Aalborg Universitet

An Agent-Based Model for Energy Management of Smart Home: Residences' Satisfaction Approach

Ebrahimi, Mahoor; Hajizadeh, Amin

An Agent-Based Model for Energy Management of Smart Home: Residences' Satisfaction Approach

Mahoor Ebrahimi[1(✉)] and Amin Hajizadeh[2]

[1] Amirkabir University of Technology, Tehran, Iran
mahoor.ebrahimi@yahoo.com
[2] Department of Energy Technology, Aalborg University, Esbjerg, Denmark

Abstract. Reducing the cost of energy leads to reduction in resident's comfort. Therefore, it is necessary to consider both reduction in cost and resident's dissatisfaction. Smart buildings include different systems such as communication system (CS), sensing system (SS), grid data collecting system (GDCS), building energy management system (BEMS), hybrid system (HS), temporary service systems (TSS) and permanent service systems (PSS). Considering the aforementioned systems, an agent-based model for energy management of smart buildings is presented in this work to reduce the energy cost as well as the resident's dissatisfaction.

Keywords: Smart home · Multi-agent system
Home energy management system

1 Introduction

Considering the importance of reducing the cost of energy for smart buildings a solution is needed to make a use of consumption management. This can be done by using the Building Energy Management System (BEMS) which is one of the main components of smart homes. Thus, the amount of energy consumed during the peak-hours should be shaved when electricity price is high, or the consumption can be shifted to other hours [1]. Moreover, Electric Vehicles (EVs) are used as energy storage systems to reduce the cost according to their potential of charging and discharging (buying and selling electricity) in the smart home [2]. However, it is noticeable that the above solutions may reduce resident's comfort. In this work, a solution is proposed to manage consumption in order to reduce the cost of energy with taking into account the residents' comfort.

2 Proposed Scheme

Energy production and consumption in smart home can be managed by the BEMS which is a decision-making agent of the smart home. The BEMS allows residents to apply several energy management mechanisms that can change the way of energy

production and consumption to achieve less energy cost and more residents' comfort. In this work, we present the multi agent-based structure for BEMS. There are several works that implement agents in the BEMS but none of does not consider a manner to consider residents' comfort in the BEMS [3–8]. Readers can refer to [9–70] to know more about multi-agent systems. Our proposed multi-agent BEMS consists of different agents that are described in the following.

The smart home is equipped with sensors and operators to collect the data and send control commands according to the resident's activities and expectations. Sensors are including in the Sensing System (SS) that measures the parameter needed for making appropriate decisions such as inside temperature of different rooms and outside temperature. The purpose of the services at the smart home is increasing the comfort and security of the residents. As highlighted before, several load management mechanisms can be used to provide an optimal management decisions based on the criteria given to the BEMS through the existence of communication network in smart home. In this way, the Communication System (CS) conveys different signals from sensors and grid data system to the BEMS, and from the BEMS to operators. Grid data collecting system (GDCS) obtains data related to grid's parameters such as hourly electricity price. The consumption management allows residents to save money by reducing consumption in hours of high energy price- e.g. peak hours of grid- or changing the start time of operations in services where the type of consumption is such that it can be adjusted to another hour- e.g. like a washing machine. Hence, there is a necessity to find a solution that optimizes both the cost and the acceptable level of satisfaction of the residents. In this work, we want to find the solution by multi-gent system.

In addition to the above solutions, we want to assess the impact of Plug-in Hybrid Electric Vehicle (PHEV) as a hybrid system (HS). The battery consumes electricity to be charged and also it can be discharged to provide electricity for smart home. It can assist the BMES to increase energy efficiency considering satisfaction of residents.

Smart home residents use their services to improve their comfort. These are service systems. These systems can be divided into two categories: permanent service systems (PSS) and temporary service systems. Permanent services are services that are necessary to be used over a certain period of time in a day. For instance, the home heating system should operate all day along to provide an appropriate temperature. PSSs participate in the cost reduction problem by reducing the amount of their energy consumption. For example, the energy cost is reduced by decreasing the energy consumption of the heating system. On the other hand, the temperature of the house also decreases which impacts negatively on residents' satisfaction of the services.

The second category are temporary service systems (TSS) whose operation takes place in a limited and certain time- e.g. dishwasher and washing machine. TSSs participate in the cost reduction problem by moving their operation time. For example, the washing machine can be used in the late hours of the night where the price of electricity is lower. In this case, the use of services in a time that is different with the preferences of residents causes their dissatisfaction.
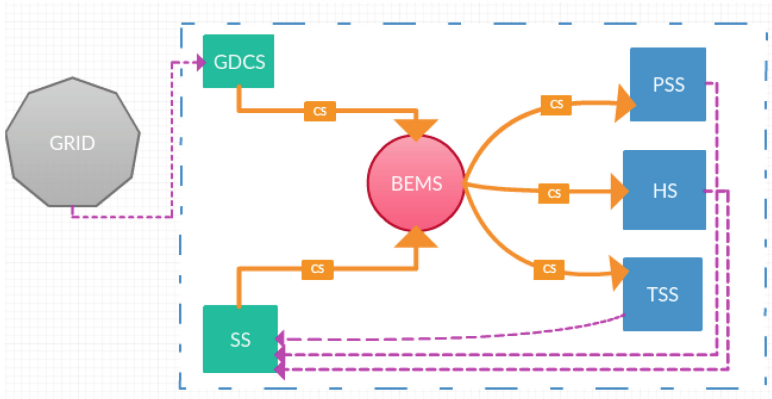
Fig. 1. General structure for multi agent-based smart home system.

Figure 1 shows the relation between different systems in smart home simply. SS and GDS obtains the information and inputs that are needed for BEMS and then this inputs will be sent to BEMS by CS. BEMS makes an appropriate decision and send it to the TSS, PSSS and HS agents.

References

1. Nassaj, A., Shahrtash, S.M.: An accelerated preventive agent based scheme for post-disturbance voltage control and loss reduction. IEEE Early Access Artic. (2018)
2. Nassaj, A., Shahrtash, S.M.: A predictive agent-based scheme for post-disturbance voltage control. Int. J. Electr. Power Energy Syst. **98**, 189–198 (2018)
3. Wooldridge, M.J.: An Introduction to Multi Agent Systems. Wiley, New York (2009)
4. Shokri Gazafroudi, A., Pinto, T., Prieto-Castrillo, F., Prieto, J., Corchado, J.M., Jozi, A., Vale, Z., Venayagamoorthy, G.K.L.: Organization-based multi-agent structure of the smart home electricity system. In: IEEE Congress on Evolutionary Computation (CEC), June 2017
5. Shokri Gazafroudi, A., Prieto-Castrillo, F., Pinto, T., Jozi, A., Vale, Z.: Economic evaluation of predictive dispatch model in MAS-based smart home. In: 15th International Conference on Practical Applications of Agents and Multi-Agent Systems (PAAMS), June 2017
6. Shokri Gazafroudi, A., De Paz, J.F., Prieto-Castrillo, F., Villarrubia, G., Talari, S., Shafie-khah, M., Catalão, J.P.S.: A review of multi-agent based energy management systems. In: 8th International Symposium on Ambient Intelligence (ISAmI), June 2017
7. Shokri Gazafroudi, A., Prieto-Castrillo, F., Pinto, T., Corchado, J.M.: Organization-based multi-agent system of local electricity market: bottom-up approach. In: 15th International Conference on Practical Applications of Agents and Multi-Agent Systems (PAAMS), June 2017
8. Shokri Gazafroudi, A., Abrishambaf, O., Jozi, A., Pinto, T., Preito-Castrillo, F., Corchado, J.M., Vale, Z.: Energy flexibility assessment of a multi agent-based smart home electricity system. In: 17th edn. of the IEEE International Conference on Ubiquitous Wireless Broadband (ICUWB), September 2017

9. Chamoso, P., Rivas, A., Martín-Limorti, J.J., Rodríguez, S.: A hash based image matching algorithm for social networks. In: Advances in Intelligent Systems and Computing, vol. 619, pp. 183–190 (2018)

10. Sittón, I., Rodríguez, S.: Pattern extraction for the design of predictive models in Industry 4.0. In: International Conference on Practical Applications of Agents and Multi-Agent Systems, pp. 258–261 (2017)

11. García, O., Chamoso, P., Prieto, J., Rodríguez, S., De La Prieta, F.: A serious game to reduce consumption in smart buildings. In: Communications in Computer and Information Science, vol. 722, pp. 481–493 (2017)

12. Palomino, C.G., Nunes, C.S., Silveira, R.A., González, S.R., Nakayama, M.K.: Adaptive agent-based environment model to enable the teacher to create an adaptive class. In: Advances in Intelligent Systems and Computing, vol. 617 (2017)

13. Canizes, B., Pinto, T., Soares, J., Vale, Z., Chamoso, P., Santos, D.: Smart city: a GECAD-BISITE energy management case study. In: 15th International Conference on Practical Applications of Agents and Multi-Agent Systems PAAMS 2017. Trends in Cyber-Physical Multi-Agent Systems, vol. 2, pp. 92–100 (2017)

14. Chamoso, P., de La Prieta, F., Eibenstein, A., Santos-Santos, D., Tizio, A., Vittorini, P.: A device supporting the self management of tinnitus. In: Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) (LNCS), vol. 10209, pp. 399–410 (2017)

15. Román, J.A., Rodríguez, S., de da Prieta, F.: Improving the distribution of services in MAS. In: Communications in Computer and Information Science, vol. 616 (2016)

16. Buciarelli, E., Silvestri, M., González, S.R.: Decision economics. In: Commemoration of the Birth Centennial of Herbert A. Simon 1916–2016 (Nobel Prize in Economics 1978): Distributed Computing and Artificial Intelligence, 13th International Conference. Advances in Intelligent Systems and Computing, vol. 475. Springer (2016)

17. Li, T., Sun, S., Bolić, M., Corchado, J.M.: Algorithm design for parallel implementation of the SMC-PHD filter. Sig. Process. **119**, 115–127 (2016)

18. Lima, A.C.E.S., De Castro, L.N., Corchado, J.M.: A polarity analysis framework for Twitter messages. Appl. Math. Comput. **270**, 756–767 (2015)

19. Redondo-Gonzalez, E., De Castro, L.N., Moreno-Sierra, J., Maestro De Las Casas, M.L., Vera-Gonzalez, V., Ferrari, D.G., Corchado, J.M.: A cluster analysis. BioMed Res. Int. (2015)

20. Li, T., Sun, S., Corchado, J.M., Siyau, M.F.: Random finite set-based Bayesian filters using magnitude-adaptive target birth intensity. In: FUSION 2014 - 17th International Conference on Information Fusion (2014)

21. Prieto, J., Alonso, A.A., de la Rosa, R., Carrera, A.: Adaptive framework for uncertainty analysis in electromagnetic field measurements. Radiat. Prot. Dosim. (2014). https://doi.org/10.1093/rpd/ncu260

22. Chamoso, P., Raveane, W., Parra, V., González, A.: UAVs applied to the counting and monitoring of animals. In: Advances in Intelligent Systems and Computing, vol. 291, pp. 71–80 (2014)

23. Pérez, A., Chamoso, P., Parra, V., Sánchez, A.J.: Ground vehicle detection through aerial images taken by a UAV. In: 2014 17th International Conference on Information Fusion (FUSION) (2014)

24. Choon, Y.W., Mohamad, M.S., Deris, S., Illias, R.M., Chong, C.K., Chai, L.E., Corchado, J.M.: Differential bees flux balance analysis with OptKnock for in silico microbial strains optimization. PLoS ONE **9**(7), e102744 (2014)

25. Li, T., Sun, S., Corchado, J.M., Siyau, M.F.: A particle dyeing approach for track continuity for the SMC-PHD filter. In: FUSION 2014 - 17th International Conference on Information Fusion (2014)
26. García Coria, J.A., Castellanos-Garzón, J.A., Corchado, J.M.: Intelligent business processes composition based on multi-agent systems. Expert Syst. Appl. **41**(4), 1189–1205 (2014)
27. Prieto, J., Mazuelas, S., Bahillo, A., Fernández, P., Lorenzo, R.M., Abril, E.J.: Accurate and robust localization in harsh environments based on V2I communication. In: Vehicular Technologies - Deployment and Applications. INTECH Open Access Publisher (2013)
28. De La Prieta, F., Navarro, M., García, J.A., González, R., Rodríguez, S.: Multi-agent system for controlling a cloud computing environment. Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) (LNAI), vol. 8154 (2013)
29. Tapia, D.I., Fraile, J.A., Rodríguez, S., Alonso, R.S., Corchado, J.M.: Integrating hardware agents into an enhanced multi-agent architecture for Ambient Intelligence systems. Inf. Sci. **222**, 47–65 (2013)
30. Prieto, J., Mazuelas, S., Bahillo, A., Fernandez, P., Lorenzo, R.M., Abril, E.J.: Adaptive data fusion for wireless localization in harsh environments. IEEE Trans. Signal Process. **60**(4), 1585–1596 (2012)
31. Muñoz, M., Rodríguez, M., Rodríguez, M.E., Rodríguez, S.: Genetic evaluation of the class III dentofacial in rural and urban Spanish population by AI techniques. In: Advances in Intelligent and Soft Computing (AISC), vol. 151 (2012)
32. Costa, Â., Novais, P., Corchado, J.M., Neves, J.: Increased performance and better patient attendance in an hospital with the use of smart agendas. Log. J. IGPL **20**(4), 689–698 (2012)
33. García, E., Rodríguez, S., Martín, B., Zato, C., Pérez, B.: MISIA: middleware infrastructure to simulate intelligent agents. In: Advances in Intelligent and Soft Computing, vol. 91 (2011)
34. Rodríguez, S., De La Prieta, F., Tapia, D.I., Corchado, J.M.: Agents and computer vision for processing stereoscopic images. In: Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) (LNAI), vol. 6077 (2010)
35. Rodríguez, S., Gil, O., De La Prieta, F., Zato, C., Corchado, J.M., Vega, P., Francisco, M.: People detection and stereoscopic analysis using MAS. In: Proceedings of INES 2010 - 14th International Conference on Intelligent Engineering Systems (2010)
36. Prieto, J., Mazuelas, S., Bahillo, A., Fernández, P., Lorenzo, R.M., Abril, E.J.: On the minimization of different sources of error for an RTT-based indoor localization system without any calibration stage. In: 2010 International Conference on Indoor Positioning and Indoor Navigation (IPIN), pp. 1–6 (2010)
37. Rodríguez, S., Tapia, D.I., Sanz, E., Zato, C., De La Prieta, F., Gil, O.: Cloud computing integrated into service-oriented multi-agent architecture. In: IFIP Advances in Information and Communication Technology (AICT), vol. 322 (2010)
38. Corchado, J., Fyfe, C., Lees, B.: Unsupervised learning for financial forecasting. In: Proceedings of the IEEE/IAFE/INFORMS 1998 Conference on Computational Intelligence for Financial Engineering (CIFEr) (Cat. No. 98TH8367), pp. 259–263 (1998)
39. Durik, B.O.: Organisational metamodel for large-scale multi-agent systems: first steps towards modelling organisation dynamics. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **6**(3) (2017)
40. Bremer, J., Lehnhoff, S.: Decentralized coalition formation with agent-based combinatorial heuristics. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **6**(3), 29–44 (2017)
41. Cardoso, R.C., Bordini, R.H.: A multi-agent extension of a hierarchical task network planning formalism. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **6**(2), 5–17 (2017)

42. Gonçalves, E., Cortés, M., De Oliveira, M., Veras, N., Falcão, M., Castro, J.: An analysis of software agents, environments and applications school: retrospective, relevance, and trends. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **6**(2), 19–32 (2017)

43. Teixeira, E.P., Gonçalves, E.M., Adamatti, D.F.: Ulises: a agent-based system for timbre classification. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **6**(2), 29–40 (2017)

44. Souza de Castro, L.F., Vaz Alves, G., Pinz Borges, A.: Using trust degree for agents in order to assign spots in a smart parking. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **6**(2), 45–55 (2017)

45. Cunha, R., Billa, C., Adamatti, D.: Development of a graphical tool to integrate the prometheus AEOlus methodology and Jason platform. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **6**(2), 57–70 (2017)

46. Rincón, J., Poza, J.L., Posadas, J.L., Julián, V., Carrascosa, C.: Adding real data to detect emotions by means of smart resource artifacts in MAS. In: ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **5**(4), 85–92 (2016)

47. Villavicencio, C.P., Schiaffino, S., Díaz-Pace, J.A., Monteserin, A.: A group recommendation system for movies based on MAS. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **5**(3), 1–12 (2016)

48. Briones, A.G., Chamoso, P., Barriuso, A.: Review of the main security problems with multiagent systems used in E-commerce applications. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **5**(3), 55–61 (2016)

49. Carbó, J., Molina, J.M., Patricio, M.A.: Asset management system through the design of a Jadex agent system. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **5**(2), 1–14 (2016)

50. Santos, G., Pinto, T., Vale, Z., Praça, I., Morais, H.: Enabling communications in heterogeneous multi-agent systems: electricity markets ontology. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **5**(2), 15–42 (2016)

51. Murciego, Á.L., González, G.V., Barriuso, A.L., De La Iglesia, D.H., Herrero, J.R.: Multi agent gathering waste system. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **4**(4), 9–22 (2015)

52. Barriuso, A.L., De La Prieta, F., Murciego, Á.L., Hernández, D., Herrero, J.R.: JOUR-MAS: a multi-agent system approach to help journalism management. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **4**(4) (2015)

53. De La Iglesia, D.H., González, G.V., Barriuso, A.L., Murciego, Á.L., Herrero, J.R.: Monitoring and analysis of vital signs of a patient through a multi-agent application system. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **4**(3), 19–30 (2015)

54. Gallego, J.Á.R., González, S.R.: Improvement in the distribution of services in multi-agent systems with SCODA. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **4**(3), 31–46 (2015)

55. Chamoso, P., De La Prieta, F.: Simulation environment for algorithms and agents evaluation. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **4**(3) (2015)

56. González, A., Ramos, J., De Paz, J.F., Corchado, J.M.: Obtaining relevant genes by analysis of expression arrays with a multi-agent system. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **3**(3) (2014)

57. Faia, R., Pinto, T., Vale, Z.: Dynamic fuzzy clustering method for decision support in electricity markets negotiation. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **5**(1), 23–35 (2016)

58. Silva, A., Oliveira, T., Neves, J., Novais, P.: Treating colon cancer survivability prediction as a classification problem. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **5**(1) (2016)

59. Sánchez, D.L., Arrieta, A.G.: Preliminary results on nonparametric facial occlusion detection. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **5**(1), 51–61 (2016)

60. Chamoso, P., Pérez-Ramos, H., García-García, Á.: ALTAIR: supervised methodology to obtain retinal vessels caliber. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **3**(4), 48–57 (2014)

61. Cofini, V., De La Prieta, F., Di Mascio, T., Gennari, R., Vittorini, P.: Design Smart Games with requirements, generate them with a Click, and revise them with a GUIs. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **1**(3), 55–68 (2012)

62. Kushch, S., Castrillo, F.P.: A review of the applications of the Block-chain technology in smart devices and distributed renewable energy grids. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **6**(3) (2017)

63. Pinto, A., Costa, R.: Hash-chain-based authentication for IoT. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **5**(4) (2016)

64. García-Valls, M.: Prototyping low-cost and flexible vehicle diagnostic systems. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **5**(4), 93–103 (2016)

65. Fernández-Fernández, A., Cervelló-Pastor, C., Ochoa-Aday, L.: Energy-aware routing in multiple domains software-defined networks. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **5**(3), 13–19 (2016)

66. Koskimaki, H., Siirtola, P.: Accelerometer vs. electromyogram in activity recognition. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **5**(3), 31–42 (2016)

67. Chamoso, P., De La Prieta, F., Villarrubia, G.: Intelligent system to control electric power distribution networks. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **4**(4), 1–8 (2015)

68. Herrero, J.R., Villarrubia, G., Barriuso, A.L., Hernández, D., Lozano, Á., De La Serna González, M.A.: Wireless controller and smartphone based interaction system for electric bicycles. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **4**(4), 59–68 (2015)

69. Fernández-Isabel, A., Fuentes-Fernández, R.: Simulation of road traffic applying model-driven engineering. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **4**(2), 1–24

70. Chamoso, P., De La Prieta, F.: Swarm-based smart city platform: a traffic application. ADCAIJ Adv. Distrib. Comput. Artif. Intell. J. Salamanca **4**(2), 89–98 (2015)