Evaluating the n-Core Polaris Real-Time Locating System in an Indoor Environment

Dante I. Tapia, Óscar García, Ricardo S. Alonso, Fabio Guevara, Jorge Catalina, Raúl A. Bravo, and Juan Manuel Corchado

Abstract. Context-aware technologies allow Ambient Assisted Living developments to automatically obtain information from users and their environment in a distributed and ubiquitous way. One of the most important technologies used to provide context-awareness is Wireless Sensor Networks (WSN). Wireless Sensor Networks comprise an ideal technology to develop Real-Time Locating Systems (RTLS) aimed at indoor environments, where existing global navigation satellite systems do not work correctly. In this regard, n-Core Polaris is an indoor and outdoor RTLS based on ZigBee WSNs and an innovative set of locating and automation engines. This paper presents the main components of the n-Core Polaris, as well as some experiments made in a real scenario whose results demonstrate the effectiveness of the system in indoor environments.

Keywords: Ambient Assisted Living, Real-Time Locating Systems, Wireless Sensor Networks, ZigBee, Web Services.

1 Introduction

Ambient Assisted Living (AAL) tries to adapt the technology to the people's needs by means of omnipresent computing elements which communicate among

---

Dante I. Tapia · Óscar García · Ricardo S. Alonso · Fabio Guevara · Jorge Catalina
R&D Department, Nebusens, S.L., Scientific Park of the University of Salamanca, Edificio M2, Calle Adaja, s/n, 37185, Villamayor de la Armuña, Salamanca, Spain
e-mail: {dante.tapia,oscar.garcia,ricardo.alonso, fabio.guevara,jorge.catalina}@nebusens.com

Raúl A. Bravo · Juan M. Corchado
Department of Computer Science and Automation, University of Salamanca, Plaza de la Merced, s/n, 37008, Salamanca, Spain
e-mail: {raulabel,corchado}@usal.es

J.M.C. Rodríguez et al. (Eds.): Trends in PAAMS, AISC 157, pp. 29–37.
springerlink.com

them in a ubiquitous way [1]. In this sense, the continuous advancement in mobile computing makes it possible to obtain information about the context and also to react physically to it in more innovative ways.

Wireless Sensor Networks (WSN) are used for gathering the information needed by AAL environments, whether in home automation, industrial applications or smart hospitals. One of the most interesting applications for WSNs is Real-Time Locating Systems (RTLS). The most important factors in the locating process are the kinds of sensors used and the techniques applied for the calculation of the position based on the information recovered by these sensors. Although outdoor locating is well covered by systems such as the current GPS (Global Positioning System) or the future Galileo, indoor locating needs still more development, especially with respect to accuracy and low-cost and efficient infrastructures [2]. Therefore, it is necessary to develop Real-Time Locating Systems that allow performing efficient indoor locating in terms of precision and optimization of resources. This optimization of resources includes the reduction of the costs and size of the sensor infrastructure involved on the locating system. In this sense, the use of optimized locating techniques allows obtaining more accurate locations using even fewer sensors and with less computational requirements [2].

This paper is structured as follows. The next section explains the problem description, as well as the most widely used wireless technologies to build indoor RTLSs. Then, the main characteristics of the innovative n-Core Polaris system are depicted. After that, some experiments carried out in a real scenario to test the performance of different indoor RTLSs are described, as well as the results obtained by n-Core Polaris. Finally, the conclusions obtained so far are depicted.

2 Problem Description

The emergence of Ambient Assisted Living involves substantial changes in the design of systems, since it is necessary to provide features which enable a ubiquitous computing and communication and also an intelligent interaction with users [1]. This kind of interaction is achieved by means of technology that is embedded, non-invasive and transparent for users. In this regard, users' locations given by Real-Time Locating Systems represent key context information to adapt systems to people's needs and preferences.

Real-Time Locating Systems can be categorized by the kind of its wireless sensor infrastructure and by the locating techniques used to calculate the position of the tags (i.e., the locating engine). This way, there is a combination of several wireless technologies, such as RFID, Wi-Fi, UWB and ZigBee, and also a wide range of locating techniques that can be used to determine the position of the tags. Among the most widely used locating techniques we have signpost, fingerprinting, triangulation, trilateration and multilateration [3] [4].

A widespread technology used in Real-Time Locating Systems is Radio Frequency IDentification (RFID) [5]. In this case, the RFID readers act as *exciters* transmitting continuously a radio frequency signal that is collected by the RFID tags, which in turn respond to the readers by sending their identification numbers. In these kinds of locating systems, each reader covers a certain zone through its radio frequency signal, known as *reading field*. When a tag passes through the reading field of the reader, it is said that the tag *is* in that zone.

Locating systems based on Wireless Fidelity (Wi-Fi) take advantage of Wi-Fi WLANs (Wireless Local Area Networks) working in the 2.4GHz and 5.8GHz ISM (Industrial, Scientific and Medical) bands to calculate the positions of the mobile devices (i.e., tags) [6]. A wide range of locating techniques, then, can be used for processing the Wi-Fi signals and determining the position of the tags, including signpost, fingerprinting or trilateration. However, locating systems based on Wi-Fi present some problems such as the interferences with existing data transmissions and the high power consumption by the Wi-Fi tags.

Ultra-Wide Band (UWB) is a technology which has been recently introduced to develop these kinds of systems. As it works at high frequencies (the band covers from 3.1GHz to 10.6 GHz in the USA) [7], it allows to achieve very accurate location estimations. However, at such frequencies the electromagnetic waves suffer a great attenuation by objects (e.g., walls) so its use in indoor RTLS systems presents important problems, especially due to reflection and multipath effects.

ZigBee is another interesting technology to build RTLSs. The ZigBee standard is specially intended to implement Wireless Sensor Networks and, as Wi-Fi, can work in the 2.4GHz ISM band, but also can work on the 868–915MHz band. Different locating techniques based on RSSI and LQI can be used on ZigBee WSNs (e.g., signpost or trilateration). Moreover, it allows building networks or more than 65,000 nodes in star, cluster-tree and mesh topologies [3]. ZigBee is, indeed, the wireless technology selected for our research.

3 The n-Core Polaris Real-Time Locating System

n-Core Polaris is an innovative indoor and outdoor Real-Time Locating System based on the n-Core platform that features an outstanding precision, flexibility and automation integration [8] [9]. The new n-Core Polaris exploits the potential of the n-Core platform, taking advantage of the advanced set of features of the n-Core Sirius devices and the n-Core Application Programming Interface [8].

The wireless infrastructure of n-Core Polaris is made up of several ZigBee nodes (i.e., tags, readers and sensor controllers) called n-Core Sirius A, Sirius B and Sirius D [8]. They all have 2.4GHz and 868/915MHz versions and include a USB port to charge their battery or supply them with power. Likewise, the USB port can be used to update the firmware of the devices and configure their parameters from a computer running a special application intended for it. On the one hand, n-Core Sirius B devices are intended to be used with an internal battery and include two general-purpose buttons. On the other hand, n-Core Sirius D devices are aimed at being used as fixed ZigBee routers using the main power supply through a USB adaptor. In the n-Core Polaris RTLS, n-Core Sirius B devices are used as tags, while n-Core Sirius D devices are used as readers. This way, n-Core Sirius B devices are carried by users and objects to be located, whereas n-Core Sirius D devices are placed at ceilings and walls to detect the tags. Finally, Sirius A devices incorporate several communication ports (GPIO, ADC, I2C and UART through USB or DB-9 RS-232) to connect to distinct devices, including almost every kind of sensor and actuator. All Sirius devices include an 8-bit RISC (Atmel ATmega 1281) microcontroller with 8KB of RAM, 4KB of EEPROM and 128KB of Flash memory and an IEEE 802.15.4/ZigBee transceiver (Atmel AT86RF230).

In Figure 1 it can be seen the basic architecture of the n-Core Polaris Real-Time Locating System. The kernel of the system is a computer that is connected to a ZigBee network formed by n-Core Sirius devices. That is, the computer is connected to an n-Core Sirius D device through its USB port. This device acts as coordinator of the ZigBee network. The computer runs a web server module that makes use of a set of dynamic libraries, known as n-Core API (Application Programming Interface). The API offers the functionalities of the ZigBee network. The web server module offers a set of innovative locating techniques provided by the n-Core API. On the one hand, the computer gathers the detection information sent by the n-Core Sirius D acting as readers to the coordinator node. One the other hand, the computer acts as a web server offering the location info to a wide range of possible client interfaces. In addition, the web server module can access to a remote database to obtain information about the users and register historical data, such as alerts and location tracking.

Fig. 1 The Web Services based architecture of the n-Core Polaris RTLS.

The operation of the system is as follows. Each user or object to be located in the system carries an n-Core Sirius B acting as tag. Each of these tags broadcasts periodically a data frame including, amongst other information, its unique identifier in the system. The rest of the time these devices are in a sleep mode, so that the power consumption is reduced. This way, battery lifetime can reach even several months, regarding the parameters of the system (broadcast period and transmission power). A set of n-Core Sirius D devices is used as readers throughout the environment, being placed on the ceiling and the walls. The broadcast frames sent by each tag are received by the readers that are close to them. This way, readers store in their memory a table with an entry per each detected tag. Each entry contains the identifier of the tag, as well as the RSSI (Received Signal Strength Indication) and the LQI (Link Quality Indicator) gathered from the broadcast frame reception. Periodically, each reader sends this table to the coordinator node connected to the computer. The coordinator forwards each table received from each reader to the computer through the USB port. Using these detection information tables, the n-Core API applies a set of locating techniques to estimate the position of each tag in the environment. These locating techniques include signpost, trilateration, as well as an innovative locating technique based on fuzzy logic.

Then, the web server module offers the location data to remote client interfaces as web services HTTP (Hypertext Transfer Protocol) over SOAP (Simple Object Access Protocol). Figure 2 shows a screenshot of the web client interface. This client interface has been designed to be simple, intuitive and easy-to-use. Through the different interfaces, administrator users can watch the position of all users and objects in the system in real-time. Furthermore, administrators can define restricted areas according to the users' permissions. This way, if some user enters in an area that is forbidden to it regarding its permissions, the system will generate an alert that is shown to the administrator through the client interfaces. In addition, such alerts are registered into the database, so administrators can check anytime if any user violated its permissions. Likewise, administrators can query the database to obtain the location track of a certain user, obtaining statistical measurements about its mobility or the most frequent areas where it moves.

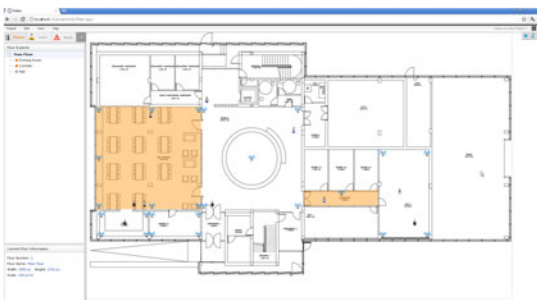

Fig. 2 Web client interface of the n-Core Polaris system.

Furthermore, users can use one of the general-purpose buttons provided by the n-Core Sirius B devices to send an alert to the system. Similarly, administrators can send alerts from the system to a user of a set of users, which can confirm the reception using other of the buttons. The system not only provides locating features, but also scheduling and automation functionalities. The system can be easily integrated with a wide range of sensors and actuators using the variety of communication ports included in the n-Core Sirius A devices. By means of the automation engine provided by the n-Core API, the n-Core Polaris system can schedule automation tasks, as well as monitor all sensors in the environment in real-time.

4 Experiments and Results

The n-Core Polaris indoor locating system has been awarded as the winner of the first international competition on indoor localization and tracking, organized by the Ambient-Assisted Living Open Association (AALOA) [10] and performed in the Experimental Research Center in Applications and Services for Ambient Intelligence (CIAMI) sited in the Technological Park of Valencia (Spain) from 27th to 29th July 2011. Among the competitors there were companies and research groups coming from all Europe, including Germany, Austria, France, Switzerland, Ukraine and Spain. Finally, the results were presented in Lecce (Italy) within the framework of the AAL Forum from 26th to 28th September 2011.

In order to evaluate the competing localization systems, the following evaluation criteria were applied [10]. Each criterion had a maximum of 10 points. To calculate the overall score, each criterion was multiplied by a certain weight:

- *Accuracy (weight 0.25)*: each produced location sample was compared with the reference position, calculating the distance error. The final score on accuracy was the average between the scores obtained in the next two phases:
  - *Phase 1*: After a random walk the user stopped 30s in each Area of Interest (AoI). Accuracy was measured as the fraction of time in which the locating system provides the correct information.
  - *Phase 2*: The stream produced by competing systems was compared against a *logfile* of the expected position of the user. Specifically, the individual error of each measure was evaluated, and the 75th percentile of the errors was estimated. In this sense, In Figures 3, 4 and 5 can be seen the performance of n-Core Polaris in this phase, which achieves a 0.97m mean distance error.
- *Installation complexity (0.2)*: a measure of the effort required to install the AAL locating system in a 70m^2 flat, measured by the evaluation committee as the total number of man-minutes of work needed to complete the installation. In this sense, the n-Core Polaris system was deployed in less than seven minutes in the flat, which demonstrates the ease of its installation.
- *User acceptance (0.2)*: expresses how much the locating system is invasive in the user's daily life and thereby the impact perceived by the user; this parameter is qualitative and was evaluated by the evaluation committee.
- *Availability (0.15)*: fraction of time the locating system was active and responsive. It was measured as the ratio between the number of produced location data and the number of expected data (one sample every half a second).
- *Integrability into AAL systems (0.1)*: use of open source solutions, use of standards, availability of developing libraries, integration with standard protocols.

As can be seen in Table 1, the n-Core Polaris system obtained the first place. These results demonstrate n-Core Polaris is a robust system suitable to be used in indoor environments, such as homes, hospitals or offices, and that can locate users and assets with up to 1m accuracy without interfering in the daily-life of people.

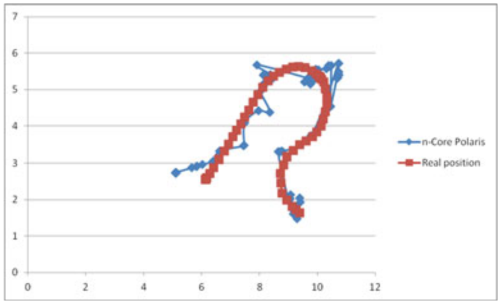

Fig. 3 Accuracy evaluation, phase 2, route 1 (Mean error = 0.777m; 3rd quartile = 1.056m).

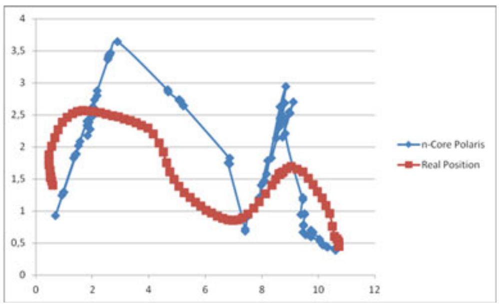

Fig. 4 Accuracy evaluation, phase 2, route 2 (Mean error = 1.055m; 3rd quartile = 1.306m).

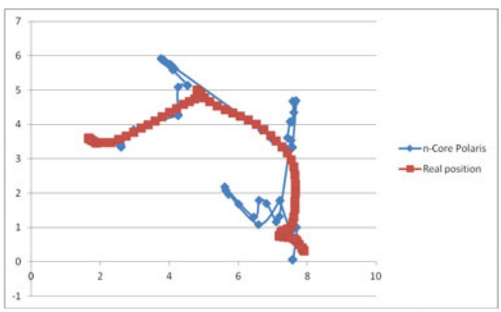

Fig. 5 Accuracy evaluation, phase 2, route 3 (Mean error = 1.088m; 3rd quartile = 1.338m).

Table 1 Intermediate and overall scores of the three best competitors in EvAAL Competition.

Competitor	*Accuracy*	*Availability*	*Installation Complexity*	*User Acceptance*	*Integrability in AAL*	Overall Score
n-Core Polaris	*5.9611*	*9.8756*	*10*	*7.625*	*6.5*	7.14
AIT team	*8.4540*	*1.3674*	*6.82*	*6.875*	*8.5*	5.90
iLoc	*7.8007*	*9.3922*	*0*	*5.875*	*4.5*	4.98

5 Conclusions

Among the wide range of Wireless Sensor Networks applications, Real-Time Locating Systems are emerging as one of the most exciting research areas. Healthcare, surveillance or work safety applications are only some examples of the possible environments where RTLSs can be exploited. There also are different wireless technologies that can be used on these systems. The ZigBee standard offers interesting features over the rest technologies, as it allows the use of large mesh networks of low-power devices and the integration with many other applications.

In this regard, n-Core Polaris provides an important competitive advantage to applications where it is necessary to know the location of people, animals or objects. Amongst its multiple application areas are the healthcare, the industrial or the agricultural sectors, as well as those related to security and Ambient Assisted Living. Its optimal indoor and outdoor functioning makes n-Core Polaris a flexible, powerful and versatile solution.

Acknowledgments. This project has been supported by the Spanish Ministry of Science and Innovation (Subprograma Torres Quevedo).

References

1. Ambient Assisted Living Joint Programme, `http://www.aal-europe.eu` (accessed October 2011)
2. Nerguizian, C., Despins, C., Affès, S.: Indoor Geolocation with Received Signal Strength Fingerprinting Technique and Neural Networks. In: de Souza, J.N., Dini, P., Lorenz, P. (eds.) ICT 2004. LNCS, vol. 3124, pp. 866–875. Springer, Heidelberg (2004)
3. Liu, H., Darabi, H., Banerjee, P., Liu, J.: Survey of Wireless Indoor Positioning Techniques and Systems. IEEE Trans. Syst. Man Cybern. Part C-Appl. Rev. 37, 1067–1080 (2007)
4. Kaemarungsi, K., Krishnamurthy, P.: Modeling of indoor positioning systems based on location fingerprinting. In: Twenty-third Annual Joint Conference of the IEEE Computer and Communications Societies, INFOCOM 2004, vol. 2, pp. 1012–1022 (2004)
5. Tapia, D.I., de Paz, J.F., Rodríguez, S., Bajo, J., Corchado, J.M.: Multi-Agent System for Security Control on Industrial Environments. International Transactions on System Science and Applications Journal 4(3), 222–226 (2008)
6. Ding, B., Chen, L., Chen, D., Yuan, H.: Application of RTLS in Warehouse Management Based on RFID and Wi-Fi. In: 4th International Conference on Wireless Communications, Networking and Mobile Computing, WiCOM 2008, pp. 1–5 (2008)
7. Stelios, M.A., Nick, A.D., Effie, M.T., et al.: An indoor localization platform for ambient assisted living using UWB. In: Proceedings of the 6th International Conference on Advances in Mobile Computing and Multimedia, pp. 178–182. ACM, Linz (2008)
8. Nebusens: n-Core®: A Faster and Easier Way to Create Wireless Sensor Networks (2011), `http://www.n-core.info` (accessed October 2011)

9. Tapia, D.I., Alonso, R.S., Rodríguez, S., de la Prieta, F., Corchado, J.M., Bajo, J.: Implementing a Real-Time Locating System Based on Wireless Sensor Networks and Artificial Neural Networks to Mitigate the Multipath Effect. In: 2011 Proceedings of the 14th International Conference on Information Fusion (FUSION), pp. 1–8. IEEE/ISIF, Chicago, USA (2011)
10. AAL Open Association. Evaluating AAL Systems through Competitive Benchmarking (2011), http://evaal.aaloa.org (accessed October 2011)