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ATRACO: Adaptive and Trusted Ambient Ecologies

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***Abstract*— ATRACO is an EU funded R&D project that considers ambient ecologies consisting of people, context-aware artefacts and digital commodities (e.g., services and content). Members of the ecology are able to adapt to each other and form trusted ad hoc collaborations to achieve specific goals resulting from the need to serve specific human activities. Our aim is to research the factors and develop the technologies that will lead to the realisation of such ecologies (ATRACOs), following an interdisciplinary effort which involves Computer Science, HCI, AI, Control Theory and Sociology. Key factors of the ATRACO problem space to be examined include adaptation, interoperability, context awareness, user interaction and dynamicity of trust. We focus our efforts on seeking abstractions and mechanisms for establishing trust relationships between its members and on devising adaptation mechanisms based on system behaviour modelling, supervisory control theory of discrete event systems and type-2 fuzzy systems.**

***Index Terms*— Ambient ecology, component platform, user interaction, adaptation and privacy policy management, ontology.**

I. Introduction

THE vision of Ambient Intelligence (AmI) implies a seamless environment of computing, advanced networking technology and specific interfaces [1]. Technology becomes embedded in everyday objects such as furniture, clothes, doors, walls, vehicles, roads and smart materials, and people are provided with the tools and the processes that are necessary in order to achieve relaxing interactions with this environment. The AmI environment can be considered to host several Ubiquitous Computing (UbiComp) applications, which make use of the infrastructure provided by the environment and the services provided by the artefacts therein.

We have introduced the *Ambient Ecology* metaphor to conceptualize a space populated by connected devices and services that are interrelated with each other, the environment and the people, supporting the users' everyday activities in a meaningful way [2]. Everyday appliances, devices, and context aware artefacts are part of ambient ecologies. A context-aware artefact uses sensors to perceive the context of humans or other artefacts and sensibly respond to it. Adding context awareness to artefacts can increase their usability and enable new user interaction and experiences.

The ultimate goal of ambient ecologies is to serve people; this undoubtedly entails interaction with users and control by them – dealing with errors and faults, customizing settings etc. On the other hand, much of its management (e.g., configuration, handling of faults and adaptation to context) will be done autonomously and people will not be aware of it. An ambient ecology may involve large populations of entities that deploy themselves flexibly and responsibly in its working sphere. We argue that an ambient ecology that pervades our lives, but remains controllable, should have the following properties:

Adaptive. Adaptation is a relationship between a system and its environment where change is provoked to facilitate the survival of the system in the environment. Biological systems have inspired the development of adaptive software systems. In biological systems two mechanisms of adaptation are commonly specified *evolutionary* and *ontogenetic* adaptation [3]. The former is a selective mechanism whereby instances of a class of system reproduce themselves with variations and the variants that have a better fit with their environment are selected, whereas the later is the ability of a system to regulate itself and change its structure as it interacts with the environment. In software systems an analogy of the ontogenetic adaptation would be the replacement of one component by another component, where both components share a common interface. This approach is common to autonomic and agent systems, and is the approach adopted in ATRACO.

Composeable. An ambient ecology can be composed of individual artefacts and in parallel itself can be used as a building block of larger and more complex systems. Composeability can give rise to new collective functionality as a result of a dynamically changing number of well-defined interactions among artefacts. This approach of building UbiComp systems may be viewed as having much in common with the process where system builders design software systems out of components. Artefacts are treated as reusable "components" of a dynamically changing physical/digital environment, which involves people. These components are dynamically coordinated and reconfigured to meet

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environmental changes or varying goals. Composeability thus helps resolving both scalability and adaptability issues of ambient ecologies.

Purposive. It should be able to exhibit goal-directed behaviour i.e., it prefers some states of the world to other states, and acts to try to achieve worlds it prefers. An ambient ecology can be understood as a complex system where a multitude of artefacts interact, typically with some intended individual or collective purpose and respond to changing environments as adaptive entities. In that respect artefacts can be modeled as agents and ambient ecologies as open multi-agent systems [4].

Autonomous or *semi-autonomous*. It should be able to act (sometimes) without the direct intervention of people (or other systems), and it should have control over its own actions and internal state.

Trusted. It will behave in a dependable manner and will not adversely affect information, other components of the system or people. Therefore, it is required to have regulatory mechanisms to guide the behaviours of artefacts and ambient ecologies which may not be simply represented by fixed rules embedded in the system. A policy-based approach, instead, to control actions allows functionality to be modified without changing the implementation of the entities involved. Deontic Logic could be used to address action control and formally define concepts such as permission, obligation and prohibition [5].

So far, we have defined the basic concepts of ambient ecologies and specified design patterns and programming principles to support the development process in terms of their composeability [2]. ATRACO will extend this work by developing a conceptual framework and a system architecture that will support the realization of the adaptive and trusted properties discussed above. Our approach is based on a number of well established engineering principles, such as the distribution of control and the separation of service interfaces from the service implementation, adopting a Service Oriented Architecture model. ATRACO applications are dynamic compositions of distributed, loosely-coupled and highly cohesive components that operate in dynamic environments. In this respect they are similar to biological systems rather than to simple deterministic machines.

The remainder of the paper is organized as follows. Section II outlines ATRACO research objectives and the expected results in terms of contributions to knowledge and technology. Section III describes the overall strategy and methodology to achieve the goals. Section IV discusses in more detail our contributions in terms of the advancements in the area concerned. We conclude our paper with the potential impact of ATRACO in the area of pervasive adaptation.

II. Research Objectives and Expected Results

The overall objective of ATRACO is to lay the foundations for the development of a new range of components, architectures and guidelines that underpin the development of ambient ecologies. More specifically, the objectives are:

1. Develop a conceptual framework for ambient ecologies of devices and services. This framework will consist of a set of concepts implemented as a core ontology, a description of capabilities implemented as a hierarchy of basic and higher level behaviours and a novel interaction metaphor.
2. Research on adaptation mechanisms aimed at understanding how the properties of self-configuration, self-optimization, self-maintenance and robustness arise from or depend on the behaviours, goals, and adaptivity of individual artefacts, the interactions among them and the context of application.
3. Research on heterogeneity by developing and testing theories of ontology alignment to achieve task based semantic integration of heterogeneous devices and services.
4. Design of a service-oriented ambient ecology architecture and to develop or adapt the necessary components to realize its services. Also, where necessary, the project will develop APIs to interface with existing hardware modules and communication protocols, ontology modules, decision making mechanisms, negotiation and learning mechanisms, trust policies and privacy enforcement mechanisms and composeable interaction components.
5. Develop a testbed application, which will be deployed in the iSpace and the iCampus at the University of Essex [6] and the use of simulated conditions to research the scalability of the ambient ecologies approach.

ATRACO architecture is a service-oriented architecture that enforces a clean service oriented design approach, with a clear distinction between interfaces and implementation. The service-oriented approach assumes that service functionality will be implemented from a wide range of sources. This is similar to assumptions of component-oriented software development, as a result of which many application component platforms seamlessly incorporate service-oriented features.

In the following we illustrate the more specific contributions of ATRACO to knowledge and technology along with the expected results.

Ecology Adaptation: Ecology self-organisation and self-adaptation can be achieved by using a controller synthesis algorithm based on combination of basic behaviours and the Ramadge and Wonham supervisory control theory of discrete event systems [7].

Adaptation of user(s) behaviour: An adaptive system based on type-2 fuzzy logic to learn the user behaviour and adapt the ecology in a life long learning mode over lengthy durations of time to the user changing behaviour and the encountered uncertainties.

Data dissemination technologies through adaptation on multiple type communication networks: Development of open source software components that allow the adaptation of non predefined communication components. A component framework will be adopted and widely used home networking protocols will be supported.

User Interaction: Easily understood metaphors for allowing people to tailor ambient ecologies to their needs (multimodal interaction [8]); Mechanisms that will allow the man-machine interaction to adapt to the user context and behaviour. It will also develop the necessary system to evolve the man-machine interface with ambient ecologies.

Privacy components: A set of privacy enhancing components which use the definitions given by the ontology and user profiles will be configured according to situation specific requirements.

Ontology components: Theories and components supporting ontology alignment through negotiation, with emphasis on applying formal models and reasoning tools.

Knowledge Representation: Contextual knowledge will be represented with the help of context, device and service ontologies. XML or RDF representation will be used to ensure interoperability.

Semantic Interpretation: System behaviour can be specified as a synthesis of basic behaviours. The set of basic behaviours will be developed based on (a) abstract user models, (b) system functionality, (c) control theory principles and (d) privacy requirements.

III. METHODOLOGY

A. Overall Strategy

Key aspects of the problem space treated by our approach are adaptation, interoperability, context awareness, user interaction and dynamicity of trust. An ambient ecology is a distributed system composed of heterogeneous, yet interoperable, artefacts which may behave in unpredictable, complex ways depending on the context of use and the semantics of operation while providing numerous services to support our daily life. Such services will rely on the use of private data, such as user profiles.

The approach that we follow towards achieving the objectives of ATRACO is defined by a few core concepts:

Modularity: We adopt at all levels the component-oriented approach. Each application or service is regarded as a composition of components, which belong to different layers. Existing or new systems have to be specified as components or component assemblies, in this manner.

Openness: This is a concept that affects several aspects of ATRACO. Firstly, the specifications of the generic architectural framework and description (or interpretation) mechanisms are open, thus guaranteeing interoperability; however, specific application implementations can be proprietary. Also, components can be open, in the sense that they will publish an interface using the open mechanisms of the framework; as a result, even proprietary applications, built by definition as components, will be interoperable. In addition, components are open to use in different contexts, as they are initially built to be "empty" (of content, context etc).

Dynamicity of trust: Systems are defined as a vertical "slice" of components at different layers, together with the necessary interfaces between them. Privacy issues are considered at each layer of the architecture. The key issues here are protecting a person's identity, protecting an identity's personal data and protecting the activities of an identity.

B. ATRACO Design Principles

In order to realise the concepts in ATRACO and to achieve openness, we adopt a small set of design principles:

Design for composeability: All components are intrinsically extrovert, that is, they can be associated with other components into a larger system.

Design for autonomy: Each artefact is aware of its functions, its capabilities and goals, the state of its resources and the environment. Thus, it can locally manage its resources in order to improve self-sustainment. It may also engage in application-wide negotiations in order to promote the sustainment of artefacts in its environment.

Design for robustness: An ambient ecology needs to achieve a balance between efficient collective use of resources, unified operation, robustness and functional autonomy. Robustness is a principle that affects all layers of ATRACO architecture and has profound impact on the acceptability of new services.

Design for change: The artefacts in ATRACO bear a strong resemblance to the physical world (i.e. they are not solely digital entities) and thus can afford the natural wear that results from use. In addition, the openness concept allows us to personalise through use the digital self of the artefacts, as they are capable of learning and locally storing and managing knowledge.

Design for scalability: AmI space will be characterised by the increasing ubiquity of devices and software. Thus, the architectural framework, the interactions between components, and the software services provided in the ATRACO computing environment must all be scalable. A formal model of the ambient ecology needs to be developed and analysed for scalability.

C. Adaptation Principles

The vision of ATRACO is to create autonomous reactive entities that use the real world (as seen via sensors), rather than abstract representations, as the working model. This avoids the well known difficulties of lack of fidelity and synchronisation in creating and maintaining model of the real world that was famously summarised by Rodney Brooks as "the world is its own best model". The resulting ecologies will be driven by autonomy, local awareness and interactions, and distributed functioning. The aim is to build autonomous interactive entities that could form ambient ecologies exhibiting adaptation and leading to a synthetic approach. An important aspect on this focus is that although the entities will not have explicitly represented models of the world or of the others the emergent ecologies will unfold coherent collective behaviour based only on the entities' own agenda of actions and their intrinsic inclination to preserve their own goals.

An ATRACO system may be viewed from two different perspectives (Fig. 1): *extrovert view* and *introvert view*. In the extrovert view the ambient ecology acts as a middleware between its external environment and its components. This view hides the details of the composition from the external environment and enables the representation of the coherent and overall behaviour of the ambient ecology. In the introvert

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view the ambient ecology acts as a controller, which is responsible for producing the coherent and overall useful behaviour. In essence, an ambient ecology can dynamically change its configuration instead of being a static configuration of its components and by this exhibit internal behaviour that monitors, reconfigures controls and organizes its components. In this conception there is no static and explicit interaction between the components of the ambient ecology. It is the introvert part of the system that acts as the connector providing its composition. The introvert part provides the data links for the composition of the system, which changes depending on the required external behaviour of the system. Using the same principle, the extrovert view provides the dynamic interconnections between the ambient ecology, its external environment and its components.

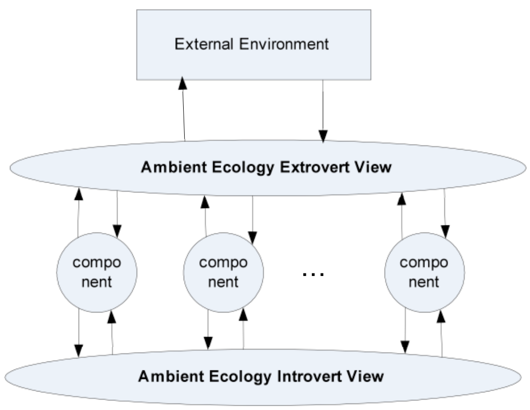

Fig. 1. Views of an Ambient Ecology

Adaptation of ambient ecologies is planned using Supervisory Control Theory. Unlike conventional methods Supervisory Control Theory allows us to, not only to verify a model against a specification, but also makes it possible to construct a solution to problem by synthesizing a supervisor, which can be seen as a device that controls the process to behave in the desired way. Supervisory control of discrete event systems addresses the problem of finding a controller C for a given plant P such that if put together, P and C conform to some specification S [7].

Instances of ambient ecologies (ATRACOs) acting as agents embed an internal controller which is responsible for self control, adaptation and reconfiguration. These controllers are based on type-2 fuzzy logic systems which could handle the environmental as well as the inter and intra users uncertainties. The controller will continuously be monitoring the external environment and the required external behaviour and by taking into account the internal structure and the status of the available artefacts/services determines the internal eligible behaviour of the system and a sequence of configurations that will accomplish the goals of an ATRACO system. The assessment of the internal behaviour of an ATRACO system can be modelled as a supervisory control problem. The external behaviour of the ambient ecology is the specification S that the system should conform to, the composition of the system is the given plant P and the internal behaviour of the system is the controller C to be found.

In addition, to support adaptation of system behaviour to changing requirements and conditions a behaviour-based metaphor is used to define system services as compositions of basic behaviours; this uniform approach allows us to treat both functional (i.e., components, services, etc) and social system aspects (social intelligence, privacy, etc.) in an equivalent way, thus permitting the manifestation of socially intelligent system behaviour. Thus, we are going to specify system behaviour as a synthesis of basic behaviours. The set of basic behaviours will be specified and developed in this task based on (a) abstract user models, (b) system functionality, (c) physical environment, (d) social principles and (e) privacy requirements. By assigning priorities on behaviours we expect to develop a system that will select its (re)action after taking into account social context and privacy requirements. In addition, by breaking down system services into basic functionality modules and decoupling them from the available sensors and devices, we expect to facilitate the emergence of adaptive behaviour.

D. Privacy and Trust Principles

Digital Territory

ATRACO's need to mark the digital boundaries of ambient ecologies for privacy negotiation requires the introduction of abstractions and mechanisms that will be based on the concepts of a digital territory and bubble [9]. The term, "digital territory" (DT), has been coined in an attempt to port a real world metaphor into the forthcoming synthetic world. Territories, that is, areas under a clearly established jurisdiction (their contour necessarily delineated by a boundary) initially referred only to land. A DT is an ephemeral AmI space: it is created for a specific purpose and integrates the will of the owner (an individual or group operator) with the means to achieve it (including infrastructure, properties, services and objects) within an AmI space. Privacy, usually synonymous to personal space, is translated into physical distance from others. A territory has a measurable quantity of elements, which are contained within its borders. Borders are no longer defined as "lines" to traverse or not. Borders are conceived as spaces "in-between", spaces of negotiation. Markers are a way of defining / denoting the boundaries, the borders and the points of negotiation and crossing.

We extend the concept of DT to that of an Activity Sphere. An activity sphere is an instantiation of an ATRACO application. An activity sphere is set up in order to support a specific user goal and it is a temporary entity; once the goal is no longer relevant, it is dissolved. It is adaptive in the sense that it has to support the tasks that realize the goal in different contexts, i.e. to realize various concrete tasks out of abstract tasks and goals. Each sphere develops a sense of common purpose for its constituent actors (which continue to operate autonomously), is capable of adapting its borders (by expanding or contracting using property based proximity metrics) and of regulating the degree of visibility of its inner state (by establishing clear markers and using adaptive filtering mechanisms) and facilitates the emergence of unified global behaviours by subsuming local artefact capabilities.

Privacy Policy Management

There are four key aspects of a privacy policy management framework in a multi-user, multi-artefact, multi-service populated ambient ecology environment: *policy representation*, *enforcement*, *generation and lifecycle*, and *deployment*.

Policy representation can be given in terms of a security/privacy ontology, covering basic security and privacy concepts, with reference to an ontological classification of data and activities in the application scenario domain. The three main policy entities are expected to be: *data policy* (e.g., the status of data, the purpose of the data, access constraints, storage constraints) *activity policy* (e.g., user participation in the activity, service participation, data input, data output) and *service policy* (e.g., which activities the service can be used in, message level and transport policies for accessing the service). All three policies can refer to abstract entities or concrete entities. Such policies can be generated using Semantic Web representation technology for a given application, based on a model of the application domain that includes activities as well as applications and data.

One of the main technical challenges is to enable automated policy generation as a side effect of carrying out application processes, since it will not be feasible to generate a consistent policy to implement privacy obligations by hand. It is also important that when new activities or services are added to the system, their policies can be automatically checked for consistency with the rest of the framework.

Also, we will need to address the question of how these semantic policy enforcement and production features should be distributed within a component based framework. We envisage that both features will be available at both ends of a P2P setup. Regarding privacy, we plan to address the privacy needs of ambient ecologies by defining policies at the level of the data flow and by embedding policy-relevant metadata in the data, so that the same privacy requirements can be enforced across different ecologies. We envisage this could be accomplished by adding semantics (metadata) relevant to the actual individual security/privacy requirements and leveraging this metadata to drive privacy measures across different ecology boundaries.

E. Prototype Testing

The testing of the ATRACO prototypes will be carried out in two stages: (1) by installing and testing within two real settings – the Essex intelligent flat (iSpace) and (2) by the use of simulations to study hundreds of entities, modelled as agents and their behaviours.

The iSpace Living Lab is at the heart of the Digital Lifestyles Centre at the University of Essex. This new apartment offers a variety of ubiquitous networked sensors and actuators, the infrastructure, some of which are accommodated within the specially constructed walls, so that the heterogeneous networking infrastructure is hidden from view. Designed to provide a flexible test-bed for research into intelligent buildings and adaptive environments, within a pervasive and ubiquitous computing context, the iSpace offers the possibility for examining the deployment of embedded agents and sophisticated user interfaces within the intelligent environments of tomorrow. Researchers will be able to deploy the latest technology to enable autonomous agents to monitor and learn from user behaviour and provide systems to particularise their behaviour to the building's users in an unobtrusive way, where the user is always in control. At the same time the iSpace will allow those concerned with the socio-technical research into the preferred interfaces and user defined development of virtual devices to explore this space with sensitivity and control.

IV. Research beyond the state of the art

ATRACO aims at complementing the existing and on-going work in areas such as cooperative artefacts [10], intelligent agents [11], uncertainty handing, ontology [12], privacy and intelligent planning [13] and adaptive interaction modeling [14] by bringing and enhancing technology that allows the development and deployment of applications and services that, in spite of heterogeneity and unreliable conditions, can display a capability for self-controlled adaptation and organisation. Adaptation will be provided in terms of artefact operation, uncertainty handling, ecology composition and man-machine interaction with respect to user context and behaviour. ATRACO proposes to integrate a combined adaptation strategy, with a sophisticated user interaction and privacy enforcement policy and will measure the technology capability as well as the user acceptance through a number of prototypes that will be tested and evaluated in the iSpace testbed.

Regarding the privacy area, we propose to complement and, where possible, build further upon ongoing security and privacy research and address the privacy needs of ATRACO by introducing "content-sensitive" and "process-sensitive" privacy policies, which can be used to integrate different platform components in a trustable manner. This will accomplished by (i) adding semantics (metadata) – relevant to the actual individual security/privacy requirements – to the purpose and execution of data flows and information processing across ecologies; (ii) leveraging this metadata to drive privacy measures across different ecology boundaries by making privacy mechanisms and/or policy frameworks in each of the different activities directly aware of the semantics.

By defining policies at the level of the data flow and information processing, and by embedding policy-relevant metadata in the data, the same privacy requirements can be enforced across different ecologies.

Ontology related research in ATRACO will advance the state-of-the-art in the direction of providing new ontology alignment mechanisms [15]. We are going to develop software components to realize such mechanisms in order to deal with the problem of proprietary, closed, possibly inconsistent third party ontologies that do not adhere to standards. Existing methods and tools in ontology alignment apply only to consistent ontologies that refer to the same domain and use only 1-to-1 correspondences. In ATRACO we are going to generalize these theories in order to apply to the more general case of 1-to-n correspondences. Moreover, we shall develop the theoretical foundations and the mechanisms to achieve the alignment of possibly inconsistent ontologies through direct negotiations between the artefacts that posses these ontologies, so as to reduce the human involvement in the process of alignment.

ATRACO will contribute to the current research on design and interaction paradigms. The diminishing amount of user interaction with applications and the changing nature of the interactions mandate the creation of new types of user interfaces. User interfaces must allow novel types of interaction that must become more natural as tasks become increasingly pervasive, such as delegation of tasks and provision of guidance to software agents. The need for universally available user interfaces will create a requirement for new methods of programming user interfaces and new models of user interaction to replace the models, centered on desktop computing, that have been widely used in the past. Regarding intelligent planning and adaptive dialogue modelling, the cited state-of-the-art uses a rigid and inflexible dialogue management strategy. In this work we will enhance the user-friendliness and efficiency of the human-computer interaction by directly integrating the results of the intelligent planning module into an adaptive dialogue strategy.

Finally, ATRACO will involve short and long term adaptation of the user behaviour to handle the short and long term uncertainties and the associated changes in user behaviour. This research will build an adaptive system based on type-2 fuzzy logic systems which will be able to learn the user behaviour and adapt in a life long learning mode over long time periods to the user's changing behaviour and the intrinsic uncertainties (which, in addition to control, can be used to enrich the underlying ontology model).

V. Conclusion

The potential impact of the ATRACO project is very considerable, in the following key areas:

ATRACO will provide an integrated approach to resolve the adaptation requirements of AmI spaces in terms of artefact operation, ecology composition and man-machine interaction with respect to user context and behaviour.

ATRACO will implement privacy management components that enable consistent privacy assurance in AmI spaces by introducing "content-sensitive" and "process-sensitive" privacy policies, which can be used to integrate different platform components in a trustable manner.

ATRACO will integrate a combined adaptation strategy, with a sophisticated user interaction and privacy enforcement policy and measure the technology capability as well as the user acceptance through a number of prototypes that will be tested and evaluated in iSpace testbed.

ATRACO will form a very important step towards the realisation of full ambient intelligent pervasive environments which are occupied by multiple users. The project will address many of the social, theoretical and practical research issues that will enable the creation of adaptable environments that can evolve in a life long learning mode to satisfy the user objectives. There are a wide range of application domains which can benefit from research in this project, these include Health, Care, Entertainment, Climate Change (Green Technology), Managed Public Environments and Practice Skills Training.

References

[1] IST Advisory Group, "Ambient Intelligence: from vision to reality", September 2003 [Online]. Available: http://www.cordis.lu/ist/istag-reports.htm

[2] C. Goumopoulos and A. Kameas, "Ambient ecologies in smart homes", *The Computer Journal*, to be published.

[3] H.R. Maturana and F.J. Varela, *Autopoiesis and cognition the realization of the living*, Dordrecht, Holland, 1980.

[4] N.R. Jennings, "On agent-based software engineering", *Artificial Intelligence* vol. 117, no. 2, pp. 277-296, 2000.

[5] G.H. Wright, "Deontic Logic" *Mind*, vol. 60, no. 237, pp. 1-15, 1951.

[6] V. Callaghan, G. Clark, M. Colley, H. Hagras, JSY Chin and F. Doctor "Intelligent Inhabited Environments", *BT Technology Journal* , vol.22, no.3, pp. 233-247, 2004.

[7] W.M. Wonham and P.J. Ramadge, "Modular supervisory control of discrete-event systems", *Mathematics of Control Signals and Systems*, vol 1, no 1, pp. 13-30, 1988.

[8] S.L. Oviatt, "Multimodal Interfaces", in *The Human-Computer Interaction Handbook: Fundamentals, Evolving Technologies and Emerging Applications*, Lawrence Erlbaum Assoc. Publ., Mahwah, NJ, 2003, chap. 14.

[9] L. Beslay and H. Hakala, "Digital Territory: Bubbles", Vision Book 2005 [Online]. Available: http://cybersecurity.jrc.es/docs/DigitalTerritoryBubbles.pdf

[10] M. Strohbach, H.W. Gellersen, G. Kortuem, C. Kray, "Cooperative artefacts: Assessing real world situations with embedded technology", in: *Proc. of the 6th Int. Conf. Ubiquitous Computing*, Nottingham, 2004, pp. 250–267.

[11] M. Wooldridge and N.R, Jennings, "Intelligent agents: Theory and Practice", *Knowledge Eng. Rev.* vol 10, no2, pp. 115–152, 1995.

[12] R. Gruber, "A translation approach to portable ontology specification", *Knowledge Acquisition*, vol. 5, no. 2, pp. 199-220, 1993.

[13] M. Ghallab, D. Nau and P. Traverso, *Automated Planning - Theory and Practice*, Morgan Kaufmann, San Francisco, CA, 2004.

[14] C. Rousseau, Y. Bellik, F. Vernier, D. Bazalgette, "A Framework for the Intelligent Multimodal Presentation of Information", *Signal Processing*, vol. 86, no. 12, pp. 3696 - 3713, 2006.

[15] E. Rahm and P.A.Bernstein, "A survey of approaches to automatic schema matching", *VLDB Journal*, vol. 10, no. 4, pp. 334-350, 2001.