VOL. 11, NO. 19, OCTOBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

# DECENTRALIZED MODEL FOR AUTONOMOUS ROBOTIC SYSTEMS BASED ON WIRELESS SENSOR NETWORKS

Andrés C. Jiménez[1], Sandro J. Bolaños[1] and John P. Anzola[2]
[1]Universidad Distrital Francisco José de Caldas, Bogotá, Colombia
[2]Fundación Universitaria los Libertadores, Bogotá, Colombia
E-Mail: acjimeneza@correo.udistrital.edu.co

## ABSTRACT

The Multi-Agents Autonomous Robotic Systems (MARS) are modeled and developed to work in process dedicated to the navigation in stochastic environments, especially in location, planning and mapping. These processes make use of design models in centralized systems that generate dependence on a central unit, being this a limitation for the autonomy of the robotic agents. On the other side, the wireless sensors networks (WSN) are an emerging technology which is based on the integration of multiple nodes in a centralized way for the capture and exchange of data. This article is based on the integration of the WSN in the design of a model for MARS oriented to the autonomy of the robotic agent in decentralized navigation tasks.

**Keywords:** decentralization, integration model, MARS, robotic agents, WSN.

## 1. INTRODUCTION

Due to the complexity of the design of the MARS in stochastic environments, and the high demand in the latest years (it was estimated that by the 2015, 22 millions of robots were employed worldwide [1]), they have become a multi-disciplinary area, making necessary a design structure based in models applied on the programming by objectives, the architecture of the robot and the administration of tasks [2]. Particularly, these models are centered on tasks of location, planning and mapping of the surroundings by applying the strategies that make use of optical tracking devices (OTD), stereoscopic vision, artificial vision techniques with smart algorithms and wireless sensors networks (WSN) [3]–[8].

Compared to other strategies, the one applying WSN technology, allows to locate the robotic agent in non-controlled environments through sensors distributed on grids of static or mobile nodes, sending the information towards a master unit in charge of performing the computing tasks [9]. This technology is characterized by its flexibility, allowing the mapping and location of the environment by reading the received signal strength indicator (RSSI) applying information fusion techniques among the different agents [10]-[13].

The problem with depending on the central unit for the system operation, lies on the necessity of the permanent operation of it, otherwise the whole system would collapse. On the other hand, the central unit needs the system to keep communication, this way, all the nodes must communicate towards the central unit, needing indirect routes of communication when the central unit is out of range, increasing the energy consumption and the computational complexity while implementing routing algorithms on the nodes [14].

So, a model integrated with the MARS with the flexibility of the WSN is presented, avoiding this way the dependence on the central unit. For this, on section 2, a brief summary of the works performed with the MARS is presented, explaining the concept of autonomy with the purpose of showing the motivation of the article. On section 3, the traditional model is described to represent the robotic agents in tasks with WSN navigation, presenting the stages of the integration model through sequence diagrams, and finally presenting the decentralized integration model called DWMARS.

## 2. PROBLEM REPRESENTATION

The main objective of the MARS is giving autonomy to each of the agents that integrate the system (Figure-1), this is, each agent must have the property of having the capability of processing the data in a distributed and decentralized way, also having an operative system able to guarantee the administration of processing tasks, guaranteeing the operation of the system in real time, without forgetting the properties of having a hybrid architecture, the generation of models, the learning capacity and the system modularity [15]-[17].

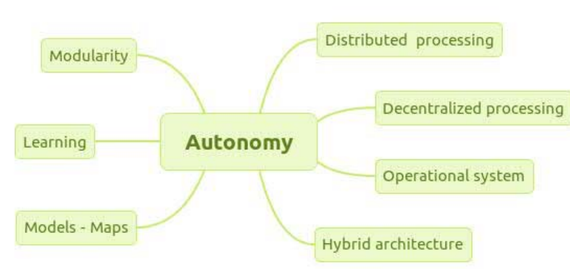


**Figure-1.** Mental map of autonomy in robotic agents.

The concept of autonomy has also been used on the WSN, being this concept oriented to work with the Multi-Agents Systems (MAS), describing each sensoring node as a technology capable of being located in any environment, sensing the characteristics of it (depending on the sensors), and based on the dynamic of the environment, pre-programmed plans of actions are executed in order to directly interact through the actuators,

VOL. 11, NO. 19, OCTOBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

or signals are sent to the central unit for the decision making [9]. These plans of action are oriented to the self-maintenance, self-protection, self- optimization and self-configuration tasks with the purpose of reducing the computing resources and energy consumption, being an excellent candidate to be used directly on mobile agents such as the robotic agents oriented to the navigation tasks [18].

The robotic agents that use the WSN to perform the navigation tasks use the nodes of the sensors specially located in the environment as static guides, these being used as location points by previously having the exact position where they are installed; these systems allow having a low level of computing to process the information, since the only thing they need is having each node as reference of the RSSI to get located without the need of turning to the image capturing as it is required by the OTD techniques [10], [19]. Other robotic agents work the navigation in two phases by using the WSN as reference; the first consists of acquiring the information of the nodes of the sensors to make an estimation through particle filters without previously knowing the location of the sensors. In the second phase, the nodes estimate their location by using an information filter to compute their position, repeating this process until getting the exact position of both the sensors and the robotic agent [20].

These applications have been worked out through techniques that perform, in a centralized way, the Simultaneous Location and Mapping (SLAM), leaving the planning aside [21], [22]. However, the models which perform the planning process always work in previously known environments, working with centralized processes which may fail if the central unit collapses. The WSN technologies are providing flexibility to work with these navigation techniques focused on the communication between the agents of the MARS indirectly, being an interesting area to implement it directly in the development of the MARS in order to work in a decentralized way [23]-[28].

## 3. MODEL OF THE SYSTEM

The model to represent the robotic agent in MARS by using WSN in navigation is showed in the diagram of usage cases in Figure-2, where the environment delivers a collection of data captured by the different sensors of the robotic agent and sends it to the central unit in charge of the decision making. While processing the information, the central unit sends the applicable actions to the agents and they execute them. It is important to highlight that the actions executed by the robotic agents depend on the characteristics of space of the environment, meaning, the elevation, type of terrain, etc. which are partially analyzed by the sensors.

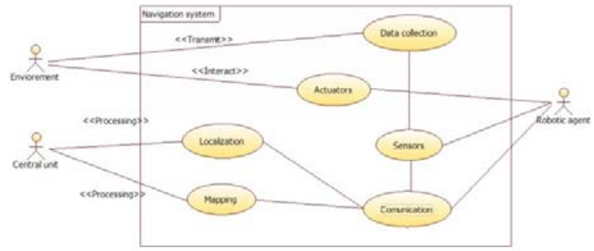


**Figure-2.** Use class diagram basic design of a centralized robotic agent in WSN.

The model in Figure-2 presents a big inconvenience, if the central system fails, all the agents involved in the MARS could be lost, since they always have to communicate with the central unit. Otherwise, if the central unit is robust and would never fail, it should always interact with the mediator between the agents which do not have direct communication, increasing the time for the decision making, directly affecting the consumption of energy and the computational efficiency of the robotic agent, taking away autonomy to the system. Because of this, the diagram of sequence is presented in Figure-3 for the design of the robotic agent, modeling the flow of the system from the catching of the data, the handling of the actuators, to the communication of the agents in the MARS in a decentralized way.

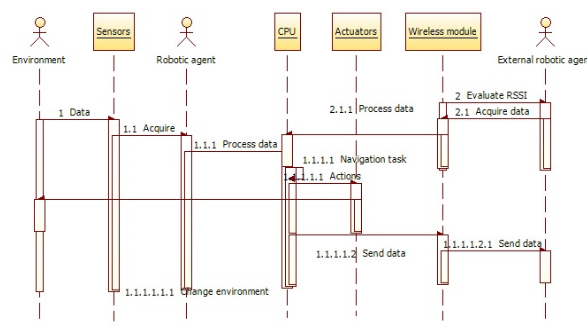


**Figure-3.** Sequence diagram for the design of the decentralized robotic agent with WSN.

The diagram in Figure-3, takes the WSN technology as referent to integrate it with the MARS, generating a model called DWMARS; each robotic agent (node) composing the MARS possess a unit with sensors, a processing unit, a wireless communications module and a unit of actuators which is normally composed by the control and motors units. Each node evaluates the environment through the sensors and the information sent by the rest of the agents through the wireless communication module, being analyzed by the processing unit, performing SLAM tasks [19], [20], [29]-[33] and the planning simultaneously without the need of waiting response from a central unit, reducing the energy consumption when performing the communication from node to node based on the RSSI among them.

ARPN Journal of Engineering and Applied Sciences



## 4. WIRELESS DESCENTRALICED MODEL FOR MULTI-AGENT ROBOTIC SYSTEMS

The decentralized model of Figure-3 generates the communication with the nearest node in a power level, based on the parameter of received signal strength indicator (RSSI). The communication is characterized by giving parameters with a specific name to each node, which must be included in the list to be shared among all the nodes of the system; so, this is the only requirement to belong to the system disregarding the type of sensors that are handled by the robotic agent. The navigation tasks are performed by the nodes with the nearest neighbor (within reach) based on the different techniques, just as it is stated in [22], [24], [34], [35], avoiding the necessity of communicating with the central unit. This function is represented in the workflow diagram of Figure-4.

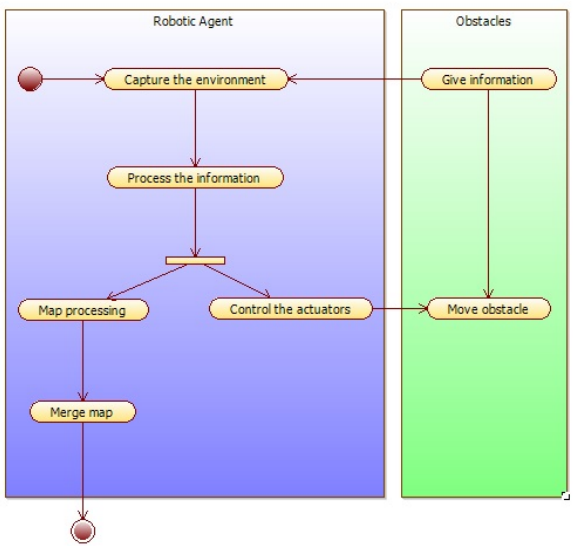


**Figure-4.** Work diagram of communication and processing of the agent with the DWMARS model.

The algorithm that models the operation of the workflow diagram is presented here:

a) For each node *n* belonging the list of nodes in the system, it has to:
   i. Capture the nodes within the power range in a List *m.*
   ii. Store the name and the RSSI.
   iii. Establish a direct communication with the node *i* having the highest RSSI.
b) Establish a time of communication for the data transfer or select the submission of information by events.
   i. If selecting the data transfer mode by time *(timeout):*
   ii. Both nodes have to send the map information stored together with a key indicating the *id* of the transfer; if it is the first submission, the key must have a value of 0.
   iii. Each node has to send the captured map; if a previous value of the key is sent, this process is avoided.
   iv. If the value of the key is new, each node has to fuse the received map with the one stored in its memory.
   v. If the contrary, the map has to be taken from the other node to fuse it with the current map without performing a keys verification.
c) Perform the location task through the captured maps.
d) If a better value is required for the location, Process 1 must be repeated by capturing the value of location and comparing it with the RSSI value to perform the connection with the nearest node value.
e) End.

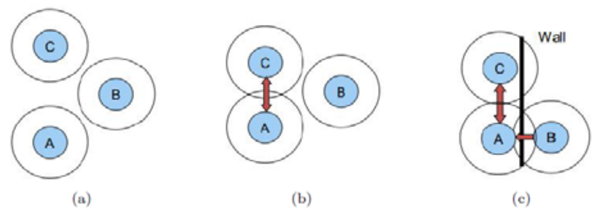


**Figure-5.** (a) Distributed nodes without connection, (b) Connection between the nodes based on the RSSI parameter, (c) Connection between the nodes based on the RSSI parameter with obstacles.

The previous algorithm can be used in three different scenarios, as an example, three nodes are left distributed in an environment randomly. The first scenario is showed in Figure-5a, where you can notice that no node is close enough to the other in order to establish communication through their RSSI, in this case each node is in charge of performing the SLAM tasks individually until finding other node sufficiently near. The second scenario is showed in Figure-5b, where nodes are close enough to establish communication, being *node_a* and *node_c* in this case. In the third scenario there is a wall as an obstacle; in this scenario, the three nodes have to search for the nearest node to establish communication and begin the location and mapping task; in this scenario you can observe that *node_a* is closer to *node_b* in distance parameters, but these are separated by a wall which significantly reduces the RSSI between them, while *node_c* is in view line with *node_a* having a higher RSSI compared to *node_b,* allowing communication as showed in Figure-5c.

## 5. FUTURE WORKS

As future work the integration model will be implemented in components using the different points of view in UML 2.0, which could be develop a generic tool that allows synthesizing the software into a structure in hardware, reducing the development time and errors generated during the design. A current problem of investigation demonstrated in [34], is the interaction between XML-UML, being an interesting investigation branch, on having represented the diagrams generated in UML on XML to realize hardware dedicated to MARS by means of Languages of Description of Hardware HDL.

## 6. CONCLUSIONS

By using the concept and technology of Wireless Sensor Networks in cooperative robotics based on Mars, simpler models can be structured for working in decentralized multi-agent systems, reducing the time of communication and eliminating dependence on the central unit, increasing the autonomy of the system in terms of modularity and distributed processing.

## REFERENCES

[1] IFR International Federation of Robotics. 2014. Statistics - IFR International Federation of Robotics. 2014. [Online]. Available: http://www.ifr.org/uploads/media/Executive_Summary_WR_2014.pdf.

[2] c/o Eu. R. EUROP Secretariat. 2009. European Robotics Technology Platform (EUROP). Robotic Visions to 2020.

[3] M. Mariappan, C. C. Wee, K. Vellian, and C. K. Weng. 2009. A navigation methodology of an holonomic mobile robot using optical tracking device (OTD). TENCON 2009 - 2009 IEEE Reg. 10 Conf. pp. 1-6.

[4] F. Zhang, J. Cao and Z. Xu. 2013. An improved Particle Swarm Optimization Particle Filtering algorithm. 2013 Int. Conf. Commun. Circuits Syst. pp. 173-177.

[5] L. McFetridge and M. Y. Ibrahim. 2009. A new methodology of mobile robot navigation: The agoraphilic algorithm. Robot. Comput. Integr. Manuf. 25(3): 545-551.

[6] O. Koch, M. R. Walter, A. S. Huang and S. Teller. 2010. Ground robot navigation using uncalibrated cameras. 2010 IEEE Int. Conf. Robot. Autom. pp. 2423-2430.

[7] B. Innocenti, B. López and J. Salvi. 2007. A multi-agent architecture with cooperative fuzzy control for a mobile robot. Robot. Auton. Syst. Robot. Auton. Syst. 50th Anniv. Artif. Intell. Campus Multidiscip. Percept. Intell. 55: 881-891.

[8] S. H. Park, Y. H. Choi, S. H. Baek, T. K. Lee and S. Y. Oh. 2007. Feature localization using neural networks for cleaning robots with ultrasonic sensors. ICCAS 2007 - Int. Conf. Control. Autom. Syst. pp. 449-453.

[9] D. Marsh, R. Tynan, D. O'Kane and G. M. P. O'Hare. 2004. Autonomic wireless sensor networks. Eng. Appl. Artif. Intell. 17: 741-748.

[10] N. Zhou, X. Zhao, and M. Tan. 2013. RSSI-based mobile robot navigation in grid-pattern wireless sensor network. 2013 Chinese Autom. Congr. pp. 497-501.

[11] W. Chen, T. Mei, H. Liang, Z. You, S. Li, and M. Q.-H. Meng. 2007. Environment-Map-free Robot Navigation Based on Wireless Sensor Networks. In: 2007 International Conference on Information Acquisition. No. 60535010, pp. 569-573.

[12] D. Cerotti, M. Gribaudo and A. Bobbio. 2014. Markovian agents models for wireless sensor networks deployed in environmental protection. Reliab. Eng. Syst. Saf. 130: 149-158.

[13] N. Sahli, N. Jabeura, and M. Badra. 2015. Agent-based framework for sensor-to-sensor personalization. J. Comput. Syst. Sci. 81(3): 487-495.

[14] S. Dogru, A. M. Erkmen, and I. Erkmen. 2009. Tracking a Sycophant Wireless Sensor Network for its seamless integration to mobile Wireless Sensor Networks. 2009 2nd Int. Conf. Adapt. Sci. Technol. pp. 110-116.

[15] S. Thrun, A. Bücken, W. Burgard, D. Fox, T. Fröhlinghaus, D. Hennig, T. Hofmann, M. Krell and T. Schimdt. 1997. Map Learning and High-Speed Navigation in RHINO. in Artificial Intelligence and Mobile Robots.

[16] J. Ota. 2006. Multi-agent robot systems as distributed autonomous systems. Adv. Eng. Informatics. 20: 59-70.

[17] S. Zieba, P. Polet, and F. Vanderhaegen. 2011. Using adjustable autonomy and human-machine cooperation to make a human-machine system resilient - Application to a ground robotic system. Inf. Sci. (Ny). 181: 379-397.

[18] F. Viani, M. Donelli, G. Oliveri, and A. Massa. 2010. A mobile wireless sensor network architecture for collaborative tasks achievement by means of autonomous robot swarm. Antennas Propag. Soc. Int. Symp. (APSURSI), 2010 IEEE. pp. 1-4.

[19] O. M. Elfadil. 2013. Navigation algorithm for mobile robots using WSN. in 2013 International Conference

ARPN Journal of Engineering and Applied Sciences



on Computing, Electrical and Electronic Engineering (ICCEEE). pp. 254-259.

[20] F. Caballero, L. Merino, P. Gil, I. Maza, and A. Ollero. 2008. A probabilistic framework for entire WSN localization using a mobile robot. Rob. Auton. Syst. 56(10): 798-806.

[21] P. Iigo-Blasco, F. Diaz-Del-Rio, M. C. Romero-Ternero, D. Cagigas-Muiz, and S. Vicente-Diaz. 2012. Robotics software frameworks for multi-agent robotic systems development. Rob. Auton. Syst. 60(6): 803-821.

[22] H.-C. Lee, S.-H. Lee, S.-H. Lee, T.-S. Lee, D.-J. Kim, K.-S. Park, K.-W. Lee and B.-H. Lee. 2011. Comparison and analysis of scan matching techniques for Cooperative-SLAM. 2011 8th Int. Conf. Ubiquitous Robot. Ambient Intell. pp. 165-168.

[23] F. Rohrmüller, O. Kourakos, M. Rambow, D. Brščić, D. Wollherr, S. Hirche, and M. Buss. 2010. Interconnected performance optimization in complex robotic systems. 2010 IEEE/RSJ Int. Conf. Intell. Robot. Syst. pp. 4113-4118.

[24] L. Cheng, D. Xue, Y. Cong, X. Jiang and S. Zhao. 2012. The research of environment perception based on the cooperation of multi-robot. Proc. 2012 24th Chinese Control Decis. Conf. CCDC 2012, pp. 1914-1919.

[25] K. Choi, J. Park, Y. Kim and H. Lee. 2015. Chapter 3.4 - Monocular SLAM with Undelayed Initialization for an Indoor Robot1, vol. 60. Zhejiang University Press Co., Ltd.

[26] C. Gamallo, M. Mucientes and C. V. Regueiro. 2015. Omnidirectional visual SLAM under severe occlusions. Rob. Auton. Syst. 65: 76-87.

[27] X. Tang, L. Li, and B. Jiang. 2014. Mobile robot SLAM method based on multi-agent particle swarm optimized particle filter. J. China Univ. Posts Telecommun. 21(6): 78-86.

[28] Y. Zhang, J. Liu, G. Hoffmann, M. Quilling, K. Payne, P. Bose and A. Zimdars. 2010. Real-time indoor mapping for mobile robots with limited sensing. 2010 IEEE 7th Int. Conf. Mob. Adhoc Sens. Syst. MASS 2010, pp. 636–641.

[29] M. Abdelhakim, Jian Ren, and Tongtong Li. 2013. Mobile access coordinated wireless sensor networks - Topology design and throughput analysis. In: 2013 IEEE Global Communications Conference (GLOBECOM). pp. 4627-4632.

[30] T. Dumont and S. Le Corff. 204. Simultaneous localization and mapping in wireless sensor networks. Signal Processing. 101: 192-203.

[31] A. Elsts and L. Selavo. 2012. A user-centric approach to wireless sensor network programming languages. 2012 Third Int. Work. Softw. Eng. Sens. Netw. Appl. pp. 29-30.

[32] G. Fortino, M. Bal, W. Li, and W. Shen. 2014. Collaborative Wireless Sensor Networks: Architectures, Algorithms and Applications. Inf. Fusion. 22: 1-2.

[33] M. Dunbabin and L. Marques. 2012. Robots for environmental monitoring: Significant advancements and applications. IEEE Robot. Autom. Mag. vol. 19, no. February. pp. 24-39.

[34] E. Domínguez, J. Lloret, B. Pérez, Á. Rodríguez, Á. L. Rubio, and M. a. Zapata. 2011. Evolution of XML schemas and documents from stereotyped UML class models: A traceable approach. Inf. Softw. Technol. 53: 34-50.