Location based Wireless Sensor Services in Life Science Automation

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Abstract. Over the last years Wireless Sensor Networks (WSN) have been becoming increasingly applicable for real world scenarios and now production ready solutions are available. In the same period the upcoming combination of Service-oriented Architectures and Web Service technology demonstrated a way to realize open standardized, flexible, service component based, loosely coupled and interoperable cross domain enterprise software solutions. But those solutions have been too resource-intensive and complex to be applicable for limited devices like wireless sensor nodes or small-sized embedded systems. Thus, more and more research investigations have been launched to bring the aspect of cross domain interoperability to the field of embedded battery powered devices. The proposed laboratory assistance solution in this paper demonstrates the benefits of Web Service enabled WSNs for process monitoring and disaster management by extending an existing system in the Life Science Automation domain. Especially, the capability to provide location based services in industrial automation environment represents a beneficial feature of the presented integration approach and results in high-quality information delivery bundled with specific data about the locational origin of the capturing sensor.

Keywords: Devices Profile for Web Services (DPWS), Disaster Management, Laboratory Information Management System, Life Science Automation (LSA), Sensor Web Enablement (SWE), Sensor Observation Service (SOS), Service-oriented Architecture (SOA), Web Services.

1 Introduction

In the domain of Life Science Automation (LSA) the experimental setups, laboratories and appliances, needed for complex automated chemical and/or biological screening analysis typically consists of closed proprietary and highly specialized solutions. These solutions are mainly configured to obtain a high throughput and satisfy the required environmental constraints for the experiments. Such closed process chains are especially designed to solve characteristic classes of analysis problems with high efficiency. The available integrated sensors/actors are wired and have fixed positions at the laboratory appliances. This makes it a hard challenge to extend or adapt them dynamically without high efforts. Using wireless sensors instead offers the needed flexibility. The additional equipment of localization capabilities for those wireless sensor nodes will enable locational tagged measurement data in combination with sensing/acting services. Furthermore, these capabilities will provide an easy reconfiguration of wireless sensor network appliances. However, today´s wireless sensor nodes are not equipped with sensors needed in life sciences, e.g. CO and H_2. In this paper we introduce wireless sensor nodes addressing the needs of life sciences.

Another important challenge relies on the handling and usability of those appliances for non-technical employees. The typical scientist, who utilizes the laboratory for the experiments, is not skilled enough on the technical domain to setup, reconfigure, maintain or extend the existing workflow.

The integration of Wireless Sensor Networks (WSNs) in enterprise systems will be the right way for the future to realize a flexible and extendable system to overcome these above mentioned deficiencies. Especially, those enterprise solutions with a tight coupling of higher software layers for enterprise process management and data processing to the underlying control of industrial production processes can benefit from the flexible integration of WSNs. Web Service technology has a great potential to support a seamless integration of WSNs and to achieve an advanced applicability. Moreover, especially the benefits for usability and abstraction of a technical system providing services will be focused by our presented work.

An existing web based Laboratory Information Management System (LIMS) at the CELISCA laboratories and the corresponding appliances are extended with the WSN (see Fig. 1). The LIMS controls the workflow (control logic) of an existing analysis process chain and supports the evaluation of data measured. We will show, that the WSN based service infrastructure, developed in this work, increases the flexibility, extensibility and usability of a given wired laboratory setup. Furthermore, we provide new interaction concepts for system control, setup and configuration.

This paper is organized as follows. In section 2 we briefly review WSN technology, service-infrastructures, and technologies for disaster management. In section 3 we give an overview of the developed system, based on Devices Profile for Web Services (DPWS) and Sensor Web Enablement (SWE) middleware, to realize disaster prevention system for LSA. In Section 4 we describe user interaction with wireless sensor network and section 5 provides concrete application scenarios for our solution. We emphasize our Laboratory Assistance WSN and its innovations, at different levels of abstraction with a detailed overview, due to our integration and deployment concepts and details about the hardware of WSN. Finally the article ends with a conclusion.

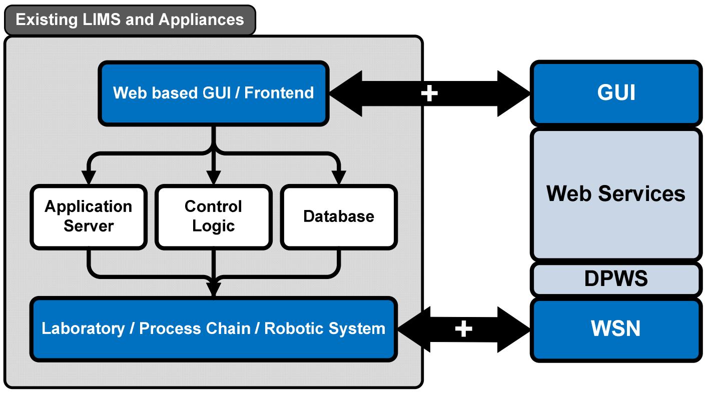

Fig. 1. Integration points of the Wireless Sensor Network into the existing Laboratory Information Management System at the CELISCA laboratories.

2 State of the art

2.1 Wireless Sensor Networks

Recent technological advances enabled the development of tiny wireless devices which are referred to as Wireless Sensor Nodes. Those devices usually consist of a number of physical sensors, gathering environmental data like temperature or light, a microcontroller, processing the data, and a radio interface to communicate with other nodes. These devices are typically battery driven to allow autonomous work and wireless deployment. Wireless Sensor Networks are interconnected assemblies of such devices [1]. In recent years, much work has been done on the various aspects of the wireless sensor networks, especially on the communication level and has result in standardized communication interfaces, like ZigBee, Bluetooth Low Energy, 6LoWPAN, Wireless HART, and SP100. However, developing wireless sensor nodes with low powered sensors measuring typical gases, which are used in life sciences, is still a challenging task. We have developed wireless sensor nodes which can measure carbon monoxide (CO) and hydrogen (H_2), two very dangerous gases. In the industrial domains WSNs become more and more attractive due to its flexibility, sizing dimensions and ease of use [2,3,4]. The main focus relies on process control and monitoring applications. In contrast to traditional wired sensors, WSN nodes can be easily placed, as close as possible to the process, without costly wiring and in combining those with actuators, reactions to measurement events can be initiated immediately. This work especially covers the benefits of WSN applications for the industrial domain of LSA.

2.2 Service-oriented Architecture

Over the last years, Service-oriented Architectures (SOA) tried to renew Enterprise Software Systems in a flexible, open standardized, interoperable and component based manner. The preferred implementation technology for SOA is the Web Service approach. But the heavy weighted first generation of upcoming standard technologies were not suitable for mobile and limited embedded devices like wireless sensor nodes. Thus, more and more research investigations were launched to bring the aspect of cross domain interoperability to the field of embedded battery powered devices [5,6,7]. The results were combined in the Devices Profile for Web Services (DPWS) [8], which represents the official OASIS standard for the seamless integration of embedded mobile systems into the Web Service concepts. In the domain of sensor applications the Open Geospatial Consortium (OGC) founded the initiative for Sensor Web Enablement (SWE) and released a collection of open standards [9]. These standards realize the high level management of sensor data and networks, accessible via Web Service technologies. Especially the Sensor Observation Service (SOS) is highly relevant for our research investigations. Our solution builds up on the above mentioned standards to realize the interoperable device connectivity and the management of sensor data.

2.3 Managing Disasters and Incidences

An automated and autonomous solution for the process observation and disaster management represents an essential part in our integration concept for WSNs. While the WSN is responsible for the data delivery another instance has to evaluate measured data and must decide if defined constraints for the processes are met. Further, correct reaction must be initiated to guarantee the behavioral correctness of an observed process. Most commonly disaster management is used as a synonym for emergency management. It deals with natural and human based disasters, like earth quakes or explosions. The four phases of emergency management are 1. *mitigation*, 2. *preparedness*, 3. *response* and 4. *recovery* [10]. The mitigation phase focuses on the prevention of that hazards will become disasters. The preparedness phase contains the development of plans for the treatment of occurring disasters. The response phase includes mobilization and coordination of emergency services, e.g. police and ambulance. Recovery treats restoring of affected areas and infrastructures. An actual example of an emergency management system (EMS) is SAHANA [11]. It impressively shows that a main purpose of EMS is to deal with a kind of resource management, planning and coordination in the case of present disasters. Another project, dealing with that topic, called SoKNOS, is further described in [12].

In contrast to the above mentioned description for disaster management, the solution of this paper focuses on the mitigation phase. The goal is to detect incidences and hazards as soon as possible to prevent disasters in observed LSA environment to ensure a correct analysis procedure. Therefore an observation service has been implemented, which analyses actual sensor readings to initiate alarm chains and react on abnormal environmental parameters.

2.4 Localization Systems

Numerous technologies and methods for locating objects were developed in the past. They differ in accuracy and reliability of the measurements, and the susceptibility to other systems or physical obstructions. Localization algorithms can be classified by their use of different parameter as inputdata for their calculation of sensor node locations [14]. The inputdata will be approximated parameters like geometric distances, locational angles and areas, topological hop counts and neighbourhood relations between sensor nodes. Furthermore, a various number of different methods like the measurement of received signal strengths (RSS), time difference of arrival (TDoA) or angle of arrival (AoA) enables the estimation of those needed parameters to calculate the sensor location [15]. Because there is often a tradeoff between the accuracy of location approximations and the energy consumption the algorithms need for the parameter extraction, localization methods can be classified into coarse-grained and fine-grained [14]. For the presented approach we decided to use the commercial Ubisense system. This is a real-time localization system based on UWB radio technology, and especially delivers the needed accuracy for indoor localization [16].

3 System overview

The following section includes an overview of our WSN infrastructure, summarizes the basic architecture and gives detailed descriptions of the used hardware, service components, workflow and the WSN itself. The core components of the solution are illustrated in the architecture overview below (see Fig. 2.).

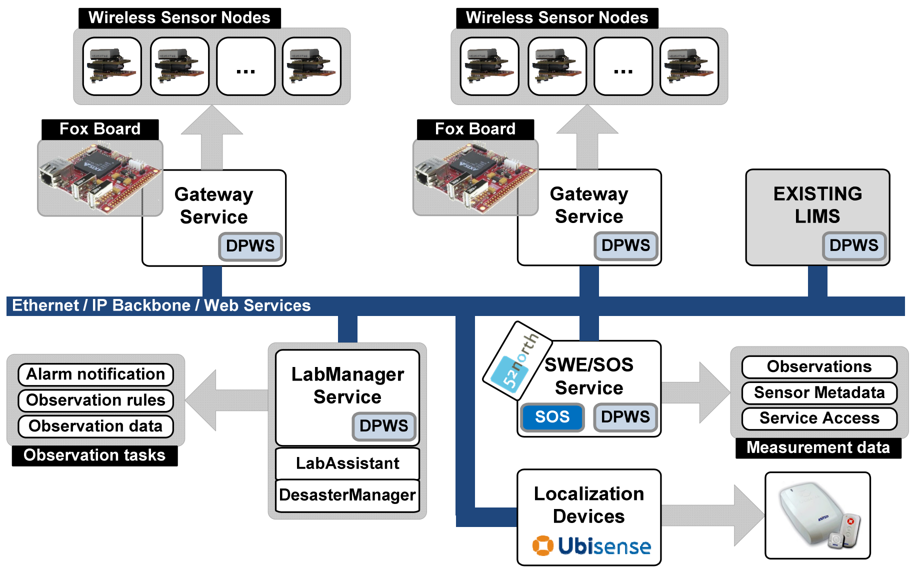

Fig. 2. Schematic overview for the complete system architecture and its components.

3.1 Hardware

The required hardware for our WSN infrastructure consists of the wireless sensor nodes itself and a gateway to enable service based interaction with the WSN. Both elements are optimized for energy aware processing.

Wireless Sensor Nodes. The wireless sensor nodes have to fit requirements like high robustness, autonomous acting, small sizing dimensions and a long battery life. To meet these requirements we build up a WSN node based on the eZ430-RF2480 platform for wireless communication via ZigBee technology, from Texas Instrument and extended this platform with the needed modules for additional measuring, communication and energy supply capabilities. To meet the special requirements in LSA, the needed sensor add-ons for measuring phenomena like temperature, gas concentrations (CO and H_2), light intensity, battery voltage and vibration were integrated. Thus, the WSN node can be integrated in typical data capturing scenarios of the LSA domain. The gas sensors are based on the electro-chemical measurement principal. This avoids the necessity for active heating and only a small current is needed, depending on the gas concentration. The figure below shows the resulting WSN node in combination with different sensor modules (see Fig. 3).

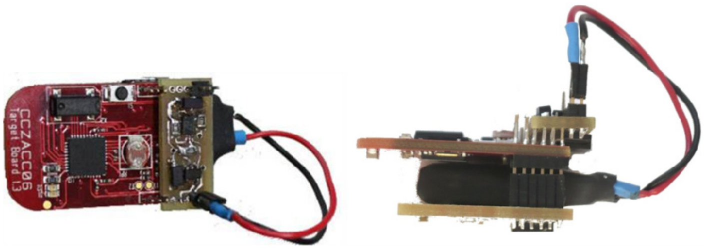

Fig. 3. Illustration of the customized wireless sensor node used at the CELISCA labs.

This WSN node has a sizing dimension of 38 x 38 x 48 mm^3. The energy source of the node consists of an internal lithium-polymer accumulator with a capacity of 100 mAh. Through an integrated mini-USB connection this accumulator can be recharged. To configure or update the software of a wireless sensor node, the ZigBee or the mini-USB interface can be utilized. For this purposed WSN node we have evaluated the runtime behavior and the energy profile to enable an optimal sensor lifetime prediction and adaption for experimental setups. Thus, the sensor nodes can be configured to fit the needs of an experiment regarding the accruing amounts of measurement data and the expected total runtime. First, the total runtime/lifetime of the WSN node (with acceleration sensor add-on) over a variation of the sampled-data period was evaluated (see Fig. 4 left data plot). The result fully fits the needs of data capturing of the experimental setups at the CELISCA laboratories. Furthermore, the energy profile for the variation of the data transmission period was evaluated for our sensor platform including additional add-ons for CO and acceleration measurements (see Fig. 4 right data plot). Both data series show that the used sensor platform is best suited for short-term experiments with high data capturing rates and long-term experiments with the need for continuous observations of environmental parameters.

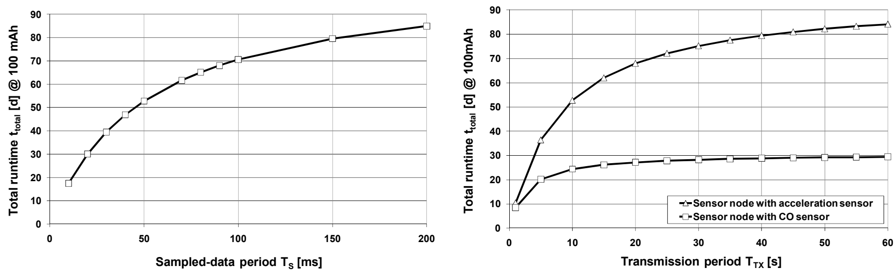

Fig. 4. The left data plot contains the total runtime capability of the customized wireless sensor node over the variation of the sampled-data period. The right data plot illustrates sensor lifetime over the variation of the data transmission period for the two different sensor add-ons.

WSN Gateway. The Fox Board LX832,produced by Acme Systems, is a compact embedded Linux server system and represents the service gateway for the WSN nodes in our solution. This board is suited with integrated interfaces for USB 1.1, Ethernet 10/100, IDE and RS232. For the WSN nodes this gateway represents the collector for their measured observation data. A sensor node registers at the gateway via ZigBee and this will make the measurement data available for the upper service instances by serving them through defined interfaces.

3.2 Service Components

The implemented service components of our WSN infrastructure represent the core concept for an easy self organized integration and deployment by abstracting the hardware and connection details through devices services.

LabManager. This service component represents the core of the disaster prevention and the process monitoring. It includes a service for notification events, a DesasterManager for the process observation and the needed functionalities to interact with the other basic system service components. The LabManager runs observation tasks, which were configured via the LabAssistant component, and is able to perform several of those tasks in parallel. An observation task consists of the following configuration subset:

- A set of observations which represents the abstract WSN measurement data and delivers the input parameter for the observation rules.
- A set of observation rules (rule set) which describes system reactions triggered by the input of the WSN observation data.
- A set of notification events (SMS, Mail, Beep or combined alarm action) that will be triggered if a violation of the corresponding observation rule takes place.

The behavior of the LabManager Service is comparable to a specialized workflow engine, which has multiple inputs and controls the firing of alarm events. The requests for sensor observations will be done via a combination of Service Discovery and Publish/Subscribe mechanism, included in the SWE/SOS Service and the Gateway Service. The realization of the Web Service connectivity was implemented using the Axis2 engine of the Apache Software Foundation.

SWE/SOS Service. This service component provides the sensor measurement data of the heterogeneous WSN combined with additional metadata through a standardized Web Service interface as WSN observation offerings. The used SOS server is based on a reference implementation of the 52°North initiative and to avoid the complicated generating/parsing of XML requests, the corresponding OX Framework is used to access and configure the SOS Services (see Fig. 5). The OX Framework offers a simplified access to SOS server via method calls. The input parameters for these methods will be send as JSON formatted set over HTTP. Defining new sensor observations and the SWE/SOS Service configuration will be realized via the SOS Assistant web frontend. The SOS Service includes three core functionalities to request all metadata about the SOS Service and its offerings, the specified observation data and the corresponding metadata, and to get detailed information about the specified sensor, which provides the observation data. Additional transactional operations enable the registration of new sensors and insertion of new observations.

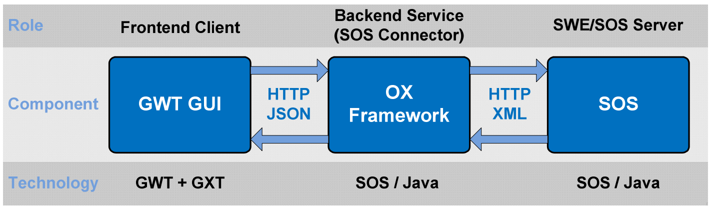

Fig. 5. Exemplary schematic block diagram to illustrate the functionality of the OX Framework in combination with the GWT frontend of the Lab Assistant.

Gateway Services. The Fox Board Gateway is abstracted through Web Services, implemented using the DPWS technology stack WS4D-gSOAP [13]. These services enable WSN nodes to dynamically discover and connect to the gateway, forward the WSN observation data to the SWE/SOS Service, discover sensors, register new sensor nodes, request locally stored sensor data and let other services subscribe for defined WSN observation events. Several Fox Board gateways and its services can run in parallel to provide a scalable and reliable access to the WSN, without concurrent behavior.

3.3 LabAssistent and SOS Assistant

The LabAssistant is a web based frontend to configure the WSN, the Gateway and the LabManager Service. It is realized as fat client web application using the AJAX technology of the open source Google Web Toolkit (GWT) and its support for Remote Procedure Calls. Additionally, the assistant guides a user through the integration and deployment process of the WSN. The SOS Assistant is similar to the

LabAssistant. It provides a web based frontend to configure the SWE/SOS Service of our solution. This includes the management of sensors, observations and the graphical illustration of observation requests/data.

LabAssistant. This component represents a web application realized with a GWT frontend, which provides the main interface for managing monitoring processes and observation tasks. The setup is divided into two subsequent flows. First of all, the setup of the sensor network in the specific observation environment has to be executed. Afterwards, the rule sets and additional data for the observation tasks have to be defined. The LabAssistant guides the user through this procedure and abstracts the underlying technological processes. Furthermore, there is no need for the user to edit configuration files or other formats, because the LabAssistant will generate them itself in a XML format.

DesasterManager. The DesasterManager is a web service component, which provides the monitoring/observation functionality. It is implemented upon the Axis2 Framework of the Apache Software Foundation. This service component provides four methods with a specific set of parameters to control the integrated multi-threaded rule engine (JRuleEngine). The START-method initializes a monitoring thread. This thread starts a new instance of the rule engine when new measurement events of defined sensor nodes arrive. The STOP-method finishes the defined observation tasks when a running experiment ends. Finally, it generates a summarizing log file that contains all executed/processed server actions. After stopping a monitoring this log file can be deleted by calling the DELETE-method. The PROTOCOL-method enables the access to the log file of currently running or stopped observation tasks.

4 Integration and Deployment

The deployment and integration strategy of our laboratory assistance solution raises the functionality, flexibility and usability of the existing LIMS system to a new level, results in cost efficient workflow turnarounds and reduces setup times. Especially the usability advantage for non-technical skilled users is a real innovation of our solution. The user now handles services of the WSN and is able to place the sensors where he needs them for his experiment. Without our WSN infrastructure the user had to be or to call a specialist, if changes in the appliances of the experiment had to be made. Especially when changing the wired sensors in their positions or measurement services. They have to be rewired, tested or recalibrated, and their new services had to be implemented. With our solution the user is able to change the hardware, replace or relocate sensors, without the need to change the software or anything else, because the setup of an experiment is bound to services of the WSN and not to the sensor hardware itself. This makes it possible to work with components-of-the-shelf WSN nodes suited with defined sensors.

Deployment. Setting up a new WSN deployment for an experiment becomes a simple procedure. Before creating a new experiment, the sensors have to be placed/plugged at the laboratory appliances and the existing sensors must be checked out. The wireless sensor nodes register themselves and their observation offerings at the Gateway Service nearest to them.

Integration. The user initiates a new experiment via the LabAssistant and creates the needed observation tasks for the process monitoring. These tasks will be suited with the necessary observation rules and the corresponding input parameter from the previously installed sensor observations. Each rule violation will be bound to a specific notification. The available observation offerings of the WSN nodes will be discovered automatically by the LabManager and the user has to pick the right ones from a list to assign them to the observation rules. If different sensor data should be combined to new observations, the user is able to create those combinations through the SOS Assistant. Assigning sensor observations to an experiment includes an automated subscription of the LabManager for observation events at the SWE/SOS or Gateway Service. The location assignment for the WSN nodes by the user will be realized through the use of the Ubisense localization tag. This tag will be placed near to the WSN node and over a push button on it the user initiates the position measurement by the wall mounted sensors. Afterwards, the calculated WSN node position will be send to the LabManager service and the user has to assign it to the right WSN node instance in the experimental setup.

After the successful deployment procedure the experiment will be started and runs now with our integrated disaster prevention. While the experiment runs external applications are able to request the corresponding observation time series via the Web Service interface of the SOS server. When the experiment ends the WSN nodes will be picked up by the user and recharged at a charge station. The complete observation data is stored in an SOS server database and will be served through a Web Service for the post data processing. The existing LIMS runs in parallel to our solution and is not affected.

5 Application scenarios

There exist three main scenarios the proposed solution will be used for at the CELSICA laboratories (see Fig. 6). These scenarios differ in the granularity of objects that have to be observed (rooms, devices or experiments), and in the associativity that the WSN nodes will have to the experiments or how the nodes will be involved in the experimental process flow (static and dynamic conditions). Furthermore, the WSN node can provide actor services to regulate or control the observed environmental conditions.

5.1 Room based monitoring

The room based monitoring focuses the observation of environmental parameters independent of the experimental setups and appliances the room contains. Thus, multiple laboratory environments will be supported and the WSN represents the hazard/risk detection system to prevent dangerous situations regarding the laboratory personal or appliances. At the CELISCA laboratories this scenario is used to observe gas concentrations (H_2 or CO) and the room temperature.

5.2 Device based monitoring

The device based monitoring scenario associates WSN nodes directly to single instances of laboratory appliances (climatic chamber or incubators) for specified observation tasks. This scenario introduces the possibility to enhance devices with new sensing/acting services or to refine existing measuring capabilities to achieve a higher measurement accuracy, sampled-data rate or observation density.

5.3 Process based monitoring

The third scenario type is represented by the process based monitoring. This observation strategy focuses on the process flow of a single experimental setup. The WSN nodes are tagged directly to single experimental probes (like a titer plate or other samples) without a fixed position and will pass through all experimental stages. Thus, a completely closed observation of the process chain can be guaranteed, and parameter variations or environmental changes for single instances of an experiment can be observed at an early stage.

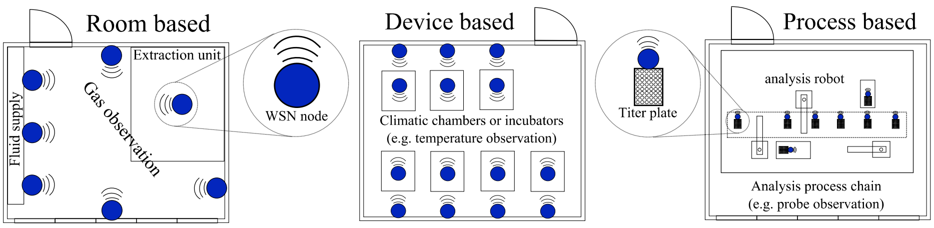

Fig. 6. Three major application scenarios for the proposed solution: room, device and process based observation strategies.

6 Conclusion and Future Work

In this paper we have presented a SOA to integrate wireless sensor networks into an existing laboratory information management system (LIMS). The architecture uses DPWS based Web Services for the collaboration and orchestration of devices, abstracted as service instances. Thus, a decoupling of the hardware and higher functionalities were reached, with the additional benefit of a higher usability and flexibility. Furthermore, the functionality of SWE/SOS is now available to the Life Science Automation domain, which is very beneficial, because measurement data will be handled on a higher level and new combinations of different sensor data can be easily created. Using a WSN in the presented application ensures flexibility necessary to construct future Life Science Laboratories. Using information from WSN in an easy way inside today's application is very challenging and this will be supported by our services over different layers.

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