A service oriented architecture to enable a holistic system approach to large system maintenance information

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Abstract

Heavy machinery in today's process industry is equipped with an increasing number of sensors for control and maintenance purposes. Each sensor is engineered and configured for a dedicated purpose; thus, the data or information provided by each sensor is confined to a specific purpose. Changing this individual approach to a holistic approach for control, operation and maintenance allows the data to be used in new ways, such as new control strategies, operation strategies and maintenance management.

The holistic approach is demonstrated for a process of continuous energy generation and distribution: district heating. The purpose-based approach is replaced with the holistic approach, which focuses on system optimization and failure detection. The system was first set up in a Simulink simulation model to capture the thermodynamic behavior of the houses attached to the district heating system. In this model, each sensor is seen as a service that can be accessed for different purposes. Model analysis in this case led to new approaches for control and maintenance of critical parts in a district heating system.

The new holistic approach is realized as a service-oriented architecture (SOA)-based wireless sensor network. It is currently installed in a small part of a district heating system in Piteå, Sweden. The system utilizes a wireless sensor network with service-oriented architecture using device profile web services (DPWS).

Based on the data and information provided by the SOA wireless sensor network, the system can be identified. For the district heating example, the system identification provides system parameters that can be used to improve the thermodynamic Simulink model. Thus, comparisons can be made over time to determine system degradation. Furthermore, possible maintenance actions can be modeled, which allows prediction of system performance improvements related to specific maintenance actions.

1 Introduction

Today, most complex machines and systems are equipped with sensors and actuators to monitor and control the system status and function. The intended use of each sensor or actuator is decided during the system design phase. At a very low level, a single sensor can be used for dual purposes, which leads to a low-cost solution for some functions. Typically, system design is governed by functional requirements, lifetime requirements, legal requirements, current technical constraints and tradition. This generates a non-optimal design. When reviewed at a later point in time, it is obvious that the system design can be significantly improved because requirements and constraints change over time.

Complex systems should be extendable and reconfigured over time; however, this is a costly and elaborate process. In this paper, we discuss how the introduction of flexible wireless communication in a complex machine/system enables the monitoring and control functionalities to be upgraded to support machine/system operation and maintenance.

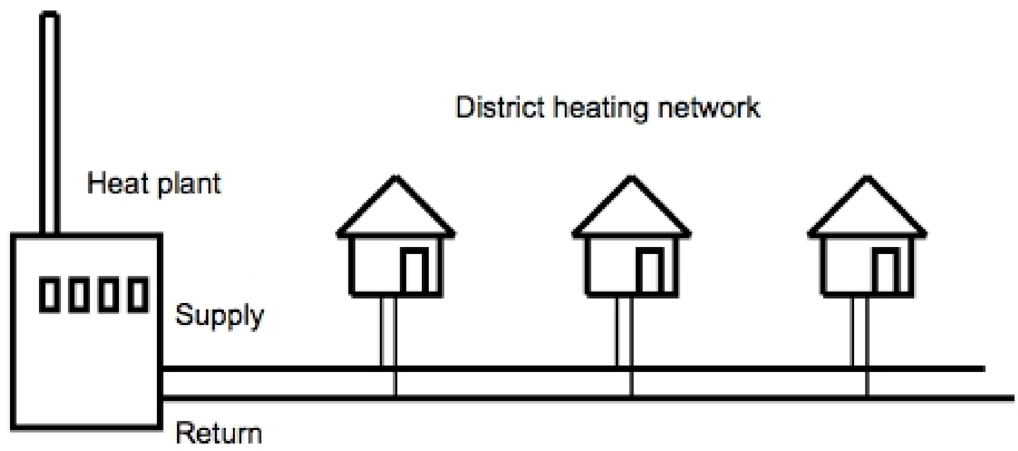

Figure 1: General design of a district heating system. The system includes a heat production facility, heat distribution system and consumer substations that provide space heating and warm tap water to the customer.

As an example of a traditional monitoring and control system for a complex system, we use district heating. A district heating system consists of at least one heat production unit, a piping system to distribute hot water and heat and consumer substations, as shown in figure 1.

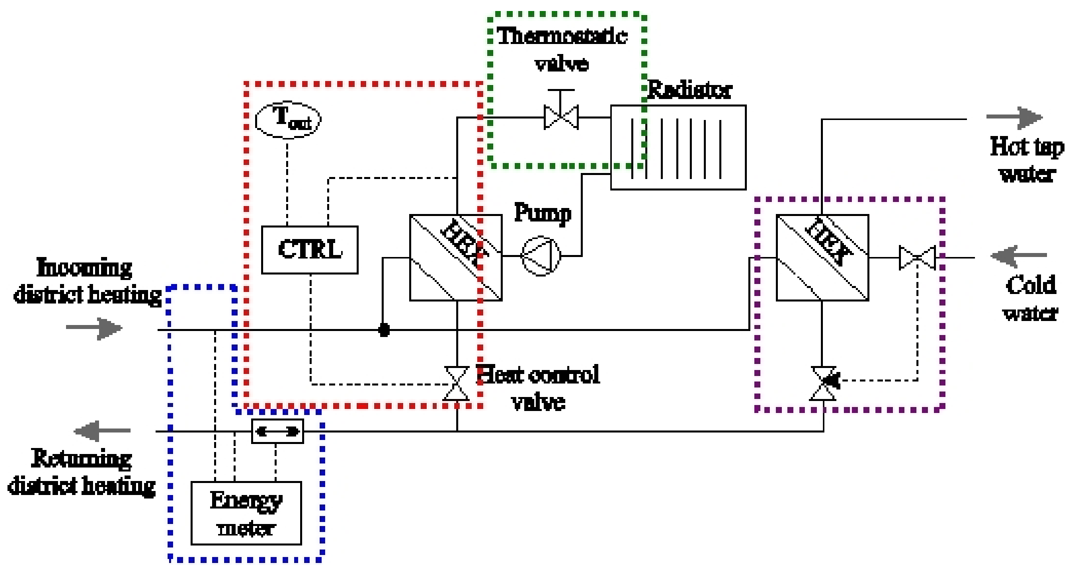

Figure 2: A standard district heating substation has numerous sensors, actuators and control systems. The four independent monitoring and control systems in the dotted boxes only have a system design relationship with each other. These systems work independently from each other. The sensor information obtained in each sub-control system is confined to its subsystem because they have no means of communication with each other or a governing system.

Modern district heating systems do find sensor and actuator setups like that in figure 2. Here, the heat measurement is used for billing purposes. Presently, these sensors are being upgraded to enable remote reading using proprietary communication protocols. The control system of the substation handles heat distribution in the customer building. Some of sensors and actuators that are local to the substation are connected to the control unit, which is isolated from other systems. Within the customer building, there are numerous systems that influence the claim of energy from the district heating substation, such as radiator thermostats, and other heat sources, such as heat pumps.

This is just one example of a complex system with numerous subsystems that cannot use local information from other subsystems. The majority of complex systems and machines suffer from this drawback.

It seems obvious that if the local sensor information and actuator capability can be made available to system functions such as operation, maintenance and engineering, then economic gains can be obtained, as well as the application of new operation strategies, maintenance analysis and engineering support.

This integrated system can be achieved by introducing an information architecture. Thus, this paper proposes, describes and demonstrates a complex system communication architecture with the following features:

- Two way communication between subsystems and device
- Online reconfiguration of subsystems and device
- Ease of retrofitting of existing systems
- Lower implementation cost

2 Information architecture

Our proposed information architecture is based on the use of wireless communication between devices and subsystems with TCP/IP as the network protocol and web service protocols (DPWS) to form a service-oriented architecture (SOA). SOAs are currently used at higher levels in large systems, for example, [1]. Many have attempted to bring SOA and the necessary protocols to the device level, for example, [2, 3, 4, 5, 6, 7].

The proposed information architecture is shown in figure 3. Sensing and actuating devices, such as flow meters, temperature and pressure sensors, pumps, valves and controllers, are all connected to the same network. The selection of physical layer communication is not critical, but for ease of use, wireless radio communication is preferred as long as bandwidth, connectivity, authentication and security requirements can be fulfilled. The approach brings web services to devices based on service-oriented architecture protocols (SOAP) [8]. All of these protocols are standardized. Implementations of these protocols are available as open sources, for example, [9].

3 Experimental setting

For the district heating example, this transfers to whats is shown in figure 4. A number of devices are connected to a common information infrastructure. The following devices located in the district heating substation and in the house are connected in the information system:

- Incoming primary heat meter
- Primary hot-water flow meter
- Primary forward-temperature sensor
- Primary return-temperature sensor
- Outdoor-temperature sensor
- Circulation pump at secondary side
- Secondary side controller
- Room-temperature sensors
- Hot-tap-water flow meters (10 tap points)

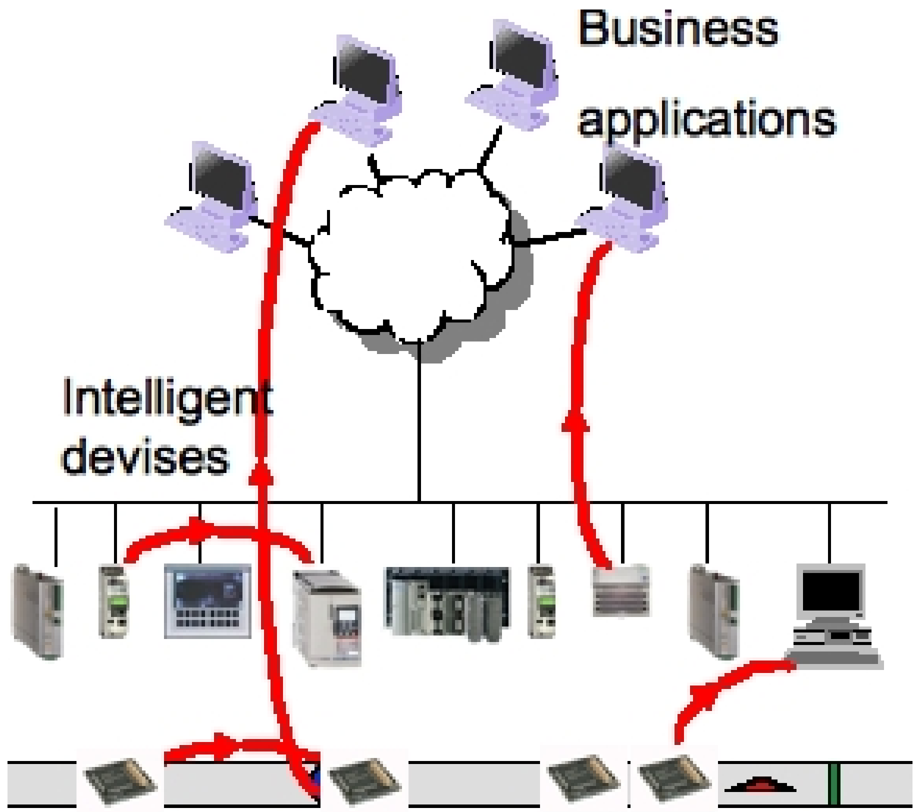

Figure 3: The proposed information architecture based on wireless communication, TCP/IP communication protocols and web service protocols enables a service-oriented information architecture.

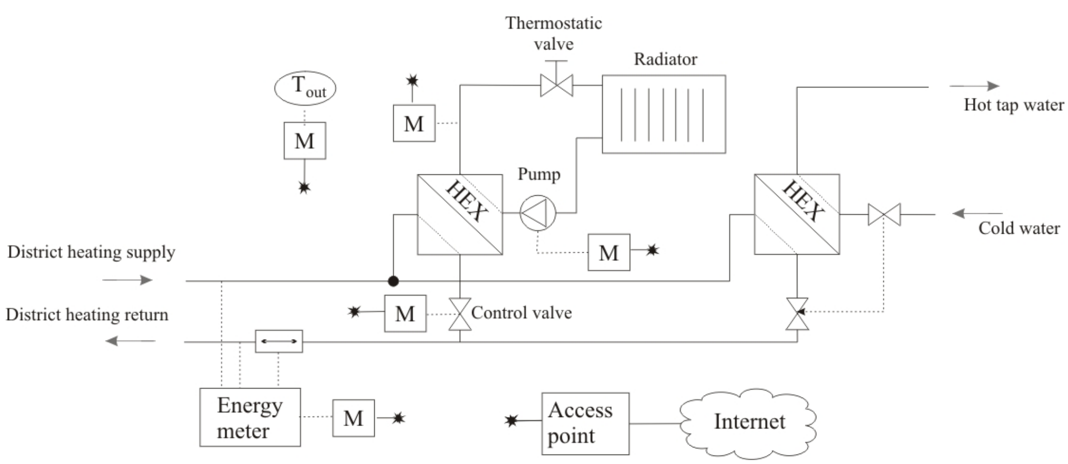

Figure 4: Adaptation of the proposed information architecture to a district heating system and its substations. Each point with a boxed “M” has a wireless connection to the Internet and some minimal SOA capabilities of at least : service discovery and service request.

- Hot-tap-water temperature sensors (10 tap points)

Each device is capable of two-way communication using TCP/IP and DPWS protocols. Moreover, each device can be discovered by the system and can discover its service surroundings. The available services for each device are described in XML using structures provided by the DPWS standard. The semantics for these XML service descriptions has to to be agreed on among the devices in the system.

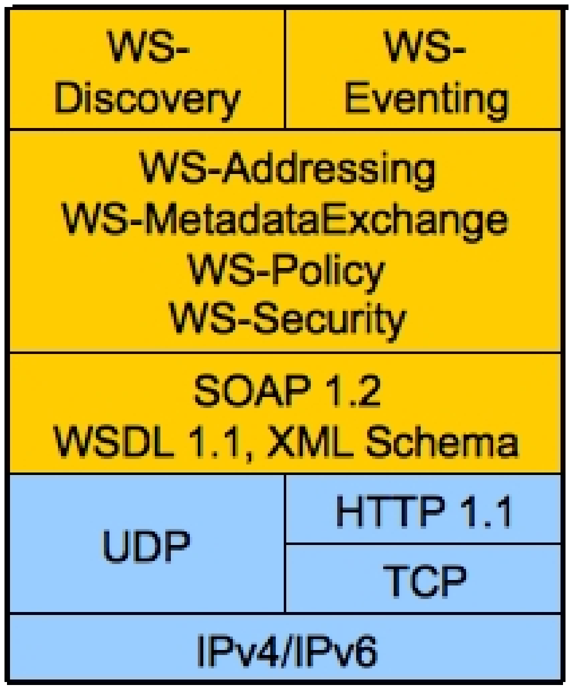

Figure 5: Adaptation of the proposed information architecture to a district heating system and its substations.

Thus, each device holds a service protocol stack, as depicted in figure 5.

Based on work by Gustafsson [10, 11], Ylimiemi [12], Wernstedt [13], Deventer [14] and Svensson [15], we can show that five different monitoring, control and maintenance information functions can be implemented on such an information architecture. Thus, the information from one device can be used for multiple purposes, and that the information usage method can be easily changed during system operation. These five functions are described below.

3.1 Advanced control for improved energy efficiency

Improving the cooling of incoming hot water at a user substation is of primary interest in a district heating system. This is most often addressed by increasing the ΔT. Gustafsson [11] has shown that substantial improvements can be obtained over all other known control strategies by making use of the primary forward temperature instead of the local outdoor temperature as the primary input parameter to the substation controller.

To implement such a change, we need to feed the primary incoming temperature sensor data to the control algorithm instead of the local outdoor temperature data. Doing this in a traditional system requires the installation of a primary temperature sensor and wiring it to the substation control box. Further, a manual update of the control box software is required to put this into operation.

In an SOA-based information system, we will make a service discovery and look for a device that provides the primary incoming temperature. Here we most likely will find that the primary incoming temperature sensor already provides this service to the heat metering calculation. The remaining task is to adjust the parameters of the substation control loop or to provide an improved control algorithm to the controller.

For the SOA-based information system approach, all of these tasks can be made as parameter changes or eventual software updates to some of the involved devices. Having the devices in an information system network architecture enables these operations to be performed online.

In this case, the computation is made locally because the result is used locally.

3.2 Fault monitoring of substations

The work by Svensson [15] shows that fairly simple analysis of the heat meter data (incoming and outgoing primary temperature and primary flow) can reveal maintenance needs for a district heating substation. To achieve reasonably accurate analysis, the heat meter data sampling interval should be in minutes.

To make use of such maintenance detection analysis in current district heating systems, one approach is to use heat meter data with the necessary sampling interval and a central analysis computer. For the majority of substation installations, there are no technical means to do this. Another approach is to update the heat meter with the appropriate analysis capabilities. Both of these operations have clear costs and handling disadvantages in systems with large numbers (thousands) of substations.

In an SOA-based information architecture, the task is handled as follows. A discovery process is initiated by looking for services that provide the necessary data. We will most likely find the same services as used for calculating the transferred heat to the substation. Next, we discover look for a device that is capable of the necessary analysis and has spare computation and communication capacity. Once found we will import the software of the identified device. Finally, we are able to run the maintenance analysis locally without any additional hardware or any need for physical intervention to the system.

This data collection and computation can preferable be made locally to minimize data traffic. Once a fault is detected, the fault information can be transferred to the appropriate receiver.

3.3 Improved customer information

One important issue in customer communication in a district heating system is to provide adequate and informative data on energy usage. Yliniemi [12] has shown that, based on the sensors used for heat meters, it is possible to extract the energy usage for space heating and warm tap water. The requirement is that the sampling interval of the primary supply and return temperature and of the primary flow be less than 1-2 seconds.

It is of course possible to reprogram the heat meter to also make this calculation. However, with current technology, this procedure requires manual intervention to the heat meter.

In a SOA-based system we can again apply the service discovery approach, as shown above, and thus “re-program” the system to accomplish also this function.

We apply the same information for yet another task that can be performed locally in the subsystem. The only information that must be transferred for further processing is status information, such as ΔT, fault operation alarms and customer information aggregated to a level specified and appreciated by the customer.

This computation is made locally at the customer installation to minimize data transfer. Customer look-up of information can be handled from a local web server embedded in, e.g., the heat meter.

3.4 Demand side management

In situations where the energy demand from a district heating system is larger than the supply, load balancing is required. There are such load balancing algorithms proposed, for example, [13]. The demand is given by the customer heat meter data, which is requested using service discovery and a data request operation in an SOA framework.

In this example, user data from several locations are aggregated for use. The computation can be made either at the actuators that are physically responsible for balancing the load/supply or at a central location with subsequent transfer of actuation information to the correct location.

3.5 Advanced model-based maintenance prediction

We again consider the same district heating substation system and the capability of discovering the requested services. Based on the data and information provided by the SOA wireless sensor, the network system can be identified [14]. For the district heating example, the system identification results in system parameters that can be used to improve a thermodynamic Simulink model. Thus, comparisons can be made over time to determine system degradation. This further enables modeling possible maintenance actions to predict system performance improvements related to specific maintenance actions.

It is clear that the computation needed for this function can be made in a small embedded device. For functionality, there is no direct need to process information at a central location.

3.6 Implementation

The system functions described above were realized using the following experimental setting in a house in the city of Piteå, Sweden

All sensors and actuators given at page 3 were retrofitted with wireless sensor network (WSN) nodes (Mulle by Eistec AB) [16, 17]. All Mulle WSN devices and their specific services can be discovered using web services. Because each WSN Mulle node can accommodate general computation, we selected one of the devices to host this particular function.

4 Discussion

Considering the five given cases, it is clear that all of them apply the same information. Four out of the five most likely apply the obtained information locally. The only example that benefits from central implementation is the demand-side management.

From the given examples, it is clear that sharing data from one or several sensors for different purposes has certain advantages. New ideas for uses of already existing data will develop over time and will be able to be implemented as configuration or software updates, which is much easier than installing new sensor/actuator hardware and related communication and/or computation devices.

5 Conclusions

In conclusion, we propose an information architecture for complex systems and machines based on SOA. This architecture is well suited for building and modifying the operation, maintenance and engineering of complex systems/machinery.

It has been successfully demonstrated that five different control and maintenance tasks can be implemented on such an architecture. The demonstration was made in a real district heating system in Piteå, Sweden.

References

[1] T. Erl, SOA Principles of Service Design, Prentics Hall, 2008.

[2] F. Jammes, H. Smit, Service-oriented paradigms in industrial automation, IEEE Transactions on Industrial Informatics 1 (1) (2005) 62–70.

[3] F. Jammes, A. Mensch, H. Smit, Service-oriented device communications using the devices profile for web services, in: Proceedings of the 3rd international workshop on Middleware for pervasive and ad-hoc computing, ACM, 2005, p. 8.

[4] M. Feike, N. Popova, A. W. Colombo, Ami-based production systems: Configuration of sequential process flow and soa-based diagnosis, in: Proc. IEEE International Conference on Industrial Informatics (INDIN), Piscataway, NJ 08855-1331, United States, 2008, pp. 517 – 524,

production systems;Mechatronic devices;Sequential processes;Design automations;Ambient intelligences;Modular systems;Service-Oriented architectures;Engineering phases;New technologies;Control softwares;Web service interfaces;Configurable;Flexible productions;.
URL `http://dx.doi.org/10.1109/INDIN.2008.4618155`

[5] V. Herrera, A. Bepperling, A. Lobov, H. Smit, A. Colombo, J. L. M. Lastra, Integration of multi-agent systems and service-oriented architecture for industrial automation, in: Proc. IEEE International Conference on Industrial Informatics (INDIN), Piscataway, NJ 08855-1331, United States, 2008, pp. 768 – 773, reconfigurability;Modular;Control architectures;Service-Oriented architectures;Reconfigurable manufacturing systems;Human interventions;Dynamic environments;Software/hardware;Physical locations;Production lines;Industrial automations;.
URL `http://dx.doi.org/10.1109/INDIN.2008.4618205`

[6] S. Karnouskos, O. Baecker, L. De Souza, P. Spiess, Integration of soa-ready networked embedded devices in enterprise systems via a cross-layered web service infrastructure, in: 12th IEEE Conference on Emerging Technologies and Factory Automation, Citeseer, 2007, pp. 293–300.

[7] L. de Souza, P. Spiess, D. Guinard, M. K
"ohler, S. Karnouskos, D. Savio, Socrades: A web service based shop floor integration infrastructure, The Internet of Things (2008) 50–67.

[8] Wikipedia, Soap (2010) [cited April 6, 2010].
URL `http://en.wikipedia.org/wiki/SOAP`

[9] Soa for devices (2010) [cited April 6, 2010].
URL `https://forge.soa4d.org/`

[10] J. Gustafsson, J. Delsing, J. van Deventer, Validation of a district heating substation model using a wireless sensor network approach, in: Proc. Int. District heaing Symposium, Orlando, 2008, p. 8.

[11] J. Gustafsson, J. Delsing, J. van Deventer, Improved district heating substation efficiency with a new control strategy, Applied Energy.

[12] K. Yliniemi, J. Delsing, J. van Deventer, Experimental verification of a method for estimating energy for domestic hot water production in a 2-stage district heating substation, Energy and Buildings 41 (2) (2009) 169–174.

[13] F. Wernstedt, P. Davidsson, C. Johansson, Demand side management in district heating systems, in: AAMAS '07: Proceedings of the 6th international joint conference on Autonomous agents and multiagent systems, ACM, New York, NY, USA, 2007, pp. 1–7. doi:http://doi.acm.org/10.1145/1329125.1329454.

[14] J. van Deventer, J. Gustafsson, J. Eliasson, J. Delsing, Independence and interdependence of systems in district heating, in: Proc. SysCon 2010, Eislab, San Diego, 2010, p. 5.

[15] B. Svensson, In-situ test methods in district heating systems : application to heat meters and subsciber stations., Licentiate thesis, LuleåUniversity of Technology (1996).

[16] J. Johansson, M. Völker, J. Eliasson, Å. Östmark, P. Lindgren, J. Delsing, MULLE:a minimal sensor networking device - implementation and manufacturing challenges, in: Proc. IMAPS Nordic, IMAPS, 2004.

[17] EISTEC, Eistec (2010) [cited April 6, 2010].
URL `http://www.eistec.se`