INTELLIGENT SENSOR NETWORKS

Jozef Hudák - Josef Blažek – Vladimír Vasiľ

Sensor networks are network of nodes that are scaning and potentially are also controlling their imediate environment, thus, enabling, interaction among peaple or computers and their evironment. The newest way of describing and designing sensor netvorks is the Fornasini-Marchesini model.

K e y w o r d s. sensor network, sensing nodes areas of application, Fornasini – Marchsesini model

1 INTRODUCTION

Sensors that are sensing lots of physical characteristics can be taken for an „interface“ between the physical world and that of the electrical devices (e.g. computers). The other end is occupied by actuators, the task of which is to convert electrical signals into a physical phenomenon. Wireless sensor and actuator networks (WSANs) are networks of nodes that are scanning and potentially are also controlling their immediate environment. They transfer information in via wireless interconnections, thus, enabling interactions among people or between computers and their environment. The data collected by the various nodes are sent to a storage, which facilitates both their local use, e.g. by way of actuators, and interconnection into other networks such as the Internet [1].

The sensing nodes are relatively the simplest devices within the network. Typically, they consist of five main parts: one or more sensors acquiring data from the immediate environment, microprocessor unit managing tasks, communication module, memory to store data generated during the operation and the battery. Fig.1. Despite of the fact that the bulk of the sensors uses batteries, the time of batteryfree sensors, based on the technology close to that of the passive RFID batterryfree circuits [2] is soon to come.

2 SENSOR NETWORKS

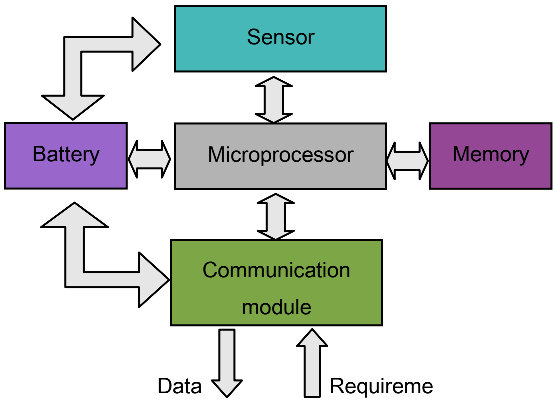

Figure 1: **Sensor node network architecture**

2.1 Areas of applications for sensor networks

Threre exist a great variety of areas of application for sensor netwoorks , e.g. monitoring the integrity of transport-, energy-, citizen- or other infrastructure with the purpose of locating damages. Another area of application is for example the field of health care for monitoring physiological data, etc. See Fig.2.

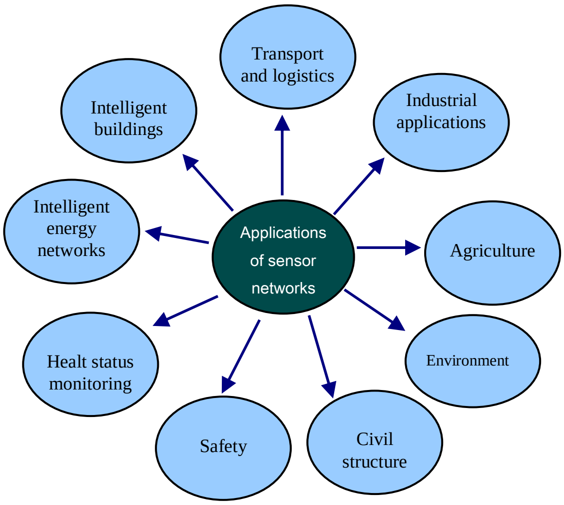

Figure 2 : Areas of applications

2.2 Communication technologies

LAN Technologies provide interconnection of various inteligent equipments on the customer side. These Technologies may be divided into three main groups: wireless IEEE standards 802.x, wire-based ethernet, as welll as communication in via 230V/50Hz power distribution systems in buildings. Wireless IEEE standards include Wi-Fi (IEEE 802.11), WiMAX5 (IEEE 802.16), ZigBee (IEEE 802.15.4) and Bluetooth (IEEE 802.15.1). Wire-based ethernet is the dominant technology of these times. Customers can be connected via the ethernet to a WAN or other networks [2].

2.3 Applying the Fornasini-Marchesini Model as the newest way of describing and designing senosr networks

In cybernetics and electronical systems great success was achieved, more than a quarter - century ago, through the introduction of the so-called internal or status description. Compared with the classical external description, it substantially raised the amount of information on the stqatus and behaviour of systes and enablied solution of hitroerto impossible ways of analysing and controlling, ie. On the basis of estimating stes of unmeasurable quantities or status trajectories of systems. Status description of systems was the basis also for the development of the so-called Kalman filtering of signals, for vector-based control of asynchronous engines and the like.

For continuous linear systems the status description is given by the status equation itself as well as the out equeation:

$$x'(t) = Ax(t) + Bu(t)$$
$$y(t) = Cx(t) + Dx(t) \qquad (1)$$

Formally, one has to deal with matrix equations, where x(t) je n-dimensional vector of the internal status of the system, u(t) vector of input quantities and y(t) the vecto of output quantities. The dynamics proper to the system is given by coefficients of a square matrix A, the influence of input signals with regard to the changes of the system status is written by way of a exciter matrix B. Matrix C in the output equation functions, as a rule, as a selector or recombiner of status quantities into output quantities, D describes the possibility of direct feed link between the system input and output (at the same moment of time). For the majority of technical systems characterized by inertia it holds that D=0. For discrete systems, the status and output equations are written formally in a simple way as:

$$x(k) = Ax(k-1) + Bu(k-1)$$
$$y(k) = Cx(k) \qquad (2)$$

Again, it is, however, important to emphasize that it is the matrix equations, wherein the signal quantities x, u, y represent vectors, for example, for x with there belong components x1, x2, x3. Status equation can by physically read also as the one indicating how all the previous components of the status and excitor singal are contributing to the present status.

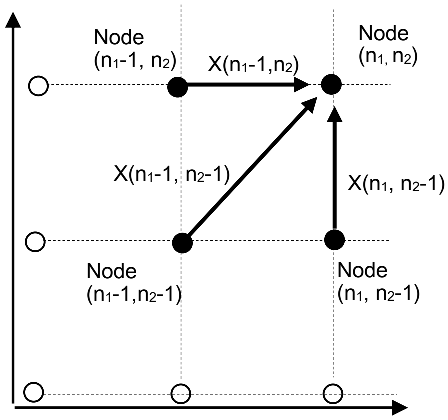

Figure 3 : Fornasini Marchesini 2-D Model

AN interesting iextension of the status description by a physically geometrical meaning and the possibility of substantial use of grid-type senor networks was introduced in the year of 2008 for example in [3], applying the so-called Fornasini-Marchesini double indexed dynamic system – state space models [4]. This model is currently designated as the FM model. Its principle is for a two-dimensional case (2D, indexed by means of n1, n2 for the actual point and the previous ones, it is about a o -1 reduction of indices in all the existing variants) as illustrated in Figure 1. The individual points stand for the nodes in the sensor network and the edges of the grpaah for the appropriate component of the state vector, the one contributing to the result of the status component in the determined node n1, n2 and all that in the moment to come t+1. For oall the stated nodes, the values in the actual moment of t are known. Status and output equation of the system perceived like this takes the form of :

$$\begin{aligned}\underline{x}(n_1,n_2,t+1) &= A_{001}\underline{x}(n_1,n_2,t) + A_{101}\underline{x}(n_1-1,n_2,t)\\ &\quad + A_{011}\underline{x}(n_1,n_2-1,t) + B\underline{u}(n_1,n_2,t)\\ y(n_1,n_2,t) &= C\underline{x}(n_1,n_2,t)\end{aligned} \qquad (3)$$

Even i fit is not apparent at first sight, the given approach to the status description by way of geometrical indexing provides the description and solution/design of sensor network a series of possibilities and advantages. They are mostly:

- Linear model is general, can be implemented to any kind of sensor network
- Diagram as in Figure 1 is fully distributed and enables solution of both communication and porcessing issues for all nodes
- Easy reconfiguration even with thousands of nodes of networks for various applications
- Minimum costs of communication
- Significant reduction in the overload and enabling defining local events
- Using quantization of status (aalso non-linear quantization) improves network stability
- Enablinling use of distributed filters and signal processing

For 1D networks, for example, to monitor vehicles and evaluate events in transportation by Vehicle – road [3] :

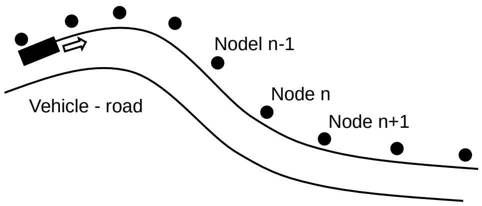

Figure 4 : **Sensor nodes placed along 1-D vehicle road**

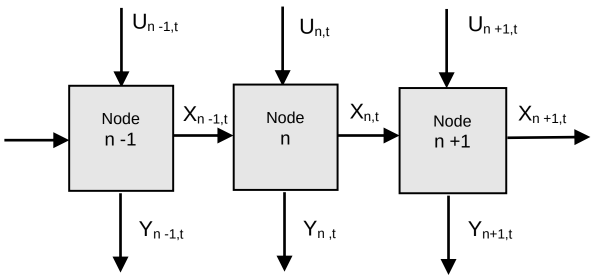

Figure 5 : Distributed FM Model 1-D field sensor array

Figure 4 and 5, status descripotion is even more simple :

$$\underline{x}(n+1,t+1) = A_{00}\underline{x}(n,t) + A_{10}\underline{x}(n+1,t) + B\underline{u}(n+1,t)$$
$$\underline{y}(n+1,t) = C\underline{x}(n+1,t) \quad (2)$$

That, at a possible op(4) – , :

For the sensor network modelled this way, it is of great advantage ([3] literally stating that it is a challenge for designing alocal status description- or its matrices A, B, C) when evaluating events using gemetrical interpretation of one or multi-dimensional Z transformation, where the postion of the basic node is indexed in the image equally as when indexing n in the original form**.** Shifting the position of the node by a discrete value will be recorded in ithe image by means of a first negative power of the corresponding z. That way, for example, for a network with a structure as illustrated in Fig. 3, we obtain the Z image of the status description:

$$X(z_1,z_2) = A_{00}X(z_1,z_2)z_1^{-1}z_2^{-1} + A_{10}X(z_1,z_2)z_2^{-1} + BU(z_1,z_2)z_2^{-1}$$
$$Y(z_1,z_2) = CX(z_1,z_2) \quad (5)$$

Now, knowledgable of the porocedure, we are able to define the transfer, or put it more precisely the discrete system function:

$$H(z_1,z_2) = \frac{Y(z_1,z_2)}{U(z_1,z_2)} = BCz_2^{-1}[I - A_{00}z_1^{-1}z_2^{-1} - A_{10}z_2^{-1}]^{-1} \quad (6)$$

Knowing the required system function H, for example to determine the chosen event from the signals of „u“ sensesors of the network, we are assigning to them the coeefficients of the matrices A, B, C, a thing simple in elementary cases (simple system functions). For more complex filters of higher orders and witt the additional need to guarantee network stability, determining the coefficients of the given matrices is not that simple. Development of formalized procedures to determine these coefficients, the so-called m-D signal filters, is currently and open problem for research. An example of a simple system function for localization of a movement with a defined speed is:

$$H(z_1,z_2) = \frac{c \cdot b \cdot z_2^{-1}}{1 - a_{00}z_1^{-1}z_2^{-1}} \quad (7)$$

That, at a possible option c = 1, b = 1, leads to:

$$H(z_1,z_2) = \frac{z_2^{-1}}{1 - az_1^{-1}z_2^{-1}}. \quad (8)$$

Speed is defined by the coefficient „a“at a given distance between sensors and the sampling time in the system.

3 CONCLUSION

One of the greatest advantages of the given approach to signal processing in sensor networks is the fact that it requires communication only between immediate neighbouring nodes. It eleminates the need for accepting high performance orders and data transfer from (to) the centre or some kind of node. Besides, it saves the needed width of the band to infromation transfer and processing and enables solving local tasks or taking actions based on locally determined system functions. Simple reconfigurability has already been mentioned.

BIBLIOGRAPHY

[1] http://www.scribd.com/doc/25270102/Smart-sensor-networks-technologies-and-applications-for-green-growth

[2] Berman, F., Fox, G. C. and Hey, A. J. G. (2003) The Grid: past, present, future. In: Grid Computing - Making the Global Infrastructure a Reality, pp. 9-50, Wiley and Sons. ISBN 0470853190

[3] Duminda A. Dewasurendra, Peter H. Bauer: A Novel Approach to Grid Sensor Networks, Electronics, Circuits and Systems, 2008. ICECS 2008. 15th IEEE International Conference

[4] E. Fornasini and G. Marchesini: Doubly-indexed dynamical systems: State-space models and structural properties, Theory of Computing Systems Volume 12, Number 1, 59-72, DOI: 10.1007/BF01776566

AUTHOR´S ADDRESS

Jozef Hudák, doc. Ing. CSc., LF KLTP TUKE
Jozef.Hudak@tuke.sk