Easy programming of integrated Wireless Sensor Network applied on ventilation on demand business case

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Abstract

Wireless Sensor Networks (WSNs) are expected to play a critical role in the next computing revolution of cooperating objects and smart embedded devices, allowing, among other things, considerable energy savings by automating different industry processes. However, industry adoption is hampered because sensor networks are

currently very difficult to program. To realize a sensor network application, programmers must be sensor network experts and must focus on low-level details instead of the high-level objectives of the application. MakeSense intends to drastically improve the ease of wireless sensor network programming by allowing programmers to express high-level objectives and leave the low-level details to the compiler and run-time system. Our approach consists of three layers: an application model layer, a macroprogramming abstraction layer, and a self-optimizing run-time system layer. The application model layer integrates the sensor networks with business application systems by allowing WSNs to be expressed as a business application concept. The macroprogramming layer provides a network-centric programming abstraction that relieves the programmer of the details of low-level, node-centric programming. The self-optimizing run-time system layer adapts to the specific conditions in the deployed sensor network by optimizing communication patterns and resource consumption based on input from the higher layers. By design, makeSense enables integration of wireless sensor networks into business processes. The project thereby enables a far-reaching adoption of sensor networks in European industry, holding the potential to become the reference sensor network programming platform in Europe.

Key words: *WSN, Energy efficiency, ventilation on demand, BPMN, Node, sensor*

Topic: Energy efficiency in building and retrofitting

1. Introduction: Key innovation

There is ample evidence that WSN can help to automate many industry processes leading to an energy efficient use of the resources but companies are still reluctant to install large-scale WSNs due to the costly low level programming and physical deployment of these systems. makeSense will lower the barrier for using WSNs by simplifying programming and creating a direct, technical link to business processes. This will allow e.g. more intelligent facility or supply chain management, resulting in better insight, energy efficiency and comfort.

Currently, total cost of deployment of a sensor network is not dominated by hardware (a few 100 to a few 1,000 €) but by the cost of programming an application that carries out the task of sensing (10,000s of €). This task requires highly skilled and paid embedded software engineers who know details of the used sensors and system platform. This also affects total cost of ownership as re-configuration requires the same skills. The tool chain developed by makeSense will reduce this need by providing a macro language that allows a skilled developer without explicit WSN knowledge to build such an application using a set of pre-defined abstractions. On top of this, makeSense will provide a modelling layer that allows business process modellers to effectively model processes that interact with the real world, as sensed by the WSN, with unprecedented integration.

By re-using concrete abstractions across scenarios, we expect the WSN development cost to be reduced by 50 %. Our approach requires some additional cost for process modeling, however overall, this could still reduce the cost compared to other systems currently used (such as SCADA) by around 30%.

2. Technical approach

makeSense will improve the ease of WSN programming by allowing programmers to express high-level objectives and leave the low-level details to the compiler and run-time system. The name of the project reflects both the purpose and the ambition level of the

project. The first part of the name, make, refers to the canonical make tool that automates complex build processes for the developer. Likewise, one of the purposes of makeSense is to relieve the sensor network developer and process modeller of low-level details of software development. Our approach consists of three layers: an application model layer, a macro-programming abstraction layer, and a self-optimizing run-time system layer.

The application model layer integrates sensor networks with business application systems by allowing WSNs to be directly integrated as parts of an executable business process. The main objective at this layer is to develop flexible modelling techniques driven by business scenario requirements, as well as abstractions to integrate WSNs into the business logic. Our project is the first to allow application modellers to specify the application model in business process modelling notation, namely BPMN. This approach is non-trivial since we need to combine the strictly centralized execution of BPMN with the intrinsically distributed operation of WSNs.

Therefore, the application modeller just needs to draw a BPMN diagram (as depicted in Figure 3) describing the bussines logic, so no further wireless sensor low-level knowledge is required from the business logic expert.

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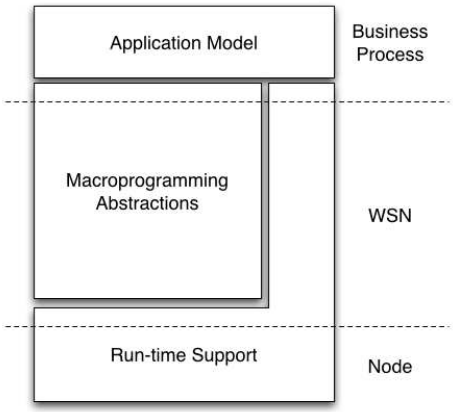
The macro programming layer provides a network-centric programming abstraction that relieves programmers from the low-level details. At this layer, we devise programming constructs to ease the integration of WSNs into business processes, developing a programming framework where different programming abstractions blend smoothly. Our framework is based on a core set of meta-abstractions, different classes of abstractions that share common features.

The self-optimizing run-time system layer adapts to the specific conditions in the deployed sensor network by optimizing communication and resource consumption based on inputs from the higher layers and the current status of the network. The run-time layer must support heterogeneous devices with varying capabilities, accommodating both resource-constrained nodes and richer devices if available.

Figure 1. Layers of makeSense approach



3. Demonstration and use

The core contribution of makeSense is a comprehensive macro programming and modelling tool chain that enables the integration of WSNs into business processes. Our

work is driven by a real-world scenario that is of interest to our end-user ACCIONA: a ventilation-on-demand use case that enables, e.g., meeting rooms to be ventilated on demand rather than at fixed rates in order to save energy and cost.

3.1. Ventilation on demand business case

The main objective of this business case is the same one established in the Energy Performance in Buildings Directive (2002/91/EC) (European Parliament and the Council of the European Union, 2003).

> Article 4: Setting of energy performance requirements (. . .) These requirements shall take account of general indoor climate conditions, in order to avoid possible negative effects such as inadequate ventilation, as well as local conditions and the designated function and the age of the building. These requirements shall be reviewed at regular intervals which should not be longer than five years and, if necessary, updated in order to reflect technical progress in the building sector.

At present, the most influential factor, on which we can act to increase the efficiency of temperature control in buildings, is the energy exchange between the air inside and outside of a building.

We can reduce the ventilation rate by using ventilation on demand. It is possible to make savings by the difference between a fixed air flow and an intermittent one as we see in Figure 2.

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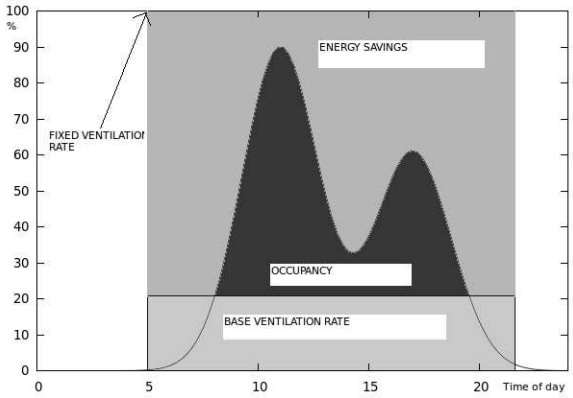
Figure 2. Energy Savings with Ventilation On Demand



There is a relation between comfort and CO_2 level, but over-ventilation does not provide any further benefit and is therefore a waste of energy. Ventilation should aim at a good compromise between CO_2 concentration and energy savings.

To create an efficient demand-driven ventilation system, we can use sensor-actuator pairs. The sensor can analyze the level of CO_2 and when it rises above a predetermined threshold, the actuator acts on the ventilation system. It is desirable to establish a system that can effectively realize these couples and to establish different levels of comfort depending on the use of the room. This situation will be described in more detail in the following sections.

So the inputs to makeSense system in order to configure the latter ventilation system are BPMN diagrams that describe the above business logic in a standardized

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manner. Thus, the application modeler just needs to know the BPMN notation and simple notions of sensor networks. He can forget about low-level details and focus only on the process modeling. This modeling could be done by a BPMN diagram editor that is predicted be completed by October 2012.

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Details on the Use of WSNs for Ventilation on Demand

To get an understanding of what we would need from the WSN for the ventilation on demand use case, the following remarks should be taken into account:

- We need to have control rules based on more than one node (for example, to ensure that the environmental conditions in a building are maintained over time). These rules express properties of the system that must be verified to ensure its correct behavior. These properties may be required to hold only for a specific time interval.
- It would be useful to offer remote operators the ability to explicitly change the configuration of sensors or actuators. This could help in case of a change in the use of the room or in case we need to recalibrate the system.
- The operators would like to have support for local interaction with the sensors/actuators, for example, the operator could force the opening of the gates and really see that the level of CO_2 is decreasing (the level of CO_2 in the street is much lower than the level considered acceptable). In order to perform these operations, the system should greatly increase the rate of WSN measurement acquisition.
- The main sensor used in this use case is one that measures the level of CO_2, however, it would be nice to also incorporate temperature and humidity sensors into the system, since the conditions of comfort vary slightly with these factors.
- The system should send an alert if a gate is open for several hours. This situation indicates a fault in the system. It would be very useful if the system sends an alert in case of a great increase in the CO_2 level. We must bear in mind that a concentration of more than 2500 ppm probably indicates the occurrence of fires.
- With the quick diffusion of gases, we can assume that the level of CO_2 is the same across the room. This allows us to use only a single sensor per room.
- The actuator to be used in this use case only has to open a gate.
- As the perception of air quality is subjective (although closely linked to the level of CO_2), it would be interesting if the system could be recalibrated (changing the acceptable threshold of CO_2) easily.
- To make the system effective, it should have a response time to change environmental parameters on minutes. This interval could be increased in case of detection of faults in the system (hours).
- The system should be programmable for personnel with limited computer skills.

Use case examples

Here we present some innovative business applications of the makeSense system for the ventilation use case. For further illustration, we depicted the first scenario in a process diagram in Figure 3.

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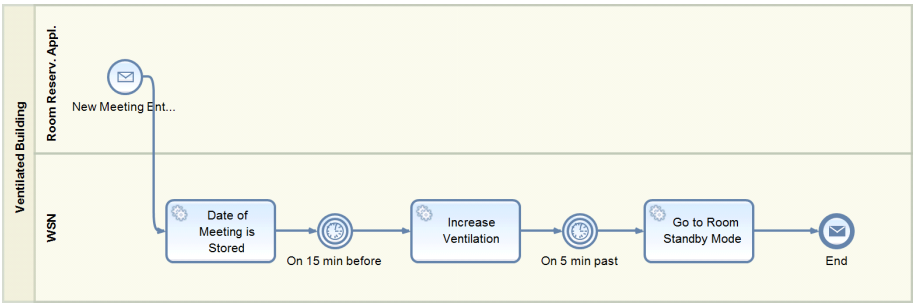
Eliminado: Figure 3

- A system that uses makeSense results connected to the meeting rooms could ventilate the room before a meeting. Ventilation could be activated by the room reservation system (e.g., Exchange or Lotus Notes calendars).

Figure 3. Efficient and Comfortable Ventilation of Meeting Rooms.



- In a logistics company a building formerly used for administrative activity is now also used to store certain types of goods. This new use of the facility means that there is an increased physical activity, and thus the level of bioefluents in the room has increased. The maintenance staff of the building only have to select a maximum CO_2 level lower than the previous one to maintain air quality without increasing the energy consumption of the building.
- A building is designed to serve a veterinary business. Different kinds of animals are kept in distinct rooms, but this association is changed from time to time. Each animal emits a different level of bioefluents, but this is not a problem because due to the ease of use offered by makeSense, it is possible for the staff dedicated to maintaining the building to change the CO_2 thresholds for driving the ventilation system.
- A construction company has started to build luxury homes. This group of customers is concerned with the environment, and getting an energy efficient house is something they value very positively. The availability of a system in which the client can control ventilation in each room separately greatly increases the speed with which such homes are sold, without increasing the price of each unit too much. The user is able to control the ventilation in his house using a simple user manual (a user has reported that he has greatly improved his greenhouse, due to the ability to control the CO_2 level).
- In the future (or already today in certain cases), electricity tariffs could exhibit variable prices, fluctuating during the day due to varying supply (e.g., through renewable energy) and demand. An expert system connected to a system by means of makeSense, could decrease the ventilation (within acceptable parameters) when energy cost is high, and could increase it if they are low.
- A ventilation system that uses makeSense could detect fires by detecting a large increase in CO_2 level (it is different for each room), in this case it could send a signal to the fire station and could activate the building alarm.

- A survey system that would help users to find their optimum CO_2 level could be developed. This optimal level is sent to a ventilation system that uses makeSense.
- With a system that uses makeSense results, it could be possible to revise the maintenance protocols to minimize interventions, since, for each room, it can calculate the time the ventilation system takes to correct the deviations of the CO_2 level.

Motivation to Use makeSense Results

Reducing energy consumption for housing is one of the biggest challenges for any constructor today. It is estimated that controlled ventilation can save up to 30% of the energy used in air conditioning of a building. A system of this type could make the installation and maintenance of ventilation-on-demand systems affordable in low-medium cost buildings because of the ease of use, installation and maintenance a system based on the technology proposed by makeSense would have.

The flexibility that allows the use of makeSense on a ventilation on demand system allows us also to link the system with other systems operated by other stakeholders such as the department of occupational hazards, human resources, finance department. That could help to make better predictions of the maximum number of people who would have a sufficient comfort per room or of money spent on ventilation.

4. Scientific, Economic and Societal Impact

Monitoring and control heavily depends on the integration of sensors and actuators. World M&C market is expected to grow from €188 Bn in 2007, by €300 Bn, reaching €500 Bn in 2020. The M&C European market follows the same trends as the M&C world one in terms of product repartition and also markets products evolutions. The European M&C market will be reaching €143 Bn in 2020. Even if a small fraction of the monitoring and control market depends on wireless sensor networks, and we can simplify their programmability and management, the impact would be significant and cross-domain. In order to fully exploit the potential of the WSN technology and reach the expected numbers of deployed nodes and the revenues predicted, several barriers need to be overcome. According to the ON World Inc. report on Wireless Sensor Networks dated Nov 2004, one of the major barriers to adoption of sensor networks is the lack of ease of use as well as long development time. This is confirmed by the Embedded Everywhere Research Agenda for Networked Systems of Embedded Computers by the National Research Council (National Academy of Sciences, 2001) which clearly states that the development of new abstractions for collective behavior, i.e. the network as a whole, will be one of the biggest contributions of research in the field of embedded networked systems. The Embedded Wisents and CONET Roadmaps also regards lack of system integration as a roadblock to the adoption of WSN technology, i.e. in an operational deployment, the cooperating object or sensor network has to be included in a bigger context of – mostly existing – frontend software that, for example, can control or query the Cooperating Object and receives in turn notifications or answers to the queries. The communication between the Cooperating Object and the frontend software involves several heterogeneous intermediate systems.

As illustrated by our deployment scenario, the goal of makeSense is the monitoring and optimization of ventilation systems in buildings with the aim of increasing energy efficiency and reducing GHG emissions. Further, makeSense enables domain experts to design innovative business processes around the deployment simplifying monitoring and control in a new way. Ease of use and enabling non-expert users to realize applications are main targets of makeSense. This can have a significant impact especially for SMEs who will now be able to afford real-world interaction via WSN-empowered business processes; a capability that up to now was only possible in big industries with many specialists on the WSN programming.

5. Main achievements

All in all, we can conclude that the main achievement of makeSense project is an easy and intuitive way of programming WSNs for non-programmers domain experts, that in turn can be divided in the following concrete attainments:

- Survey of existing programming abstractions and applications
- Design of overall system architecture, including
  - Extensible macro-programming language
  - Concept for expressing WSN applications in BPMN and transforming them to macro-code
  - Concept for interaction of WSN applications and business processes
  - Common data structures describing system meta-data
  - Design of the self-optimizing run-time architecture

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7. References

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