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Agent technology applied to Intelligent Buildings

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Abstract: - The main goal of this paper is to evaluate the levels of previous research on the application of agent technology to the Intelligent Buildings (IBs). For the above meta-research purpose we use a specific methodology that we describe. A number of variables are selected related to all basic aspects of software agent technology that we estimate important to include. Based on this number of variables the meta-research is transacted through statistical processing over selected literature related to IBs. Our basic motive is to promote future theoretical investigations and stimulate researchers' efforts.

Key-Words: - Intelligent Buildings, Agents, Meta-research.

1 Introduction

Generally speaking, intelligent building (IB) is a concept according to which a computerized scheme regulates building components, utilities, electrical circuits, and HVAC (heating, ventilating, and air-conditioning) systems so as to monitor building functions, security, energy consumption, and provide a comfortable environment to the building's residents [1]. To be more precise, IBs are composed of numerous sensors, effectors and control units interconnected in such a way as to effectively form a machine [2]. Actually, an intelligent building constantly adapts itself by learning from its users and takes actions to control the effectors of the building. By doing so it gradually learns what a user's behaviour is and adapts to it [3]. As the environment of an IB is very complex (inaccessible, non-deterministic, non-episodic, dynamic and continuous) [4], a good solution for controlling it is multi-agent systems. If a problem domain is particularly a complex, large, or unpredictable, then the only way it can reasonably be addressed is to develop a number of functionally specific and (nearly) modular components (agents) that are specialized at solving a particular problem aspect [5]. A MAS can be defined as a collection of, possibly heterogeneous, computational entities, having their own problem solving capabilities and which are able to interact among them in order to reach an overall goal [6].

In this paper, we conduct a meta-research evaluation of the previous research activity on agents in intelligent buildings (IBs). A number of variables-parameters are selected related to all basic aspects of software agent technology that we estimate important to include. Based on this number of variables and using a specific methodology we transact the meta-research through statistical processing over selected literature related to IBs. The evaluation of previous research activity on agents in IBs is accomplished in terms of percentages that depict the magnitudes that contemporary research activity studies the specific variables-parameters of agent technology. This study is based on theoretical investigation focusing on promoting theoretical work in future and constitutes a methodological exploration for synthesizing inhomogeneous literature. Our main purpose is to stimulate and support potential researchers' efforts. Before starting a research project, researchers must acquire all the essential background knowledge and the state of the art fundaments of the related research. We try to facilitate researchers in the above goal.

2 Methodology

As discussed earlier, this study performs a meta-research of previous research activity on agents in IBs. A meta-research is a study on research and an analysis of analysis and it can be defined as the synthesis of primary research results into more general conclusions [7]. As meta-research method we use Rogers, E. M. (1981) propositional inventory with some divergence from the actual method definition. Propositional inventory is the synthesis of general conclusions from research where the original data is not available and hence where only written conclusions from each of the primary studies are available to the meta-researcher. The key methodological issue when conducting a propositional inventory is to closely define the parameters of the research to be included in the analysis prior to beginning the literature search [7]. The propositional inventory uses the categorizing of discrete elements such as variables, methods or findings in a specific study. Once similar studies have been broken down, the strengths and weaknesses of the body of the research can be understood as a whole and gaps in knowledge can be identified [8].

The body of literature over which the meta-research is conducted was identified by doing a review of articles' communication abstracts and titles firstly and articles' body secondly searching for relevant work under the key words, agent(s), multi-agent system(s) or MAS concurrently with the key words, intelligent building(s), (smart or intelligent) home(s) or house(s) or room(s) or dorm(s), ambient intelligent environment(s), ambience, inhabited intelligent environment(s), intelligent interactive home(s), human home interaction(s), interactive home(s), adaptive environment(s), home automation, ubiquitous environment(s), building automation. In addition other key words were taken into account but with low priority that are relevant with the intelligent buildings' area from a broader view, such as intelligent work space(s), elder independence, (home) appliances, etc. The reference lists from the obtained works were considered to identify additional studies in the area of the agent technology in IBs. As relevant studies were identified, their references also were used to expand the body of research that was examined. Using this approach, a total of 72 literature sources in majority conference and journal papers, were identified as potentially focused on some aspect of agent technology in IBs.

A number of variables-parameters are selected, related to all basic aspects of software agent technology that we judge important to include, over which the meta-research is transacted. We consider an aggregation of sets of variables. The variables that constitute each set are associative with each other under the prism of a concept that determines the specific set. The concepts that determine the specific sets of variables comprise all the different aspects of the agent technology that we judge important to include into our meta-research evaluation of IBs. An important point that we must underline is that the evaluation of a variable is performed only in comparison with the other relative variables of the same set and not taking into account any other variables of the other sets.

We estimate the level of previous research activity (the selected body of literature referred above) in terms of percentages that correspond to the % percent that a specific variable is ignored by the literature body and to the % level of variable performance[1] in terms of moderate, good, very good and excellent[2]. In other words, we try to provide the level of coverage of a specific variable by the body of literature in terms of 'ignore', 'moderate', 'good', 'very good' and 'excellent'. The study provides an overall view of the literature level of relevance to specific aspects of agent technology without presenting separately in details the studies that correspond to each result or categorizing the literature body according to the results mentioning separately each distinct study.

In order to carry out our research aims, we propose an explicit evaluation model. The proposed evaluation model, utilizing the above mentioned sets of variables, puts the evaluation of previous research activity into practice in a simple but reliable way.

Evaluation model's considerations: i) it uses SPSS 11.0 for Windows in order to conduct the statistical processing; ii) for every distinct variable the following question is set: to which extend this variable is used by the IBs applications.

iii) it uses qualitative variables, which registration became accordingly with the principle of registration of qualitative data in scale of order. Each answer that corresponds to the question of each variable is coded giving a number as code and then the codes are registered in the cells; iv) for the purposes of codes' definition we define the variable performance as 'the degree of positive answer and cover in the question that corresponds to each distinct variable; v) we define five codes:

Code No 1: <<Ignore>> it is reported in that the particular variable is not examined by the particular article as autonomous significance. It is not taken into consideration the fact that from the total estimate of the article it can come out some arbitrary conclusion with regard to the specific variable because this would lead to not valid and reasonably implicit estimate.

Code No 2: <<Moderate>>, Code No 3: <<Good>>, Code No 4: <<Very good>> and *Code No 5: <<Excellent>>* is reported in the fact that the 'variable performance' of the particular variable, based on the opinions, the estimate and the conclusions of researchers of the specific article as well as the opinions and conclusions of other articles that are taken into consideration in the specific article, is satisfied at moderate degree, good degree, very good degree and excellent degree correspondingly; vi) each set of variables is

[1] The term variable performance is defined below.

[2] The terms 'ignore', 'moderate', 'good', 'very good' and 'excellent' are also defined below.

examined separately by a sector of Statistics that is reported in the Descriptive Statistics where the examination rates (Frequencies) of the various variables per set of variable were studied.

3 Meta-research Results

The 1st set of variables concerns the agent systems and consists two variables: Single agent systems and Multi-agent systems. According to our findings, some research activity considers the environment of the intelligent house as an intelligent agent that is decomposed into lower level agents which are responsible for subtasks within the home. It is rare the case that an intelligent agent is used as a centralized agent which communicates with all other devices present in home in order to achieve the intelligent home's requirements. When research is referred to a single agent, it is usually used for specific purpose and probably cooperates with other agents. Both of the cases referred above are included in the content of the single agent system parameter. The previous research activity prefers the use of the multi-agent system approach for the intelligent buildings. According to the percentages of ignorance, MASs dominate (ignored at 32.9 %) in comparison with single agent systems (ignored at 87.7 %). MAS technology is studied at a very good degree of performance at 28.8%, at a good degree of performance at 24.7%, and at a moderate degree of performance at 13.7%.

The 2nd set of variables concerns the agent typology and consists the following variables: Collaborative agents, Interface agents, Mobile agents, Information/Internet agents, Reactive agents, Hybrid agents, Smart Agents, and Heterogeneous agent systems [9] [10]. The majority of previous research activity does not advert separately to distinctive agent types such collaborative agents, interface agents, mobile agents, information/internet agents, reactive agents, hybrid agents, smart Agents, and heterogeneous agent systems. Researchers prefer to describe in detail the agent-based systems they use and focus on their properties and usually they give their own labels to the agent types that they refer to. However, we observe some research activity that referred to the above distinct agent types. Smart agents' type is the most popular (ignored at 63 %). Mobile agents follow (ignored at 79.5 %). The percentages of ignorance for the rest agent types vary from 89 % to 98.6 %. Moreover smart agents are studied at a very good degree of performance at 8.2 %, at a good degree of performance at 16.4 %, and at a moderate degree of performance at 12.3 %.

The 3rd set of variables concerns the agent architectures and consists the following variables: Logic based agents, Reactive agents, Belief-desire-intention (BDI) agents, and Layered architectures [11]. It was observed that most research activity focused on layered architectures (ignored at 74 %) with the reactive agents' architectures to follow (ignored at 80.8 %). The other two agent architectures are almost ignored. Layered architectures are studied at moderate degree of performance at 5.5 %, at a good degree of performance at 12.3 %, and at very good degree of performance at 8.2 %.

The 4th set of variables concerns the agent communication and consists the following variables: Communication protocols and Evolving languages [12]. Communication protocols are common in IBs (ignored at 69.9 %). They are studied at moderate degree of performance at 24.7 % and at good degree of performance at 5.5 %. Previous research activity does not indicate any special interest to evolving languages.

The 5th set of variables concerns agent communication languages (ACLs) and consists the following variables: KQML (Knowledge Query and Manipulation Language), ARCOL (ARTIMIS COmmunication Language), FIPA-ACL (FIPA Agent Communication Language), KIF (Knowledge Interchange Format), COOL (domain independent COOrdination Language), ICL (Interagent Communication Language), AgentTalk, CoLa (Communication and coordination Language), TuCSoN (Tuple Centres Spread over Networks), LuCe, STL++ (Simple Thread Language ++), and SDML (Strictly Declarative Modelling Language) [13]. KQML is the most popular ACL (ignored at 80.8 %) referred by previous research activity and indicates moderate degree of performance 13.7 %. FIPA-ACL, KIF and ICL are almost ignored while the rest ACLs are totally ignored.

The 6th set of variables concerns the agent transportation mechanisms and consists the following variables: CORBA (Common Object Request Broker Architecture), OMG (Object Management Group) Messaging Services, JAVA Messaging Service, RMI (Remote Method Innovation), DCOM (Distributed Component Object Model), and Enterprise Java Beans Events [14] [15] [16] [17] [18] [19]. CORBA constitutes a popular agent transportation mechanism for IBs (ignored at 90.4 %). The rest agent transportation mechanisms are totally ignored.

The 7th set of variables concerns the ontology languages and editors and consists the following variables: Ontolingua, Frame Logic, CLASSIC, LOOM, CycL, SHOE (Simple HTML Ontology Extension), XOL (Ontology Exchange Language), OIL (Ontology Inference Layer), the DAML (DARPA Agent Markup Language) languages DAML-ONT and DAML-OIL, Protégé, Webonto, and OntoEdit [13]. Regarding ontology languages and editors, LOOM is almost ignored while all the other ontology languages and editors are totally ignored.

The 8th set of variables concerns the languages for constructing agent-based systems and consists the following variables: Java, C/C++, AGENT-0, Concurrent MetateM, AgentSpeak(L), 3APL, ConGolog, April (Agent PRocess Interaction Language), MAIL/MAI2L (Multiagent Interaction and ImplementationLanguage), VIVA, Actors, Placa, TCL/Tk, Safe-TCL, Safe-Tk, Java, Telescript, Active web tools, Python, Obliq, April and Scheme-48, RTA/ABLE, Pascal, C, Lisp, Prolog and Smalltalk [13] [20]. Java is extensively present in intelligent building research activity (ignored at 60.9 %). The percentages of ignorance for April, C, Prolog, C++, Lisp, and Python vary from 91.8 % to 98.6 %. All the other languages are totally ignored.

The 9th set of variables concerns the tools and platforms that support activities or phases of the process of agent-oriented software development and consists the following variables: ZEUS, JADE (Java Agent DEvelopment framework), LEAP (Lightweight Extensible Agent Platform), agenTool, RETSINA, JATLite (Java Agent Template, Lite), FIPA-OS, MADKIT, SIM_AGENT, JAFMAS (Java-based Agent Framework for Multi-Agent Systems), ABS (Agent Building Shell), OAA (Open Agent Architecture), Agentis, AgentBuilder, JACK, Intelligent Agent Factory, Grasshopper, Concordia, Gossip, FarGo, IBM Aglets, MAST, Ascape, Microsoft Agent, Voyager, and NetStepper [13] [21]. Jade, JAFMAS, ZEUS, RETSINA, JATLite, MADKIT, and OAA are almost ignored while all the other tools and platforms are totally ignored.

The 10th set of variables concerns the AOSE (Agent Oriented Software Engineering) methologies and consists the following variables: Gaia (Generic Architecture for Information Availability), SODA (Societies in Open and Distributed Agent spaces), Cassiopeia, Aalaadin, KGR, MaSE (Multiagent Systems Engineering), MASSIVE (MultiAgent SystemS Iterative View Engineering), AOAD (Agent-Oriented Analysis and Design), MASB (Multi-Agent Scenario-Based), CoMoMAS (Conceptual Modelling of Multi-Agent Systems), MAS-CommonKADS (Multi-Agent System CommonKADS), Tropos, Agent-Oriented Analysis and Design, Agent Modelling Technique for Systems of BDI agents, Agent Oriented Methodology for Enterprise Modelling, PASSI (a Process for Agent Societies Specification and Implementation), Prometheus , AOR, ROADMAP, OPM /MAS, Ingenias, DESIRE, AAII methodology, Cooperative Information Agents design, Adept, AUML, ADELFE, MESSAGE /UML, The Styx Agent Methology, SABPO, EXPAND (Expectation-oriented analysis and design), and ODAC [13] [22] [23] [24] [25] [26]. Gaia is almost ignored by previous research activity while all the other AOSE methologies are totally ignored.

4 Conclusion

We performed an evaluation of previous research activity on agent technology applied to IBs. A number of variables-parameters were selected related to all basic aspects of software agent technology that we estimated important to include. Based on this number of variables and using a specific methodology we transacted the meta-research through statistical processing over selected literature related to IBs. We tried to estimate the level of previous research activity in terms of percentages that correspond to the % percent that a specific variable is ignored by the literature body and to the % level of “variable performance” in terms of moderate, good, very good and excellent. The term “variable performance” is the degree of positive answer and cover in the question that corresponds to each distinct variable. In other words, we tried to provide the level of coverage of a specific variable by the body of literature in terms of ‘ignore’, ‘moderate’, ‘good’, ’very good’ and ‘excellent’. We hope that this may become an accessory step for promoting theoretical work in future.

References:

[1] R. Giladi, “Heterogeneous Building Automation and IP Networks Management”, ICDCS Workshops 2004, pp. 636-641.

[2] S. Sharples, V. Callaghan, and G. Clarke (1999), “A multi-agent architecture for intelligent building sensing and control”, Sensor Review, Vol. 19, No. 2, 1999, pp.135-140.

[3] J. Trindler1, R. Zwiker1, U. Rutishauser, R. Douglas and J. Joller1, “Discovery of Logical Structure in a Multisensor Environment Based on

Sparse Events Discovery of Logical Structure in a Multisensor Environment Based on Sparse Events", AI*IA 2003 Workshop on Ambient Intelligence, 8th National Congress of Italian Association for Artificial Intelligence.
[4] U. Rutishauser, and A. Schafer, "Adaptive Building Automation. A multi-Agent approach", Research project, 7/20/02. http://www.easc.ch/aha/Docu/aha1_1_0.pdf
[5] K. P. Sycara, "Multi-agent Systems", AI magazine, Vol.19, No. 2, 1998, Intelligent Agents Summer.
[6] Oliveira, E., K. Fischer, and O. Stepankova, "Multi-agent systems: which research for which applications", Robotics and Autonomous Systems, Vol. 27, 1999, pp. 91-106.
[7] E. H. Rogers, "Methology for meta-research", Presidential address at the conference of the International Communication Association, 1981.
[8] A. Hollifield, "Crossing borders: Media management research in a transnational market", Environment, Journal of Media Economics, Special Issue: Transnational Media Management, Vol. 14, No. 3, 2001, pp. 133-146.
[9] Camelia Chira. Software Agents, IDIMS Report, 2/21/03, http://pan.nuigalway.ie/code/docs/agents.pdf
[10] H. S. Nwana, "Software Agents: An Overview", Knowledge Engineering Review, Vol. 11, No. 3, 1996, pp. 1-40.
[11] M. Wooldridge, "Intelligent Agents", The MIT Press, 1999.
[12] D. Bussink, "A Comparison of Language Evolution and Communication Protocols in Multi-agent Systems", 1st Twente Student Conference on IT, Track C - Intelligent_Interaction, 2004, http://referaat.ewi.utwente.nl/
[13] G. Weiß, "Agent orientation in software engineering", Knowledge Engineering Review, Vol. 16, No. 4, 2002, pp. 349–373.
[14] http://www.omg.org/gettingstarted/corbafaq.htm
[15] www.omg.org
[16] The CORBA Object Group Service (1998). A Service Approach to Object Groups in CORBA, THESES N° 1867. http://lsrwww.epfl.ch/OGS/thesis/
[17] A. Bracho, A. Matteo, and Ch. Metzner, "A taxonomy for comparing distributed objects technologies", CLEI Electronic Journal, Vol. 2, No. 2, 1999.
[18] DCOM Technical Overview (1996). Microsoft Corporation. http://msdn.microsoft.com/library/default.asp?url=/library/en-us/dndcom/html/msdn_dcomtec.asp
[19] Tuukka Vartiainen. Java Beans and Enterprise Java Beans. http://www.cs.helsinki.fi/u/campa/teaching/tukka-final.pdf
[20] H. Nwana, and M. Wooldridge, "Software Agent Technologies", BT Technology Journal, Vol. 14, No. 4, 1996, pp. 68-78.
[21] Serenko, and B. Deltor, "Agent Toolkits: A General Overview of the Market and an Assessment of Instructor Satisfaction with Utilizing in the Classroom", Working Paper #455, 2002, http://www.business.mcmaster.ca/msis/profs/detlorb/nserc/McMaster_Working_Paper_455.pdf
[22] Agent-Oriented Software Engineering, "Research Area Examination", 3/31/05. http://www.deg.byu.edu/proposals/ResearchAreaExamMuhammedJM.pdf
[23] C.A. Iglesias, M. Garijo, and J.C. Gonzalez, "A Survey of Agent-Oriented Methologies", Intelligent Agents V, Proceedings of the Fifth International Workshop on Agent Theories, Architectures, and Languages (ATAL-98), Lecture Notes in Artificial Intelligence. Springer-Verlag, Vol. 1555, 1999, pp. 317-330.
[24] L. Cernuzzi, M. Cossentino, and F. Zambonelli, "Process Models for Agent-Based Development", International Journal on Engineering Applications of Artificial Intelligence (EAAI), Elsevier, 2004, http://www.pa.icar.cnr.it/~cossentino/paper/eaai_zambonelli_draft.pdf
[25] M. Wooldridge, and P. Ciancarini, "Agent-Oriented Software Engineering: The State of the Art", First Int. Workshop on Agent-Oriented Software Engineering, P. Ciancarini and M. Wooldridge (ed.), Berlin: Springer-Verlag, Vol. 1957, 2000, pp. 1-28.
[26] AOSE Methologies http://www.science.unitn.it/~recla/aose/