A Pattern for a Sensor Node

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Sensors are widely used in everyday life in household appliances, fire alarms, traffic control systems, battlefields, banks, and museums. Sensors are used either as standalone devices or in networks. Understanding the basic structure of a sensor node is essential to be able to use the sensors in different types of devices and different kinds of environments. Many applications require different types of sensor nodes that communicate with each other to perform a specific function. We present a pattern that describes an abstract view of the architecture of a sensor node. This description would help the application designer to choose from different types of sensor nodes for his application and to integrate it with other functional units. Moreover, this model also helps the designer to reuse, combine, or modify the architecture of a node to suit more complex needs.

Categories and Subject Descriptors: **D.2.11 [Software Engineering]**: Software Architectures—*Patterns*; **B.4.1 [Input/Output and Data Communications]**: Data Communication Devices; **D.1.5 [Programming Techniques]**: Object-oriented Programming

General Terms: Design

Additional Key Words and Phrases: Architecture, pattern, sensors, wireless communication

1. INTRODUCTION

A sensor is a device that measures a physical quantity, e.g. light, temperature, or pressure, and converts it into a signal which can be read by a human or by an instrument. Sensors are typically small, self-contained, battery-powered, low cost devices. A sensor node is a node in a wireless sensor network able to perform some processing, gathering sensory information, and communicating with other connected nodes in the network (Sensor 2010). Today, sensors, either alone or as part of sensor nodes, perform many activities in our society with potential applications in military, civilian, and medical application. Sensors are found in household appliances such as microwave ovens, air conditioning units, motion-detecting systems, smart phones, fire alarm systems, and many more. In the military and industrial domain, sensors are used in robotic landmine detection, battlefield surveillance, target tracking, environmental monitoring, wildfire detection, air-traffic control, industrial automation, and traffic regulation. In medical applications, sensors can be deployed to monitor patients and to assist disabled patients. Sensor nodes also play an important role in other systems such as Supervisory, Control, And Data Acquisition (SCADA) systems, as well as in crisis and emergency response systems such as Responding to Crises and Unexpected Events (RESCUE) (Mehrotra et al. 2004).

Usually sensor nodes are not used individually, but are part of a larger and more complex system. In order to monitor a system, a group of sensors is deployed, sometimes as many as millions or billions (Sutter 2010). Sensor nodes have communication capabilities (usually wireless) that allow them to send the collected data to users or other processors. Sensor nodes are the building block and the most important component of such a system, therefore a sensor node pattern can be useful in designing sensor-based systems and in the design of the corresponding network structures. This pattern is the first of a series of patterns for wireless sensor networks.

2. THE SENSOR NODE PATTERN

Aka: Mote, Sensing Node.

INTENT

This pattern describes the architecture of a Sensor Node, a unit intended to sense, store, and communicate local information about a physical environment. For those purposes the architecture includes sensors, memory, and communication channels.

EXAMPLE

Consider a chemical plant where crude oil is processed and refined into more useful petroleum products. In this system the pipes can burst due to excessive pressure. The pipes also may have high temperatures that may lead to

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fires. We already have had some accidents. If this situation continues, the chemical plant would incur huge losses and could also endanger the lives of its employees.

Context

There are physical environments that need to be monitored for the presence of living beings or for recording some physical attributes or for detecting any abnormal conditions. These environments could be inside buildings or could be external environments. For example, a battlefield may be monitored for detecting the presence of enemy soldiers and tanks, a wildlife sanctuary may be monitored for recording the population of migratory birds, and industrial plants could be monitored for detecting fire accidents (Chong and Kumar 2003). This pattern can be used to describe the nodes used in those environments or in similar situations, either as standalone units or as parts of networks.

Problem

Important events may get missed if nobody is watching for them. For example, in the battlefield, an attack by the enemy can take an army by surprise when it is not ready to fight; in a wildlife sanctuary the population of migratory birds may be reduced due to change in environmental factors and we would not react to it; fires in homes, industrial plants and offices could lead to loss of lives and properties. Without a way to sense some attributes of the physical environment these situations can go undetected for so long that effective countermeasures cannot be taken. Human monitoring is not convenient or efficient.

A possible solution to this problem is constrained by the forces defined below, which have been grouped into related aspects.

Forces about the functions of the device:

- Functionality: The device should be able to sense and collect local information about its surrounding environment such as temperature, pressure, light, smoke, humidity, or sound.
- Controllability: If required, the device should have the ability to support actuators such as switches, servos, and motors that would allow it to control various actions (Bose 2009).
- Extensibility: The architecture of the device should be extensible so that new functions can be added if required. For example, some nodes may need human-readable displays.

Forces about the use of the information collected:

- Storage: The device should have sufficient memory in order to store the collected data. It should also be able to perform simple computations and transmit only the required data and routing information if the device is part of a network.
- Conversion: The information detected by the sensors should be converted to appropriate formats for storage and processing.
- Communication: The device should be able to communicate (send and receive) with other devices in order to gather or forward information about the physical environment.

Forces about the use of the devices:

- Power autonomy: The device should have its own source of power.

Solution

Place in a common container a collection of one or more sensing devices together with other components to store, process, and transmit the collected information. The sensor node may also contain some optional components that provide more specialized functions. A sensor node can act both as a data collector and as a data router. A sensor node can have different types of sensors that can detect pressure, humidity, light, acoustic, temperature, and various other physical properties. A sensor node includes some basic components that are organized as shown in the block diagram of Figure 1 (Sensor 2010):

- The *processor* is responsible for managing and coordinating various activities of the sensor node and for processing data. The *sensors* measure some properties of the physical environment. The *Analog-to-Digital Converter (ADC*) converts the analog data measured by the sensors to digital format so that it can be stored and processed.
- The *transceiver* is a radio device that can receive and transmit information. If the node is part of a network, data can be transmitted from the source to the destination using single hop or multiple hops communication.
- The *power source* supplies power to the sensors and to the other components of the sensor node. The power source may be supported by power scavenging units such as solar cells (Akyildiz et al. 2002).

- The processor also stores the collected data in the *memory* until it is forwarded to the next node.
- The processor generates control messages that direct the sensor to start or stop collecting information about the environment and direct the transceiver to be either in the receiving mode or transmitting mode depending upon the scenario.
- When the node is part of a network, the processor also keeps information about its neighboring nodes, decides the routing path and communicates the routing information to the other nodes.

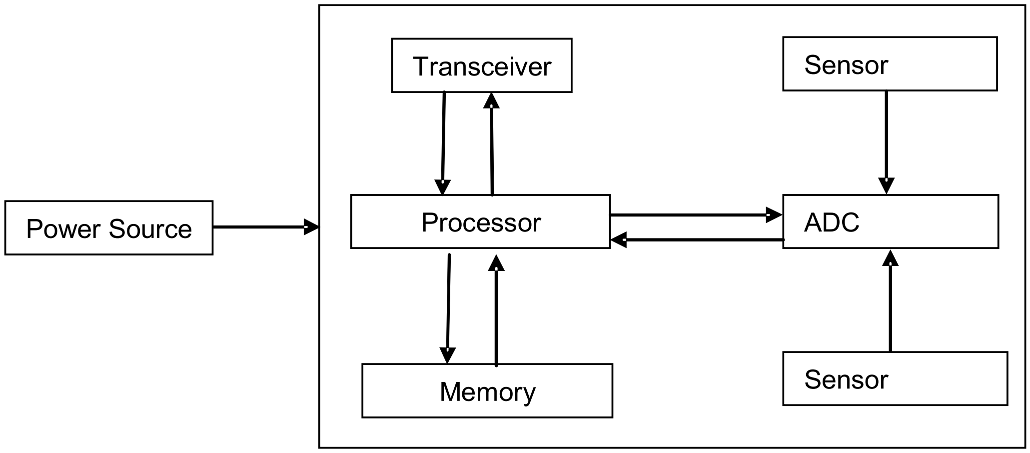

Figure1. Block diagram of a sensor node

STRUCTURE

Figure 2 shows the PowerSource supplying power to the Sensor, ADC, Processor, Memory, and Transceiver according to the block diagram of Figure 1. This class diagram is a precise description of the physical and information aspects of the device.

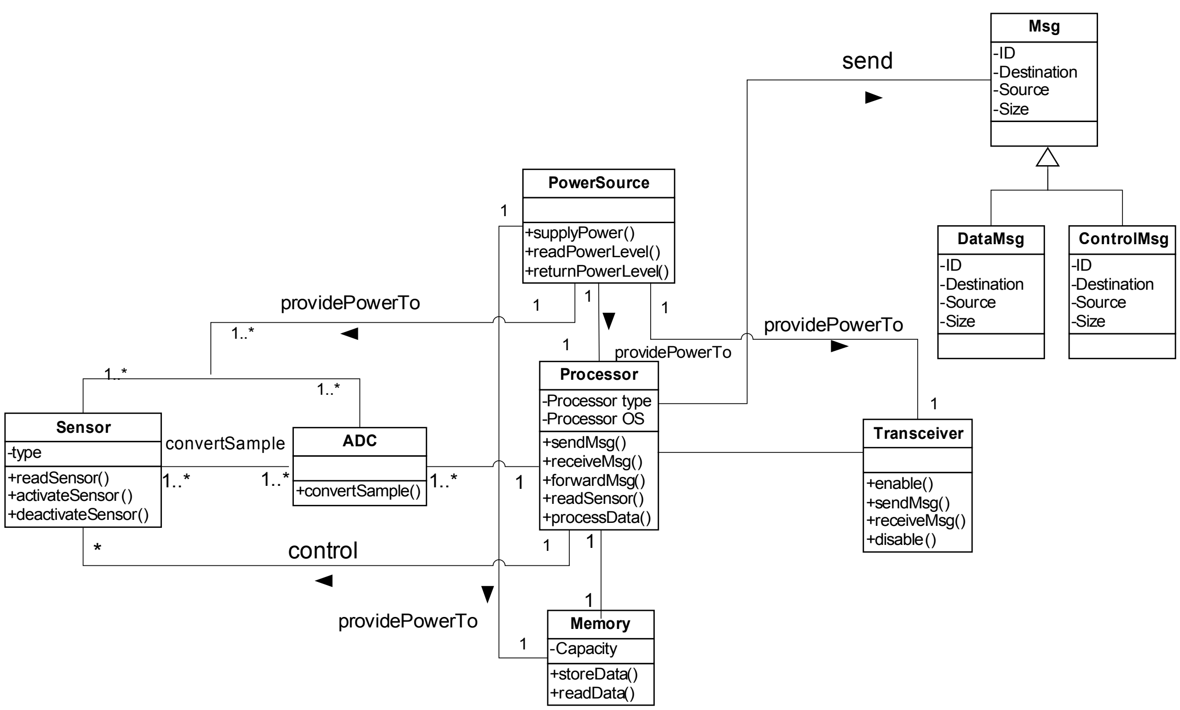

Figure 2. Class diagram of a sensor node

Dynamics

Figure 3 describes the dynamic aspects of the sensor node using a sequence diagram for its use case Sense, Collect, and Transmit data.

Description:

1. The processor sends a control message to enable the sensor.
2. The sensor reads the information in analog form and sends to the ADC.
3. The ADC converts the analog information into digital format and sends it to the processor.
4. The processor processes the data locally.
5. The processor stores the collected information.
6. The processor sends the collected information to the transceiver and/or memory.

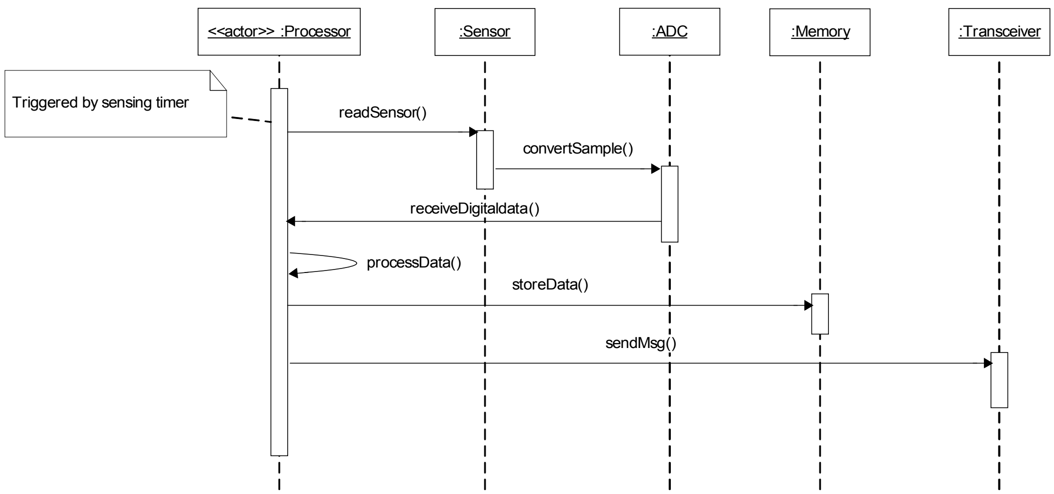

Figure3. Sequence Diagram for Sense, Collect and Transmit Data

Figure 4 describes the dynamic aspects of the sensor node using a sequence diagram for its Forward Data use case.

Description:

1. *Precondition*: The processor stores routing tables and runs various routing protocols in order to route the data from one node to the other.
2. The processorP1 sends a message to the transceiverTx1 which then routes the data to transceiverTx2 of the neighboring sensor node.
3. The transceiverTx2 of the neighboring node forwards the data to its processorP2.
4. The processorP2 processes together the received data from transceiverTx2 and its own data and sends it back to transceiverTx2.
5. TransceiverTx2 might go ahead and send this data to the transceiver of another sensor node for the purpose of forwarding data.
6. Sometimes the processor might locally store a small amount of data in the external memory until it is ready to be routed to the next sensor node.

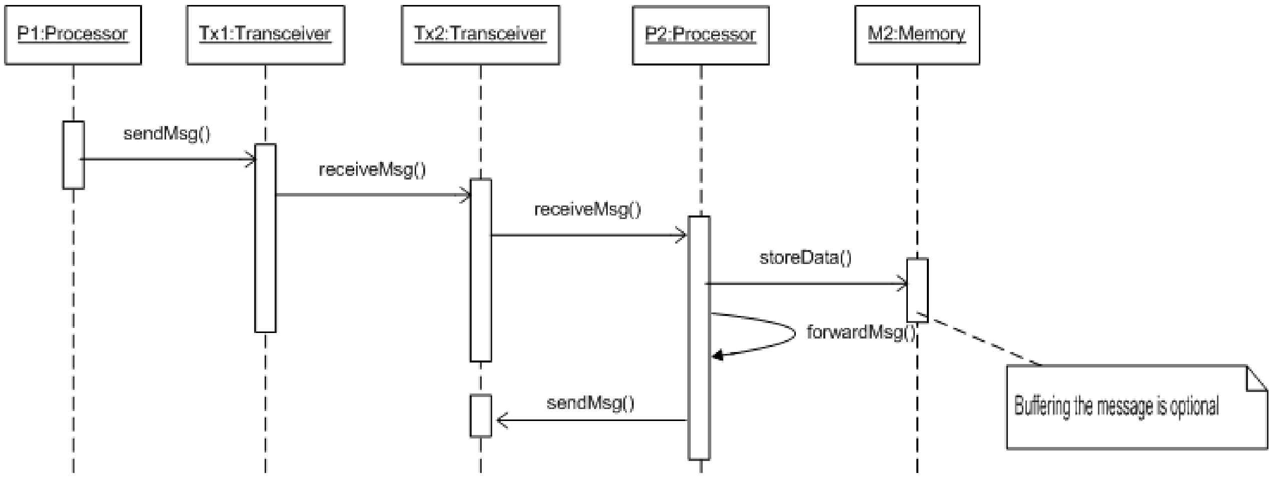

Fig.4 Sequence Diagram for use case Forward Data

Known Uses

- Berkeley Motes like MPR400 manufactured by Crossbow Technologies (Berkeley 2010). Some of its specifications are:
  - Frequency range of 902-928 MHz and T1 CC1000 transceiver
  - ATmega 128L processor
  - 4K bytes of RAM, 10 bit ADC
  - Light, humidity, and temperature sensors
- IPsensor Node manufactured by Arch Rock (IP 2010). Some of its specifications are:
  - TelosB-compatible, 2.4 GHz IEEE 802.15.4 low-power radio
  - T1 MSP 430 processor
  - 10K bytes of memory and 12 bit ADC
  - Temperature, humidity, and total solar radiation sensors
- Squidbee Mote manufactured by Libelium (Squidbee 2010). Some of its specifications are:
  - Frequency range of 2.4 GHz
  - ATmega8 processor
  - 8K bytes of flash memory and 1K byte of RAM
  - Light, humidity ,and temperature sensors

Implementation

Users can buy commercially manufactured sensor nodes from the market based upon what kind of sensors they want for their application. These nodes are either pre-programmed and start collecting information once they are installed or they can be programmed depending on the application characteristics. Sensor nodes are configured to transmit their data using a transceiver. Data can be transmitted to the user directly or using a network (Intanagonwiwat et al. 2000 and Heinzelman et al. 2000).

Sensor nodes have independent processing capabilities needed to run the code for operating system and different operations such as data communication, data acquisition, data processing, data encoding, aggregation, encryption, filtering, and network routing. Memory is another important component used to store the code and data of the software running on the sensor node (operating system, data acquisition, data communication, and other operations), and for storing the sensed data. The transceiver is used to transmit and receive data wireless, according to a communication protocol. Wireless communication is preferred, sensor nodes are easier to deploy and maintain, especially in hardly accessible areas.

Implementation of a sensor node involves two main steps: hardware implementation and software implementation. Hardware implementation depends on the characteristics of the application, expected performance, etc. The designer has to select the hardware components (see Figure 1) and the interconnections (e.g. buses), to meet the application requirements. These components are laid out on a circuit board in order to promote extensibility. Depending on the application requirements and circuit parameters, the power budget must be determined, and an appropriate power source selected. Several sensor platforms are available on the market and they can be customized to different applications, for example Crossbow sensor nodes (Berkeley 2010).

The software implementation involves operating system and application code (firmware). The operating system manages the system resources and access to them, and is designed to be application independent to promote reusability. The operating system usually contains services for data message transmission and reception using the radio transceiver. The application code implements behaviors specific to the sensing application. Off-the-shelf sensing platforms come with the operating system and a software development kit for applications. The kit also provides a mechanism for uploading the application firmware on the sensor node program memory. For example, Crossbow motes come with TinyOS operating system and the nesC programming language and tools.

Aspects that are important in the use of sensor nodes are:

- *Ruggedness:* The device should be able to operate in harsh environmental conditions.
- *Autonomy:* The device should be able to operate autonomously and unattended.
- *Dimensions:* The device should be small in size so that it can be easily deployed in large numbers (Bose 2009).
- *Cost:* The device should have a relatively low cost if it needs to be used in large quantities.

Example resolved

Sensor nodes were installed in the pipes of the chemical plant. The sensor nodes constantly monitor and report if there is an abnormal increase of pressure and temperature in the pipes or in the chemical processing units. The sensor nodes can also activate water sprinklers in case of a fire. It is now possible to minimize the bursting of oil pipes and fire accidents in the refinery. This implies that the personnel are also safer.

Consequences

The Sensor Node pattern has the following advantages:

- *Functionality:* This solution performs the required functions of sensing and collecting local information.
- *Controllability:* This device can control actuators.
- *Extensibility:* It is possible to easily add new functions
- *Autonomy:* This device has its own processor, memory and power supply and can operate on its own.
- *Communication:* This device can communicate with other devices for the purpose of gathering and forwarding information in the network.
- *Storage:* This device can store the collected data.

The Sensor Node pattern has the following disadvantages:

- Because of their size and cost, they have limited resources in terms of processor performance, radio reach, memory capacity, and battery life.
- Sensor nodes are usually unattended so they can be physically tampered or destroyed.
- Their use can potentially affect the privacy of individuals and their deployment must take this possibility into consideration.
- There are no standards for sensor node architectures, which make their integration with other systems more complex than necessary.

Variants

Apart from the basic components, the sensor node might also have some additional application- specific components. For example, a sensor node can have a location-finding system or GPS to keep a track of its location and of its neighbors. The sensor node can have a mobilizer which can help the sensor node to move short distances if required, or it can have a power generator which supplies continuous power to a node having some additional functionality (Akyildiz et al. 2002). Some of the sensors may have human-readable displays to facilitate data reading. Another important variant is a secure node, able to withstand some intentional attacks.

Related Patterns

A pattern for sensor network architectures that can be built using the Sensor Node pattern as a unit is presented in (Cardei et al. 2010). The Sensor Node pattern is also used as a component in the SCADA pattern (Fernandez and Petrie 2010).

3. CONCLUSIONS

We have presented a pattern that describes the architecture of a sensor node. This pattern is part of a set of patterns that we are developing for wireless sensors networks and their applications.

In particular, in this paper we studied the various components of a sensor node, including its static and dynamic aspects. We also discussed the advantages and constraints of a sensor node and its implementation details, required to use sensor nodes for an application. This abstract description makes it easier to combine these units with other functional units.

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REFERENCES

Akyildiz, I., Su, W., Sankarasubramanium, Y., and Cayirci, E. 2002. A Survey on Sensor Networks. *IEEE Communications Magazine*.

Berkeley Motes data sheet online at http://www.xbow.com/Support/Support_pdf_files/Product_Feature_Reference_Chart.pdf last accessed on March 28, 2010.

Bose, R. 2009. Sensor Networks- Motes, Smart Spaces, and Beyond. *Proceedings of IEEE.*

Cardei, M., Fernandez, E. B., Sahu, A., and Cardei, I. 2010. A Pattern for Sensor Network Architectures. Submitted for publication.

Chong, C.Y. and Kumar, S.P. 2003. Sensor networks: Evolution, opportunities, and challenges. *Proceedings of IEEE.*

Fernandez, E.B. and Petrie, M.M. Larrondo. 2010. Designing secure SCADA systems using security patterns. *Proceedings of the 43rd Hawaii Conf. on Systems Science*, Honolulu. 1-8. http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5428672

Heinzelman, W. R., Chandrakasan, A., and Balakrishnan, H. 2000. Energy-Efficient Communication Protocol for Wireless Microsensor Networks. IEEE *Proceedings of Hawaii Int'l.Conf. Sys. Sci.* 1–10.

Intanagonwiwat, C., Govindan, R., and Estrin, D. 2000.Directed Diffusion: A Scalable and Robust Communication Paradigm for Sensor Networks. *Proceedings of ACM MobiCom*, Boston, MA. 56–67.

IP Sensor node data sheet online at http://www.archrock.com/downloads/datasheet/IPsensor_Node_DS.pdf last accessed on March 28, 2010.

Mehrotra, S., Butts, C., Kalashnikov, D., Venkatasubramanian, N., Rao, R., Chockalingam, G., Eguchi, R., Adams, B., and Huyck, C. 2004. Project RESCUE: Challenges in Responding to the Unexpected. *Proceedings of SPIE.* 5304. 179–192.

Sensor node, Wikipedia, http://en.wikipedia.org/wiki/Sensor_node, last accessed on August 17, 2010.

Squidbee Mote data sheet online at http://www.libelium.com/squidbee/upload/c/c1/SquidBeeDataSheet.pdf last accessed on March 28, 2010.

Sutter, J. D. 2010. 'Smart Dust' Aims to Monitor Everything. CNN Labs. http://www.cnn.com/2010/TECH/innovation/05/25/smart.dust.sensors/index.html?iref=allsearch, last accessed on July 15, 2010.