static obstacles. It is activated when static obstacles are sensed. The agent's velocity is adjusted depending on the distance of the nearest obstacle (accelerate, slow down or stop).

Avoid Kin: allows agents to avoid collisions with other agents. It is activated when nearby agents are sensed. The agent's velocity is adjusted depending on the distance from the nearest agent (accelerate, slow down or stop).

Low Oxygen: allows agents to identify a respiratory insufficiency problem. In each activation, a (LO) signal is being transmitted.

Oxygenation: allows agents to provide the patient with oxygen. The behaviour is triggered by the patient.

Supply Oxygen: allows agents to supply oxygen to a device. The behaviour is triggered when the sensor understands that a device is connected.

Algorithm for Supply Oxygen behaviour

```
Supply Oxygen:
  If connected agent dispenser is not full
    Add an oxygen unit to connected agent
  Else
    Set connected agent oxygen status to normal
    Disconnect agent
```

Supply Power: allows agents to charge the batteries of a device. The behaviour is triggered when the sensor understands that a device is connected.

Wake Up: allows agents to prepare the patient to receive oxygen. The behaviour is triggered when the sensor understands that the patient is carried and an (LO) signal is received.
Alert: allows agents to send a message to the carer's PDA. This behaviour is triggered in a critical situation.
Docking: allows agents to dock with another non movable agent and refuel with oxygen or charge. The links are at the back of the mobile agent.
Manual Operation: transfers control to another control unit, handled by the patient.

C. *Artefacts*

The artefacts that make up the swarm are:
Pulse Oximeter: it is a device placed in the patient's finger, counting the level of oxygen saturation in the blood and helps to identify the patient. Once the level falls below the permissible limit it transmits an (LO) signal. If the saturation level remains low for a specific time it sends a message to the carer's PDA.

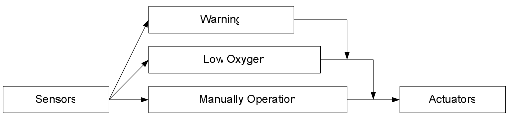

Fig. 1 Oximeter subsumption architecture schema [7]

Wheelchair: it is a mobile device that carries the patient at all accessible points, moving independently under certain conditions. After receiving an (LO) signal, it takes control and tries to reach the nearest oxygen supply point, following a (PO) signal. As soon as it realizes that the energy level has fallen below 5%, it is leaded to the charger and stays there until it is fully charged, simulating the self-preservation instinct. When the recharge process fails, the wheelchair sends a message to the carer's PDA.

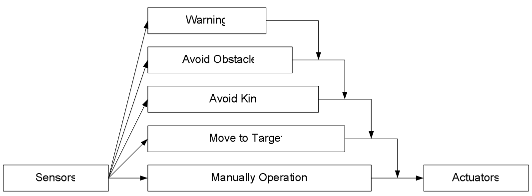

Fig. 2 Wheelchair subsumption architecture schema [7]

Oxygen Bottle: it is a mobile device capable of autonomous movement in the living space. It is able to provide oxygen to the patient at all accessible points. When it perceives an (LO) signal then it takes control, transmits a (PO) signal and tries to reach the patient. When it starts to provide oxygen to the patient any other function is being suppressed. As soon as it realizes that the energy level has fallen below 5%, it is leaded to the charger and stays there until it is fully charged, simulating the self-preservation instinct. When it realizes that its oxygen level has fallen below 2% it is leaded to the condenser and stays there until it becomes fully refuelled.
Oxygen Condenser: it is a solid device with ability to provide oxygen to the patient or to other devices such as oxygen bottles. It transmits a (PO) signal continuously until an oxygen bottle it being connected. When it supplies oxygen to the patient, any other process is suppressed.

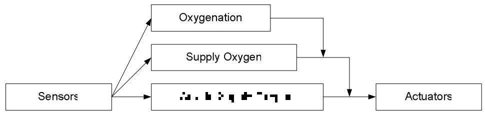

Fig. 3 Condenser subsumption architecture schema [7]

Charger: it is a solid device with ability to provide power to devices with a rechargeable battery such as wheelchairs or portable oxygen bottles. It transmits a (PP) signal continuously until a device is connected.
Patient bed: the patient uses the bed during sleep or rest. After receiving an (LO) signal, it takes control, sets an alarm sound and finally is transformed into a patient's chair.
Personal Digital Assistant (PDA): it receives messages from other devices. As soon as the carer receives a message from an agent, the system has partially failed and an external intervention is obligatory to continue its operation.

IV. Simulation Environment

For the purposes of this study, we analysed, designed and developed a standalone multi-agent simulation application running under Windows systems, using GUI for user interface and Java2D platform for the simulation environment.

Fig. 4. A simulation screen [7]

The obstacles appear as dark grey areas, wheelchair as blue circle with a blue bow (Fig 4, up & right), the portable oxygen bottle as a white circle with a red bow (Fig 4, middle & left), the oxygen condenser as a green circle with a yellow bow (Fig 4, down & right), the power charger as orange circle with a yellow arrow (Fig 4, down & left), the finger oximeter as a pink circle with a dark pink bow (Fig 4, inside wheelchair), the patient's bedside as dark grey rectangle with a grey arrow (Fig 4, up & left), and the signals as concentric circles (green in PO, orange for PP and dark pink on LO). Oximeter transmits LO signals, power charger transmits PP signals and condenser and oxygen bottle transmit PO signals.

V. Experiments

One of the main goals of the system is to provide the patient with oxygen within a reasonable time. This is critical for patient's life. To evaluate the system on this axis, we performed a series of experiments which measured the temporal response of the system in relation to the number and arrangement of obstacles in the living space. As agents try to avoid obstacles, they delay to achieve their goal and bring the patient's life at risk. Also, this continuous obstacle's detection and avoidance emerges the property of self-protection. Since the measurement of time needed is seriously affected by the composition and capabilities of the computer running the simulation, we decided to measure time by the steps of the basic algorithm of the simulation. We also performed another series of experiments measuring the successful and unsuccessful efforts to maintain the capacity of agent (instinct of self-preservation). Similarly, this is related to the number and arrangement of obstacles in the living space.

A. Experiments evaluating system's response time

In this series of experiments, the parameters of interest are the number of obstacles and their arrangement in the living space. Thus, we kept all the other parameters invariable. At the first three experiments we tried to demonstrate a messed-up house by spreading obstacles therein. Every time the experiment ran, the number of obstacles was increased by five. In the latter three experiments, we tried to demonstrate a tidy house. Similarly, we run our experiment three times, as above.

The experiment is as follows: the patient sits in his wheelchair and watches TV. An incident of respiratory insufficiency takes place. The wheelchair starts to move towards the nearest oxygen device. Time starts to count from the moment the incident occurs until the agents approach very near to each other.

Throughout the first three messed-up house experiments we kept track of the properties of self-protection, self-optimization and self-configuration. The wheelchair perceives the (LO) signals and then moves to the nearest source of (PO) signals, avoiding obstacles that are in its way. In parallel, the portable oxygen bottle perceives the (LO) signals and moves to the source of (PO) signals, avoiding obstacles that are in its way.

As we expected, the number and arrangement of obstacles affect the response time of the system.

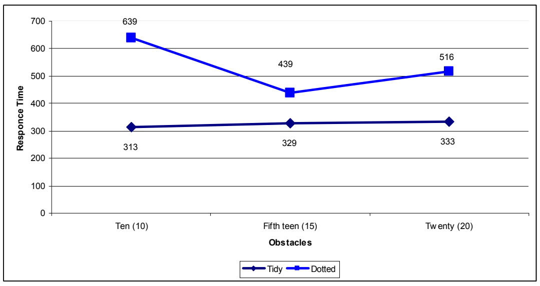

Fig. 5 Response Time Results [7]

We noticed that in a tidy living space, the gradual increase of the obstacles leads to a gradual increase of achieving time. We noticed similar results in the messed up living space with the exception of the few obstacles value. This is probably due to the characteristics of reactive agents, used to decide based on local information.

B. Experiments evaluating system's operation

Similarly in this series of experiments, the parameters of interest are again the number of obstacles and their arrangement in the living space. Thus, we kept again all the other parameters invariable. At the first three experiments we tried to demonstrate a messed-up house by spreading obstacles therein. Every time the experiment ran, the number of obstacles was increased by five. In the latter three experiments we try to demonstrate a tidy house. Similarly, we run our experiment three times, as above.

The experiment is as follows: The portable oxygen bottle has low energy and low oxygen. It starts moving towards to the power supply device (charger), avoiding obstacles in its way. Then, it recharges and moves towards the nearest oxygen device (condenser) avoiding successfully the obstacles on its way and refuels its oxygen stores.

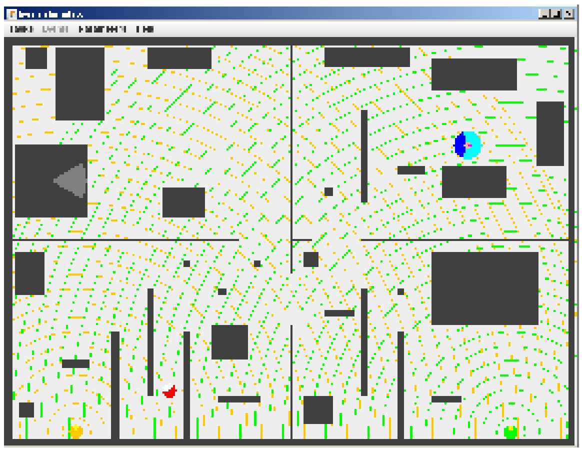

Fig. 6 Oxygen bottle moves to charger avoiding obstacles [7]

Throughout the second set of experiments, we kept tract of the properties of self-protection and self-configuration. The portable oxygen bottle perceives the (PO) and (PP) signals and moves towards avoiding obstacles in its way. As expected, the number and the arrangement of the obstacles affect the success or failure of the system to remain capable to provide full support to the patient.

These are stated in the table below:

TABLE I
SYSTEM'S OPERATION

Obstacles				
10	15	20	25	30
Success	Success	Success	Success	Fail

We noticed that the gradual increase of obstacles and complexity of obstacles affects the performance of the system. When the obstacles overcome a number then the system fails to meet its objectives.

VI. CONCLUSIONS

During our experimental simulations, the examined multi-agent system exhibited a functional behaviour which emerges from the interaction of basic behaviours among agents. Thus, specific self*-properties emerged, which were necessary for the effective attainment of the system's objectives. The properties that emerged were self-optimization, self-healing, self-protection and self-configuration. These properties are essential for the proper functioning of the system. We also noticed that our system is functional with a small number of obstacles and a tidy living space. The swarm of the agents achieves its goal without significant problems. Thus, the approach is workable. Key features like the computational cost of the subsumption architecture and the ease of integration and implementation of this architecture in everyday objects lead us to conclude that our approach is easy feasible.

VII. REFERENCES

[1] Bonabeau, E., Dorigo, M., and Theraulaz, G. Swarm Intelligence: From Natural to Artificial Systems. Oxford University Press, 1999.

[2] Brooks R. A., Intelligence without Reason. In: Proceedings of 12th Int. Joint Conf. on Artificial intelligence, Sydney, Australia, pp. 569-595 (1991)

[3] Brooks R. A., Intelligence without Representation. Artificial intelligence 47, pp. 139-159 (1991)

[4] Brooks R. A., Elephants Don't Play Chess, Robotics and Autonomous Systems, vol. 6, pp. 3-15 (1995)

[5] Brooks R. A., A robust layered control system for a mobile robot. IEEE Journal of Robotics and Automation, vol. 2, pp. 14-23 (1986)

[6] Zaharakis, I.D., Kameas, A.D.: "Social Intelligence as the Means for Achieving Emergent Interactive Behaviour in Ubiquitous Computing Environments" In Jacko J., (Ed.) Human-Computer Interaction, Part II, LNCS 4551, 2007, pp. 1018-1029, Springer-Verlag Berlin Heidelberg.

[7] Ouzounis A.G, Zaharakis, I.D., Kameas, A.D. Self*-properties in symbiotic ecologies, Hellenic Open University, 2008.

[8] The Vision of Autonomic Computing, Computer magazine, January 2003, IEEE Computer Society

[9] I. Zaharakis and A. Kameas, "Emergent Phenomena in AmI Spaces". In Proceedings of 1st International EASST-EU Workshop on Future Research Challenges for Software and Services, associated to The European Joint Conferences on Theory and Practice of Software (ETAPS'06), April 1st, 2006, Vienna, Austria. Also in the EASST (European Association of Software Science and Technology) Newsletter, Volume 12 (March 2006) pp. 82-96.

[10] Mataric J. M., Designing and Understanding Adaptive Group Behavior (1995)

[11] Wooldridge M., Intelligent Agents, in G. Weiss (ed.) Multi-agent Systems: A Modern Approach to Distributed Artificial Intelligence, MIT Press (1999)