Wireless Sensor Networks for Life Science Automation

Ralf Behnke**, Frank Golatowski*, Kerstin Thurow*, Dirk Timmermann**
* CELISCA, Center for Life Science Automation
18119 Rostock, Germany
** Institute of Applied Microelectronics and Computer Engineering
University of Rostock
18051 Rostock, Germany
{ralf.behnke, dirk.timmermann}@uni-rostock.de; {frank.golatowski, kerstin.thurow}@celisca.de

***Abstract*— This paper identifies life science automation (LSA) as a predestinated field of application for wireless sensor networks (WSN). We are presenting a variety of environmental and process parameters which are measured in LSA using wired sensors today, but are best candidates to be replaced by wireless sensors. We show how they can be used and what kind of additional information can be derived from the parameters. In various examples we show the applicability of WSN in LSA and sketch a laboratory environment which is augmented with various sensor nodes. Additionally, we propose to use WSN for localization of equipment as well as persons carrying a sensor node beside the measurement of physical phenomena. Thereafter, we have a closer look at localization in WSN and present our experimental results. The use of localization in LSA is presented with the help of a scenario. A WSN with multi purpose abilities provides the flexibility to adjust laboratory installation to LSA.**

I. Introduction

Recent technological advances led to the development of smart devices, capable of sensing environmental data, process the data and transmit it among each other and to a base station (BS), respectively. Large networks of such devices, called wireless sensor networks (WSN), have come into the focus of many researches. Various hardware platforms, communication, aggregation and localization protocols have been developed over the past years. Today WSN technology is established and applications will prevail more and more. However, the number of real-world applications is relatively small. Some well known applications exist in the fields of habitat monitoring and environment observation. Therefore, one task for the next years is to find some good and useful applications for WSN.

In this paper we propose a WSN especially dedicated to the field of life science automation (LSA) which can be used for multiple purposes. This area provides a bulk of process and environmental parameters which have to be controlled. This predestines LSA as a good field of application for WSN. In the rest of this paper we will discuss the variety of purposes in this special field, the environmental parameters which can be measured and the information which can be gained from these parameters. Especially, we propose to use the WSN for localization within our scenario presented below.

The remainder of the paper is organized as follows: Section II mentions an assortment of existing WSN applications and motivates LSA as an appropriate field of application for WSN. Section III addresses the range of measurements in that field classified into two main categories. Section IV describes our scenarios and deals with localization in WSN. Section V describes some basic design conditions. Section VI gives an overview of our actual state, and section VII provides conclusion and outlook.

II. Applicational Fields

A. *Existing Applications*

Well known applications of WSN exist in the fields of habitat monitoring as well as in the field of environment observation. A well known application in this area is Great Duck Island. Here, the aim of this WSN is to observe environmental conditions in the vicinity of birds (storm petrels) [1]. Monitoring the water and atmospheric conditions on a lake is the aim of another application called CORIE. There are also existing applications in the areas of weather forecasting, logistics, agriculture and human health. A brief overview of existing applications is given by [2] and [3]. Additionally, there are also a large number of other scenarios like forest fire surveillance, target tracking for military or civil use, measurement of volcanic activity or office applications. Nevertheless, the number of real-world applications is quite small.

B. *Life Science Automation as an applicational field*

Most of the mentioned applications and scenarios are designed for observing a large area in an outdoor environment. Also, most WSN consist of extensively homogeneous sensors. And in particular they are intended for answering only one special purpose.

Life science automation is a field with a bulk of process and environmental parameters which have to be controlled. Typical process parameters in chemical applications include pressure, temperature, flow or the concentration of different reaction compounds used. Various gases can be measured for specific process monitoring as well as for fire prevention or the detection of explosive concentrations. For biological applications it is necessary to assure constant environmental parameter such as humidity, critical temperatures, air flow, light or concentration of carbon dioxide. In special cases even the air quality or the degree of air contamination has to be monitored. All measured parameters have to be stored in laboratory information management systems (LIMS) [4] together with experimental planning and results. In addition, vibration of specific machines serves as an indicator whether the machine is running or not. Today, monitoring of process and environmental parameters is realized with classic wired sensors. The installation of wired monitoring systems for environmental parameters is a critical point in the planning and realization of life science laboratories. High costs will not only result for the installation but also for every necessary change in the configuration of sensors due to changing applications and installations.

In contrast to classical applications of WSN, processes in LSA are indoor applications with a wide range of parameters. Some of the mentioned measurements have to be done within complex machines or sealed chambers. Additionally, the position of mobile equipment has to be detected as well as the position of various persons. In our opinion this can also be realized with the help of a WSN. Last but not least common environmental parameters such as temperature may be stored for later investigations. The entirety of these purposes predestines laboratory automation as a good field of application for WSN. Furthermore, it provides the possibility to build a multi-purpose WSN.

III. MEASUREMENTS IN LABORATORY AUTOMATION

Bearing in mind the idea of ubiquitous computing we believe that there is something more to measure than the raw environmental parameters like carbon dioxide or brightness. Therefore, we propose to distinguish between direct measurements and derived measurements which bring a kind of intelligence into the network by combining several parameters to identify different situations.

A. Direct Measurements

Direct measurements consist of a single parameter only. For example measuring the motion of a vibrating machine indicates that the machine is still running. For this purpose we can imagine two kinds of measurement. The first possibility is to use a sensor node with a fixed power reservoir, i.e. a battery, sensing the vibration with the help of acceleration sensors. The second, smarter, possibility is a sensor node which gets the power from the vibration itself and sends just a message when enough power is available. A similar device was presented in [5], gathering enough power for sending a measured temperature every 20 seconds.

Beside this special measurement there are also classic parameters like temperature and light. Both may affect physical and chemical processes and may also cause the disaggregation of some substances. Furthermore, there are some processes which proceed under special conditions, e.g. excessive air pressure. This is also a good environmental parameter which can be captured by a sensor node.

Another group of parameters is related to gases. In this context we are planning to measure carbon dioxide (CO_2) for biological applications or carbon monoxide (CO) as well as hydrogen (H_2) as reaction gases in catalytic synthesis. The measurement of CO and H_2 are closely associated with safety aspects. Since gas measurements usually require a higher amount of energy than for example the measurement of temperature, it has been rarely combined with WSN in the past. But new efficient gas sensors make this combination more feasible.

B. Derived Measurements

More interesting than direct measurements is the group of derived measurements. This requires a kind of intelligence within the network or on the nodes. Considering gases, one task could be to distinguish between fire indicating gases and, for example, an increased amount of CO_2 as a result of the presence of a group of people. In the first case an alarm message should be send while in the second case opening a window would be suitable. Another step could be the detection of human presence combined with brightness measurements to the derived value “too little light”. This kind of information could be used to control light and therefore to enhance the working atmosphere. This kind of deriving measurements can be characterized as parameter combination.

A more complex approach of gaining derived measurements is analysis and estimation of progresses. Therefore, sensor nodes must have information about a machine’s progress. Assuming this knowledge is available at a certain sensor, this sensor would be able to detect characteristic points such as start and end, memorize the actual state of the process and send the process state instead of less useful measurements. Parameters which could be used for such a scenario could be acoustic noise, temperature, or vibration.

IV. LOCALIZATION AND LABORATORY AUTOMATION

A. Scenario A

In conjunction with localization we strive for a location based guide through the Center for Life Science Automation (CELISCA). The center consists of different laboratories housing an amount of complex modern machines. We imagine three main classes of people which have a reasonable interest in closer information about these machines. On the one hand there may be visitors who are interested in the aim of a specific machine and maybe in the main work principle. The second class contains third party engineers whose aim is to maintain and repair a machine. These would be interested in datasheets and instruction manuals. Permanent staff, e.g. chemists and laboratory assistants, is the third group. They may be interested in actual information like remaining time of a running process or the time when a machine ran last time. All of them, the visitor, the engineer and the staff, are not willing to rummage for the specific information of a machine and to lug dozens of information with them.

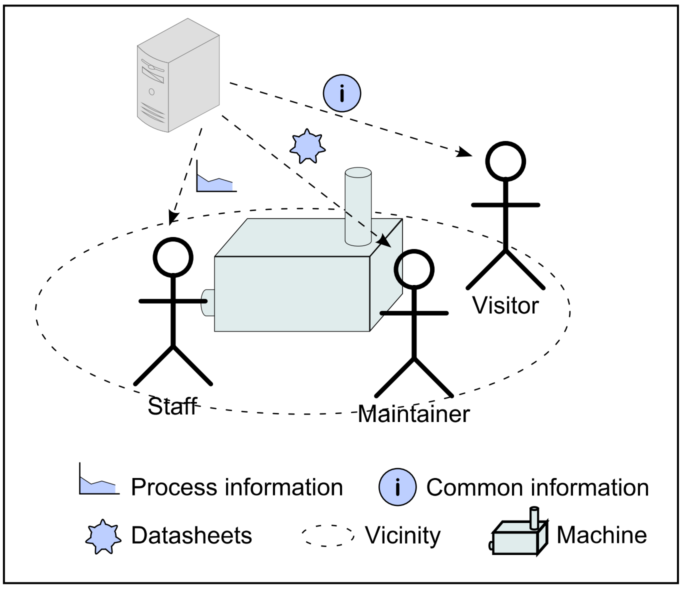

Figure 1. Scenario A: different persons within the vicinity of a machine get different information about this machine

Our goal is to provide those persons with situation specific information. Depending on its position and its spatial relation to a machine, respectively, useful information about the machine of interest should be offered to the user on a mobile device, e.g. a tablet PC. In a first step, we therefore need the person's position or distance to a machine. This can be achieved via a kind of tag which has to be carried by the particular person. This tag can be a sensor node.

For this scenario it is not important whether such a mobile user node measures additional data. But in the future one can imagine that these nodes serve as physical fitness monitor measuring medical parameters of the user like his pulse.

B. Scenario B

Having a closer look at scenario A, one has to admit that it will probably also fit on other application fields than LSA. A more specific scenario is the following. One characteristic of LSA is to work with toxic gases, i.e. carbon monoxide and hydrogen. Usually, these gases are stored within a hood which can additionally be situated in a cleanroom. The gas concentration within such a room has to be observed for detecting leaks. It is important to detect it as early as possible for preventing further damage as well as poisoning. A wireless sensor node equipped with an appropriate gas sensor is able to detect the gas concentration and send out a message. But detecting the endangerment and switching on an alarm is only the first step in such a situation.

The second task is to find out if there are people left in the danger zone. Assuming each staff member carries a personalized sensor node it can be used to find out which persons are in the danger zone. The same sensor node which detected the gas concentration would be able to find out if there are other nodes, i.e. the users nodes, in its vicinity by simply trying to connect directly to them or listening for incoming messages which are periodically send by a user node. In the described situation it is only important to obtain a rough position of the person so a coarse grained localization or even proximity detection as mentioned above would be sufficient.

C. WSN for localization

Localization in WSN is primarily used for purposes of the network itself, e.g. location based clustering [6][7], location based routing [8] or simply locating a fixed node for combining its measurements with its position and augmenting the measurement with geographic data. Various localization algorithms have been developed for this purpose. They can be classified into coarse-grained approaches and fine-grained approaches [9]. A fine grained localization with high accuracy was achieved with the so called "Medusa Node" which uses ultrasound for distance measurement and gets to an accuracy of several cm [10]. More often coarse-grained approaches exploiting RSSI (radio signal strength indicator) measurements are used. These algorithms can be realized without extra components, using the normal communication device. A very simple approach is the so called centroid localization (CL) proposed in [9]. In this algorithm nodes with known position, called beacons, are arranged in a regular grid. Unknown nodes use the position of the beacons within their receiving range and calculate the centroid as their estimated position. Assuming a regular assembly with a beacon distance of 10 m as described in [9] this algorithm and its derivates like WCL [11] reach an average failure less than 2 m. The simple CL algorithm for instance reached an average error of 1.83 m and a maximum error of 4.12 m within a 10 m x 10 m Array. This corresponds to an error rate of 18 % and 45 % of the beacon distance of 10 m. This accuracy could be outperformed by WCL which uses RSSI as a weight and achieves an average error of 6.5 % of the beacon distance [12]. It was also shown that the accuracy depends on the proportion between communication range and the distance between the nodes. Additionally modern IEEE 802.15.4 platforms like CC2420 provide better RSSI / LQI (link quality indicator) values. On that account we expect further improvements in location estimation. In our opinion WSN have the potential to serve as an alternative of proprietary systems like Ubisense, which is actually one of the leading indoor positioning systems on market and reaches localization errors within 10 cm and 1 m depending on the environment.

Having a closer look at our scenario described in section IV.A one can see that such an accuracy in the range of some meters will be quite sufficient for our purpose. In this matter, it is not very important where the user is situated but more important is to detect if the user is in the vicinity of a certain machine. Presuming that every machine has mounted at least one sensor node for further measurements like temperature or other physical parameters, the distance between these node and a user node can be equated with the distance between the user an the machine. Although, RSSI is generally a rather unreliable estimation for distances our measurements with CC2420 motes, which are illustrated in Figure 2. , showed that LQI of these IEEE 802.15.4 devices is an appropriate distance indicator especially in a short range of up to 3 meters. Since our second scenario only depends on presence detection it is obvious that it will work with the given communication hardware regardless of LQI characteristic.

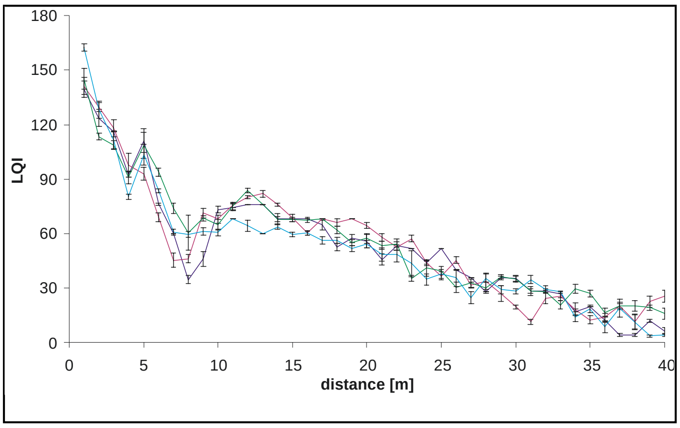

Figure 2. LQI vs. distance between two Zigbee-based sensor nodes (CC2420) in 20 loops in an outdoor environment. Each graph belongs to another sensor node

We also conducted some measurements in a LSA environment with typical indoor problems like obstacles and reflections. The measurements for various transmission power levels are illustrated in Figure 3. It is clear that the progression differs from the outdoor ones but, except for one graph, one can see that it is possible to decide if a sensor node is within a circle of about three meter. Therefore, a proximity check should be realizable with those sensor nodes.

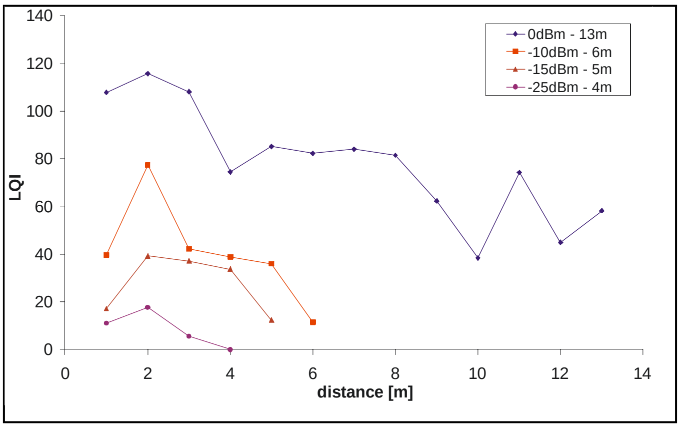

Figure 3. LQI vs. distance between two Zigbee-based sensor nodes (CC2420) in an indoor LSA environment for various transmission powers

V. Architectural Characteristics

Laboratory automation is a field of science which is still in motion. This led to the situation that such laboratories often accommodate an IT-infrastructure consisting of several specialized components which are more or less coupled together, e.g. measurement databases and laboratory information management system (LIMS). Recent developments try to bring all these information together to get a common survey of the whole environment. Therefore, it is a must to design new applications in a way that they are easy to integrate in existing or prospective systems like LIMS. We propose to design our system as a service-oriented architecture (SOA) [13]. This facilitates an easy access to the measured data and gives the possibility to divide the system into logical parts, e.g. data service and location service.

VI. Current Work

A. *Wireless Sensor Network*

At the moment a Sensor Network is running at CELISCA. The network consists of Chipcon's CC1010 nodes which use common RF and a proprietary protocol for communication. The nodes are measuring the temperature in the environment. One node serves as a gateway to a PC and to the intranet. As proposed in section V the WSN is integrated into the existing LIMS. Furthermore, measurements are available via a website within the intranet as shown in Figure 4.

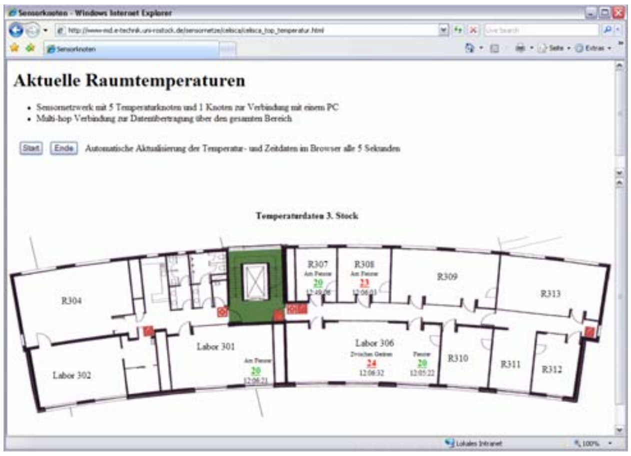

Figure 4. Measured temperature values within a browser

B. *Localization*

We tested the WSN based localization within a small testbed of five CC2420 nodes using IEEE 802.15.4 communication. Four nodes have been used as beacons with a fixed position and the fifth node calculated its position with the help of the beacons. This arrangement is illustrated in Figure 5. For the position estimation we used the weighted centroid algorithm (WCL) which is described in [11]. We reached a relatively good but, as expected, coarse-grained localization with this installation. Closer information about this work is provided in [12].

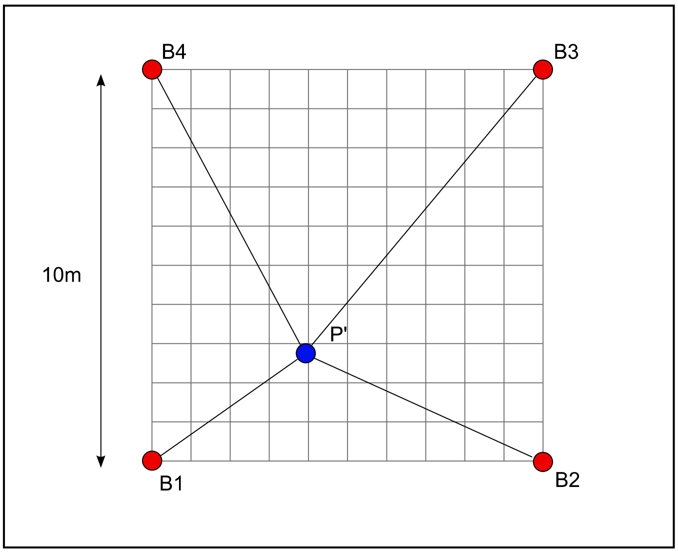

Figure 5. Testbed with 4 beacon nodes and 1 unknown node

VII. Outlook and Conlusion

In this paper we pointed out the potential measurement parameters which can be found in the environment of life science automation, predestinating this field of research for WSN applications. Additionally, we categorized potential measurements into direct measurements and derived measurements. We outlined our concept of a smart environment which is augmented with a number of sensor nodes measuring various environmental parameters which can be used for machine monitoring, emergency prevention and environmental monitoring in general. The WSN based sensor system offers the advantage over common wired systems of changing an installation easily and fast. In addition, this environment can be used for locating the position of mobile nodes. The use of this localization is outlined in two scenarios, a first scenario which is based on more accurate but coarse-grained localization and a second one which needs only proximity detection. After a closer look on location estimation in WSN we discussed some basic design constraints. In the final section we gave a brief overview of our current work and the WSN environment currently running at CELISCA.

In future work we will implement sensor nodes with gas sensing abilities. They will probably use IEEE 802.15.4 communication based on CC2420 nodes. After this step a WSN environment like it is described in this paper can be installed. Probably further localization algorithms will be developed and tested.

References

[1] A. M. Mainwaring, D. E. Culler, J. Polastre, R. Szewczyk, and J. Anderson, "Wireless sensor networks for habitat monitoring," in *WSNA* (C. S. Raghavendra and K. M. Sivalingam, eds.), pp. 88–97, ACM, 2002.

[2] T. Arampatzis, J. Lygeros, and S. Manesis, "A Survey of Applications of Wireless Sensors and Wireless Sensor Networks," in *Intelligent Control, 2005. Proceedings of the 2005 IEEE International Symposium on, Mediterrean Conference on Control and Automation*, pp. 719–724, 2005.

[3] F. Chiti and R. Fantacci, "Wireless Sensor Network Paradigm: Overview on Communication Protocols Design and Application to Practical Scenarios," *EURASIP News Letter*, vol. 17, pp. 6–27, Dec. 2006.

[4] K. Thurow, B. Gode, U. Dingerdissen, and N. Stoll, "Laboratory information management systems for life science applications," *Organic Process Research & Development*, vol. 8, no. 6, pp. 970–982, 2004.

[5] S. C. Yuen, J. M. Lee, W. J. Li, and P. H. Leong, "An AA-Sized Vibration-Based Microgenerator for Wireless Sensors," *IEEE Pervasive Computing*, vol. 6, no. 1, pp. 64–72, 2007.

[6] J. Salzmann, S. Kubisch, F. Reichenbach, and D. Timmermann, "Energy and Coverage Aware Routing Algorithm in Self Organized Sensor Networks," in *4th International Conference on Networked Sensing Systems*, (Braunschweig, Germany), pp. 77–80, June 2007.

[7] Y. Xu, J. Heidemann, and D. Estrin, "Geography-informed energy conservation for Ad Hoc routing," in *MobiCom '01: Proceedings of the 7th annual international conference on Mobile computing and networking*, (New York, NY, USA), pp. 70–84, ACM Press, 2001.

[8] E. Kranakis, H. Singh, and J. Urrutia, "Compass Routing on Geometric Networks," in *Proc. 11 th Canadian Conference on Computational Geometry*, (Vancouver), pp. 51–54, Aug. 1999.

[9] N. Bulusu, J. Heidemann, and D. Estrin, "GPS-less low cost outdoor localization for very small devices," *IEEE Personal Communications Magazine*, vol. 7, pp. 28–34, Oct. 2000.

[10] A. Savvides, C. Han, and M. Srivastava, "Dynamic Fine-Grained localization in Ad-Hoc networks of sensors," in *Proceedings of the Seventh Annual International Conference on Mobile Computing and Networking (MOBICOM-01)*, (New York), pp. 166–179, ACM Press, July 16–21 2001.

[11] J. Blumenthal, F. Reichenbach, and D. Timmermann, "Position Estimation in Ad hoc Wireless Sensor Networks with Low Complexity," in *Joint 2nd Workshop on Positioning, Navigation and Communication 2005 (WPNC 05) & 1st Ultra-Wideband Expert Talk 2005 (05)*, (Hanover), pp. 41–49, Mar. 2005.

[12] J. Blumenthal, R. Grossmann, F. Golatowski, and D. Timmermann, "Weighted Centroid Localization in Zigbee-based Sensor Networks," in *IEEE International Symposium on Intelligent Signal Processing, WISP 2007*, (Madrid), Oct. 2007.

[13] E. Zeeb, A. Bobek, H. Bohn, and F. Golatowski, "Service-Oriented Architectures for Embedded Systems Using Devices Profile for Web Services," *2nd International IEEE Workshop on Service Oriented Architectures in Converging Networked Environments, SOCNE 2007 / AINAW*, vol. 1, pp. 956–963, 2007.