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*Rapport SGC A43*

# **Networked energy measurement and control in a natural gas grid**

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Jörgen Held

## **Excecutive summary**

The application of sensor network technology to gas metering and control in a gas distribution grid is discussed. Introduced by a brief overview of sensor network and sensor fusion ideas two different scenarios for applying networked sensors to gas metering and control are discussed. Possibilities for improved gas metering accuracy and improved customer communication are discussed. Such improvements will possibly result in new customer services that can be offered by the gas supplier and better energy efficiency.

Based on this it is proposed a demonstration project. Here sensor networking applied to gas metering, the resulting services and related ideas will be tested and demonstrated at 10 customers. In addition investigations on customer realtions and future system cost and quality will be made. A very rough project cost estimate is 4.75 MSEK.

To further investigate the possibilities of sensor networks in the gas distribution business also a research project is proposed. The research project will investigate new technology for estimating data on energy usage and system performance and system daignoses. Furhter architectures for suitable for networked sensors fusion in gas metering will be investigated. Project results will possibly provide more cost efficient system maintenance and improved system energy efficiency. A research project over 3.5 year is cost estimated to 5.82 MSEK.

# 1 Background

A currently very hot theme for global research is sensor networks. Here sensors are given the capability of communication using either wired or wireless technology in combination with very capable protocols like the Internet suite of protocol named TCP/IP see for example [1]. In the context of sensor networks sensor self-diagnostics [2, 3] and system diagnostics [4, 5] can be achieved. In both cases sensor fusion technology is the basis for improved measurement accuracy and system performance.

At the same time we see a large change in the energy industry where regulation requests individual measurement of electricity, gas, heat etc. This has triggered a number of work on sensor communication that already is commercialized. Most of this technology is making use of proprietary protocols and communication schemes. Thus making interoperability and exchangeability both hard and expensive.

This forms the incentives for this study on networked sensing and control in a natural gas grid. This work will sketch two scenarios with networked sensor in a natural gas grid. One scenario will consider networking of the sensors involved in forming the energy measurement on which the billing is based. The other scenario will discuss the possibility of networking both the gas energy measurement and the gas usage control system at the customer. Both scenarios will be applicable to different type of customers like:

- Industry customer
- Heat customer

- Co-generation customer
- Single family household

Based on the two scenarios I do propose a demonstration project and a research project regarding:

- Demonstration of networked gas energy measurement a natural gas grid
- Improved measurement and control in a natural gas grid based on sensor fusion networks

## 2 Sensor fusion networks in energy distribution

In this report the sensor network approach used is based on the Embedded Internet System (EIS) architecture [1] where every sensors and actuators in a system can be individually connected to a network using the Internet protocols. This implies that every sensor/actuator will have both computation and memory resources in combination with the capability of communicating on the Internet. The communication capability can be wired or wireless.

A general illustration of such sensor network is given in figure 1. Here data can be exchanged between sensors/actuators thus enabling one sensor to improve its functionality due to additional information obtained from a nearby sensor. Further sensor fusion can be made to calculate new data based on data from a number of involved sensors and actuators.

Applying the ideas of sensor networks to natural gas distribution and customer substations is illustrated in figure 2. Here different sensors like flow and temperature as

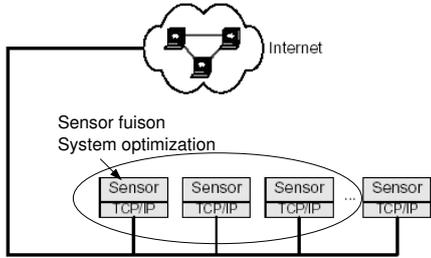


Figure 1: Principal sketch of a sensor network using EIS architecture capable of doing sensor fusion.

well as the control devices controlling the gas burner can be networked.

The necessary electronics enabling sensor networking is not commercial today. Based on university research devices providing the necessary electronics for the sensor networking capabilities has been developed. Platforms like MULLE [6] provides sensor interface, computation and memory resources in combination with wireless Bluetooth communication. Devices like MULLE automatically builds Internet networks between devices. In figure 3 we see an example of a temperature sensor with the necessary EIS electronics for putting the temperature sensor wirelessly onto Internet.

Based on the EIS architecture all sensor and actuator including the flow computer and the control system at a customer can be networked. This will allow for new and us-

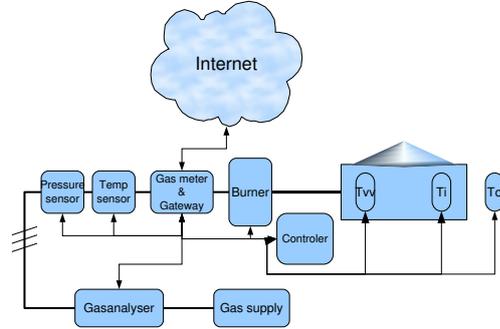


Figure 2: Principle sketch of sensors and control devices connected in a sensor network architecture and its connection to Internet.

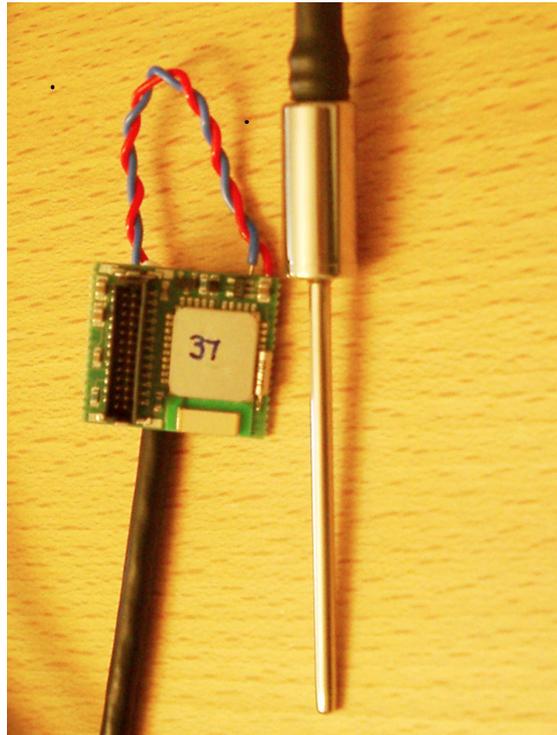


Figure 3: Standard gas temperature sensor with EIS electronics

age of sensor and actuator data. Most possibilities due to this are presently unknown. But taking inspiration from work in the district heating domain we can speculate in that removing the wall between the metering system and the control system will open up for a number of interesting improvement. This opens for flow of data from the gas meter to the control system opening new possibilities for control and data estimation. It also opens for data from the control system to support improvement in the gas measurement [4, 5, 7].

In a first development for a gas system the following devices and their data can be networked:

- Flow meter,  $Q$
- Gas temperature
- Gas pressure
- Indoor temperature  $T_i$
- Hot water temperature,  $T_v$
- Out door temperature,  $T_o$
- Flow computer
- Control unit
- Heating control system

By local fusioning the data and capabilities of these devices new services can be devised. With reference to work in the district heating domain it is rather easy to foresee system improvements like [4, 5, 7]:

- Improved gas metering accuracy
- Potentially cheaper installation

- Improved customer behavior feedback information
- Structures for cheap and effortless changes of gas distributor
- Simpler and cheaper maintenance

In such an distributed sensing and actuating system other issues that have to be addressed are data security and customer integrity. Basically each sensor can have a number of resources for ensuring security and integrity. Examples are authentication (login), data encryption and action logging. The level of security and integrity should be selected based on the value of the data.

### 3 Scenarios for networked sensing and control

We will here sketch two different scenarios for applying networked sensors in a gas customer set-up. The first scenario is providing the gas measurement with network capabilities i.e. the flow meter, temperature sensor and pressure sensor. Further at least one gas-analyzer in the gas grid will be networked. The second scenario is developing a gas installation where both the gas metering and the gas usage control is networked with all present sensors and actuators connected to the same communication network.

#### 3.1 Scenario I - Networked gas measurement

In this first scenario the following devices will be networked, see figure 4:

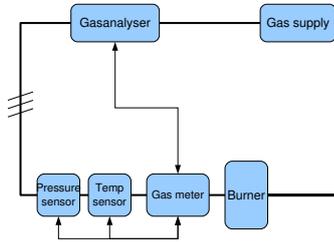


Figure 4: Principle sketch of sensors devices based on a sensor network architecture. This enables simple integration of information from the necessary gas energy metering sensors.

- Gas flow meter
- Temperature sensor
- Pressure sensor
- Gas analyzer

Providing that also some data measured centrally like gas composition and heat value are made available to the network we can find a situation like in figure 4. Here the gas meter will act as flow computer and be capable of continuously gather data from the temp and pressure sensors as well as from the gas analyzer. Thus being able of calculating a more correct amount of energy transferred to the customer.

The case of making gas analysis data available opens for a discussion on what gas composition is actually present at a customer. Previously the gas quality was rather stable based on one single supply. With the inclusion of more local sources like

waste gas and bio gas the gas quality reaching a customer can be more problematic to determine. This will in the future call for more gas analyzers in the network and potentially also for cheaper and faster gas analyzers. But making gas analyzers connected to the same network as the sensors at a customer will clearly improve the measurement quality at the customer.

For the data exchange between the involved devices I will suggest a reactive scheme. This means that the gas flow meter using a service discovery scheme finds the local temperature sensor and pressure sensor and the gas analyzer with most appropriate location for the particular gas meter. From this service discovery the gas meter asks the sensors to provide data to the gas meter according to a system model saying that when temperature data has changed more than X degrees, send that new value to the gas flow meter. The same goes for the pressure sensor and the gas analyzer. The the gas flow meter continuously can calculate the transferred gas energy according to the most appropriate. This can be done at the sample rate of the flow meter.

Further more the gas meter will make synchronization checks with all the involved sensor/analyzers at certain time intervals, say one day to ensure that the sensors are alive.

The only difference for different type of customers are which sensors that are locally available or where data has to be “borrowed” from a sensor/analyzer located elsewhere.

This scheme of possibly borrowing data from elsewhere located sensors opens up for reducing the number of pressure and temperature sensors in the network. This since

we probably can find installations that very likely have the same pressure and temperature situation. In a networked scenario one installation can borrow the pressure and temperature data from an installation considered having the same operating condition.

Having networked sensors with its own “intelligence” also enable the use of self diagnostics at each sensor. Meaning that if for example a temperature sensor can find that it is providing unreliable data this can be notified to the gas meter and of course the maintenance organization. The gas meter can then try to find another temperature sensor within the service discovery lookup scheme available for the gas meter.

This enables for a new approach to maintenance where a broken temperature sensor first can be identified secondly can be exchanged in a planned manner provided that the gas meter can find another source for the temperature data.

### 3.1.1 Customer relations

All data from the sensors are in a networked paradigm available to anybody having authority to access data. This opens up for giving data to customers enabling customer feedback. A total wide open unprocessed data feedback to the customer is probably unwise. The feedback should probably be processed in a way providing potentially an individual feedback to the customer. Thus opening up a possibility for making new services with an economic value to the customer. This provides a foundation for new business relationships with the customer.

Examples of possible feedback are:

- Energy usage pattern

- Possibility to correlate energy cost to customer behavior
- Predictions of energy cost based production scenarios.

A customer will in the future be able to change gas supplier. This calls for new methods providing easy transition of “ownership” of gas metering data. There are several possible technology approaches for this. One approach is having an authentication routine enabling a new “owner” of data to login to the gas metering webserver and acquire the ownership and thus change passwords etc. of the gas metering webserver. Another approach is making use of SIM card technology from the telecom business. Here a number of such “ownership” transactions have been solved in a way which is accepted by the telecom market. This approach is interesting provided that a GPRS communication technology is used. Thus also the billing can be made over the phone bill. In this case telecom operators has to be involved in the process.

## 3.2 Scenario II - Networked gas measurement and control

In this second scenario both the gas metering devices as well as all devices necessary for the control of energy usage will be networked. For a heating application in a larger building the following devices will be networked see figure 5:

- Gas flow meter
- Temperature sensor

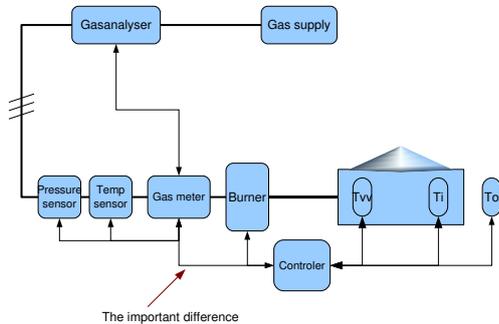


Figure 5: Principle sketch of sensors and control devices based on a sensor network architecture. This enables simple integration of information from the the heat metering and the control system.

- Pressure sensor
- Gas analyzer
- Burner control
- Indoor temperature
- Hot water temperature
- Out door temperature

It is obvious that for other applications other sensors and actuator devices will be of interest to network.

In addition to the functionality for scenario I we can see more possibilities when more data is made available. For example can data from the customer side i.e. process demand data, heat demand data etc influences the controlling of the gas burner. The control signal to the burner can be utilized by the gas meter to change for example the sampling rate (at least for ultrasonic gas

meters) and thus provide more accurate gas metering [4].

Other opportunities are improved heat utilization based on accurate knowledge of the gas heat value. In such a situation the burner control is asking for the start of energy usage at a certain level. By knowing the heat value of the gas the burner control can adjust the burner operation to meet the demand with a faster response than not knowing the current gas heat value.

Looking at work done in district heating, see for example [5], it is also expected that a better understanding of the system and its parts will enable system and part diagnostics using the gas metering data possibly in combination with data from the control system. The fact that alla data will be “available” to different parts of the larger system will enable new possibilities for system maintenance.

Further energy usage predictions can be more accurate providing new tools and possibilities for spot market business. Where an accurate prediction of gas usage can provide valuable information for purchase of energy on a spot gas market.

Obviously if more to customer and supplier relevant data can be extracted from the already present sensors and presented in a feasible way more efficient use of energy can be made.

I expect more possibilities to be found in the future. Here research possibly will provide new ways of extracting new information as indicated above The way to investigate such possibilities is a research project. I do sketch such a research project below.

## 4 Project proposals

I here propose two different projects. The first is for demonstrating gas measurement based on scenario I above. The second project proposal covers research on system understanding based on availability of sensor data from both gas metering and the customer process according to scenario II..

### 4.1 Development and demonstration of networked gas metering system

#### 4.1.1 Objectives

The project objectives are:

- Demonstrate networked gas metering for at least 10 customers
- Develop networked gas metering on available and proven sensor technology
- Investigate ways of changing gas supplier and billing practise
- Develop gas provider and customer information tools.
- Analyze a test period run of at least 12 months operation

#### 4.1.2 Project description - Networked

Currently to my knowledge no commercial gas metering technology is available capable of the two scenarios described above. For the purpose of demonstration technology like Webmaster from Abelko Innovation AB (<http://www.abelko.se/>) can be used. Webmaster has a built in web server and

sufficient sensor inputs. Webmaster can connect to the Internet using either Ethernet or GPRS communication. Webmaster is programmable thus an application can be developed doing both the data generation as well as provide data communication using the built in web server.

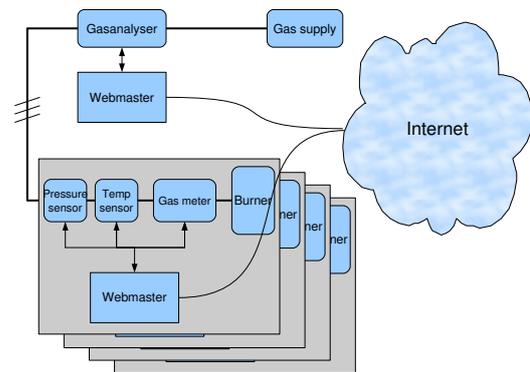


Figure 6: Demonstration system based on one Webmaster at each customer and one at the gas analyzer site.

Webmaster can be applied as indicated in figure 6. Here one Webmaster is used at each customer participating in the demonstration plus one at a feasible gas analyzer. The customer Webmasters does read data from the gas meter, temperature sensor and pressure sensor. Based on that data plus data from the gas analyzer the gas consumption is calculated. Gas analyzer data is updated at each customer Webmaster in a reactive way. Thus the Webmaster will act as a flow computer. An application for Webmaster has to be developed to accomplish these tasks.

Data presentation for both the gas supplier and the gas customer has to be developed. An important task of the project is

to define a number of interesting data service scenarios for both gas suppliers and gas customers.

Based on such a development at least 10 selected customer installations will be equipped with Webmasters. The numbers of installations is mostly an economical question. This demonstration will then run for at least 12 months during which the different data services will be tested and evaluated. More demonstration installation can be added to the extra cost of hardware and labor

I do see four major project phases with the following major project tasks:

1. Demonstrator development
  - (a) General system and services design
  - (b) Development of applications in Webmaster for data reading, gas energy computing and data services
  - (c) Develop data services suitable for gas suppliers and different gas customers
2. Technology investigations
  - (a) Investigate different technology solutions for changes of gas supplier
  - (b) Investigate system requirements and cost based on future technology like MULLE microweb servers
  - (c) Investigate and develop quality assurance routines for sensor networked systems
3. Demonstration

- (a) Selection of customers
- (b) Installation and start-up
- (c) Demonstration run for 12 months with 10 customers

#### 4. Evaluation and documentation

- (a) Evaluation system benefits to gas provider and gas customer
- (b) Documentation and reporting

It is expected that the development phase is 6 months, the demonstration phase is 14 months and evaluation and documentation phase is another 3 months

In table 1 a very indicative budget is provided. The budget is based on 2 man year in development, 1 man year in technology investigations, 0.5 man year in demonstration and 0.75 man year for evaluation and documentation. In addition to this 500.000 is needed for equipment provided that existing sensor equipments like flow meters, temperature sensors, pressure sensors and gas analyzers can be used.

Adding more demonstration installations will add 400.000 per 10 more installations plus additional 10

Task	SEK
Demonstrator development	2.000.000
Technology investigations	1.000.000
Demonstration	1.000.000
Evaluation and report	750.000
<b>Total cost</b>	<b>4.750.000</b>

Table 1: Very indicative project budget

## 4.2 Networked gas metering and control system

This project is targeting research on technology for more efficient energy usage in a energy gas customer - supplier relationship.

### 4.2.1 Objectives

The project objectives are:

- Development of a simulation model enabling investigation of gas usage system optimization
- Investigate networked gas metering control methodologies targeting improved measurement and control quality and customer feedback possibilities
- Demonstrated gas metering and control methodologies in lab environment
- Investigate secure Internet technology for sensor localisation, identification service provision

### 4.2.2 Project description - Networked gas metering and control system

To enable a system investigation of a gas supply installation at a customer modeling is the most appropriate approach. For the purpose a matlab model will be developed modeling a gas usage installation comprising at least parts like gas burner, gas metering, control devices, energy use like house heating, etc. according to scenario II above.

This simulation and modeling environment will then used to investigate new approaches to:

- Improved gas metering accuracy
- Sensor fusion approaches to gas usage control targeting higher energy efficiency
- Sensor fusion approaches targeting relevant energy usage measures that when used in a customer/supplier feedback can improve total energy efficiency.

The sensor fusion approach will make use of control information at the energy use side to improve the gas metering. Here advanced knowledge of process status by the customer will provide more information that can be used for improving the gas metering accuracy. This information can also be used for improving the gas burner efficiency as well as energy distribution from the burner.

Based on findings using the simulation tool a physical demonstration of results will be made under lab conditions. This will be made using today's most advanced EIS technology, the MULLE platform. Thus the appropriate sensors and actuators will be connected in a network providing the framework for using sensor fusion within the networked sensors/actuators.

The following main tasks is needed in such a research project:

- Simulation model development
- Gas metering accuracy optimization
- Sensor fusion for improved gas usage control
- Sensor fusion including customer/supplier feedback for improved total energy efficiency

- Networked sensor architecture providing localisation, identification and service provision architecture.
- Demonstration of sensor fusion on an advanced sensor network technology
- Result dissemination

Result dissemination will be made using standard scientific publication as well as dedicated seminars for national gas industry.

Designing the project as a research project with a PhD. student and one senior scientist as major resources we project a total project time of 3.5 years. This will in addition to the project objectives enable the student to obtain a PhD.

In table 2 a very indicative budget is provided. The budget is based on 1.5 PhD student and one senior scientist at 35% over 3.5 years. year in development and 0.5 man year in demonstration and a quarter man year for evaluation and documentation. In addition to this 250.000 is needed for equipment provided that existing sensor equipments like flow meters, temperature sensors, pressure sensors and gas analyzers can be used.

Cost	KSEK
PhD student 3.5 year	3.900
Senior scientist 25%	1.370
Lab and equipment	300
Travel and expenses	250
<b>Total cost</b>	<b>5.820</b>

Table 2: Very indicative research project budget

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