Fuzzy calculating and fuzzy control in wireless sensor network

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Abstract

At present time configurable wireless sensor networks are given special consideration. Wireless sensor networks are now a static elements union. To make such a network a powerful system that is able to replace traditional computers, research is required of the application of different theories and technologies for sensor network development. However, building models of approximate reasoning and its usage in computer systems presents an important scientific problem. Fuzzy logic provides effective representation of real world information. The mathematical method of fuzzy information representation allows the building an adequate model of the reality. The article describes an algorithm of a fuzzy controller used to make soft computing and soft managements of a wireless network. Such a network consists of devices with limited resources which are able to work during many months and possibly years.

It has been suggested that AI methods can be used to benefit the technological development of wireless sensor networks (WSN). Now, WSN conception changes the human role, as its elements - sensor microcontrollers - become more independent and underlying of human tasks. The Homocentric model of network calculating, with humans as the main network unit becomes a thing of the past. Humans shift from calculating central to its periphery, concentrating on process control, becoming the mediator between real world and computers. Actually a new class of distributed computers has been created which will open new outlooks. WSN has made its first step on the road to the next epoch when computers will be connected with the physical world. At this point they will be able to pre-determine users wishes, and will be able to make independent decisions.

In last time, fuzzy controllers are widely adopted for practical issues. They allow managing of complex and ill formalized processes basing on linguistic information. In this paper, research of fuzzy logic algorithm application has been carried out for optimization of WSM work. One of the application examples can be optimization device work frequency. WSN consist of tiny devices with limited resources but they have to work without recharging over periods of many years. So issues of energy saving occur. To prolong the devices "life" methods of fuzzy analyses are suggested for more flexible management of device work. For example, if the network is intended for environment observation and has to report about unusual cases then the fuzzy controller algorithm is convenient to optimize device work frequency. If the situation around is normal, network nodes work less frequently to lose less energy. As soon as the situation oversteps the limits network the device begins to work more frequently to store all information. Stored data can be used to analyze by device itself, network or network administrator.

Fuzzy controller block is placed in every network device. In our example, frequency of sensor data reading, the Fuzzy controller input is sensor data and output is a required value. If we take for example a network which watches the temperature conditions i.e. the network device periodically reads the temperature value. In this case the fuzzy control input is temperature value and the output is the temperature reading frequency value. A Network device containing such a fuzzy controller module can react with more flexibility to changes in its environment. This makes it possible to save a great deal of energy. This module works without the assistance of human interaction and so therefore provides a device for independency.

Fuzzy controller input can be heterogeneous data, for example temperature and light or temperature and humidity. Thus a device can analyze different parameters depending on the task at hand.

There are 2 main methods to design a fuzzy controller module to application work based on hardware capabilities.

The first method is the use of a special device for fuzzy management applications. They are divided into 2 types:

- Fuzzy coprocessors. These are special devices for execution of input fuzzy operations. They are controlled by universal microprocessors or microcontrollers, for example VY86C570 (Togai InfraLogic, Inc);
- Microcontrollers, which have special commands and registers to execute

fuzzy input, for example Motorola 68HC12;

The Second method is the use of universal microprocessors or microcontrollers. Fuzzy controller module is implemented as software in this case. To do it there are several variants:

- Using of fuzzy frameworks. They collect variables information, fuzzy sets and fuzzy operators which are selected by the user and generate program code afterwards;
- Using of finished libraries. They are designed especially to develop fuzzy controller applications;
- Developer designs whole system. Such a fuzzy controller module has a slower response rate than special fuzzy hardware. In spite of this, this particular way of fuzzy module development is more flexible in making some changes in fuzzy application. Such fuzzy controllers allow humans to try several various variants of applications without the devices changing.

To design the fuzzy controller module it is necessary to create a Knowledge Base which should include concept information divided into Data Base and Rules Base. Knowledge Base is a static data structure which has predefined size and installed contents. Knowledge Base structure should be defined before starting application work. Data Base contains information about fuzzy sets which are linguistic terms used in fuzzy rules. To simplify a calculation, each fuzzy set membership function is presented as a piecewise-linear function and has three or four points. Points count depends on the membership function form: triangular or trapezoidal.

These point values in a fuzzy set match up places which they have in variable definitional domain. An Example of variable definitional domain division into five trapezoidal fuzzy sets is shown on the picture below.

Rules Base is rule set. Each rule uses matched fuzzy set from the Data Base. There are two possible data structure designs to store Knowledge Base. The decision depends on hardware capability.

If computer is power optimal, structure design can consist of entries array where each entry is a rule from Rules Base and has variable fields (antecedents and consequents) of integer or point type. These integers or points are reference to fuzzy sets array. Sometimes it is necessary to use dynamic count of rules and fuzzy sets for several Knowledge Bases. In this case, static arrays should be replaced by lists in dynamic memory.

Microcontrollers can use only simple data structures consisting of integer or float arrays. Structure bases on as many arrays as antecedents and consequents and defining points of fuzzy sets. For example for trapezoidal fuzzy sets Data Base is float arrays. Each element of these arrays contains information about antecedent i, fuzzy set j and defining fuzzy set point k. Rules Base consist of three arrays. These arrays size are rules count. Rules link to fuzzy sets which Data Base keeps.

Each node of network has a fuzzy controller module which has a set of input and output linguistic variables. Thus this type of sensor node can be called a fuzzy sensor. Fuzzy sensor contains linguistic variables called also attributes, Knowledge Base consisted of fuzzy rules and машина вывода which carries out calculation of output variables.

In order for the fuzzy system to be more flexible, capability of linguistic rules and Knowledge Base remote setting has been added. Thus it is possible for the fuzzy sensor to change its behavior if the user wishes, whether it is human or a computer program. Input variables are linguistic mapping of physical sensors placed on the device. Output variables values are results of fuzzy controller work.

A set of such fuzzy sensors which are wireless network nodes can organize hierarchy. Thus, it is possible to form a distributed system of information processing and storing. The hierarchy is created in the following way, output variables of some fuzzy sensor can be input variables of other fuzzy sensor or sensors. Multilevel hierarchies of fuzzy sensors are created using this principle. This distributed system allows tasks of any complexity to be implemented.

There is capability to build distributed Data Base to process fuzzy queries in wireless sensor network. This capability is easily realized, but is not expedient, as queries to Data Base and fuzzy modifiers presented in the form of ordinary relational Data Base are limited. Also the Data Base has a large memory size. Therefore the use of SQL extended to fuzzy case to process fuzzy queries is not effective. Following this a special fuzzy query language, and communications in distributed systems were developed. This language can be used for

- sensor network requests
- fuzzy triggers creating
- fuzzy active Data Bases creating
- fuzzy sensors communications

It is based on this approach that the distributed Data Base was created. Its data is stored in various network nodes. The Client uses such distributed fuzzy Data Base as ordinary Data Base. The query can be both simple, for example a query of attribute values for a given period, and complex containing aggregation functions. Also it can be fuzzy which asks output attributes fuzzy calculation. If the node does not have enough information to execute a query it creates and sends its own queries to other nodes.

Five general, goal-oriented, data fusion methods are in use today in WSN (ordered by data complexity) - data association, identity fusion, effect estimation, pattern recognition and artificial intelligence. Ten discrete data fusion techniques can be identified within these five general categories: figure of merit and gating technique in the data association, Kalman filters in the identity fusion, Bayesian decision theory and Dempster-Shafer evidentional reasoning in the effect estimation, adaptive neural networks and cluster methods in the pattern recognition, expert systems, blackboard architecture and fuzzy logic in the artificial intelligence.

The sensor data fusion technology focuses on the acquisition of high-level information (artificial intelligence level), i.e. information that is related to many conventional physical quantities in a non-analytical way. In these complex cases, fuzzy production systems and fuzzy neural networks are more effective and they compute and report linguistic assessments of numerically acquired values. Two methods are proposed to realize the aggregation from basic measurements. The first one performs a combination of the relevant features by means of a rule-based description of the relations between them. With the second, the aggregation is realized through an interpolation mechanism that creates a fuzzy partition of the numeric multi-dimensional space of the basic features. This partition can be realized with fuzzy neural networks. But fuzzy sensor can also can be used on low levels of data fusion, e.g. for filtering and for pattern recognition.

Aggregation functions can be modeled using T-norm and T-conorm. To do it only one membership function of line form should be built. But rules are different for various aggregation functions. For example it is required to calculate maximum of two temperature values which are measured different nodes. Two linguistic variables, *Temp1* and *Temp2*, should be created and membership functions, *f1* and *f2*, should be built for these variables. So every variable has one membership variable of line form. Result is output linguistic variable *Max* which has line function *fmax* as *Max* membership function. In this case rules have to be following:

IF Temp1 =f1 OR Temp2 = f2 THEN Max =fmax

To calculate minimum of *Temp1* and *Temp2* rules have to be following:

IF Temp1 = line AND Temp2 = line THEN Max = line

Factors which can influence on exactness of fuzzy logic system has to be take into account. For example:

- selecting of fuzzy sets kind and number
- selecting of defuzzyfication method
- selecting of operators which are used in rules. Operators selecting is very important and directly influences on result exactness.

In this fuzzy system following T-norm and T_conorm are used:

- Zade’s T-norm and T_conorm
- probabilistic T-norm and T_conorm
- Lukasevich’s T-norm and T_conorm
- parametric Franc’s nd T-conorm
- parametric Sugeno’s d T-conorm

The same system can use various types of T-norm and T-conorm. Setting can be made in any moment during system working.

Such module can be separate into following parts:

- fuzzy controller algorithm extended to using of T-norm and T-conorm
- initial data download
- result storing
- fuzzy model setting
- dynamic changing of T-norm and T-conorm

In subsystem of dynamic changing of T-norm and T-conorm their queue task is executed. They change at all time during managing process. It allows to do the system management is more appropriate of expert opinion about its work.

Data fusion algorithms in production form can be easily decomposed and they have hierarchical form by nature. So sensor nodes hierarchy can realize data fusion inside WSN. The knowledge bases for processing of data in given node is distributed inside WSN.

WSNs are huge dynamic databases but for more effective using of information we need more effective organization. The most interesting approach is to use WSN as distributed computing environment for intelligent data processing methods and as storehouse of this methods and not only tools for data measuring and transmitting.. Thus methods are to provide distributed accumulation, transmitting and using of these knowledge. One of approaches is to use expert system with knowledge base distributed among fuzzy sensor nodes in WSN. The physical data attributes are processed by fuzzy sensor node knowledge base and by knowledge base of neighbor fuzzy sensor nodes.

But the main problem is the cost and the complexity of data delivery in data fusion fuzzy sensor because the position of this fuzzy sensor has to be fixed and closed to the user. So the assignment of WSN as point for data fusion must be dynamic procedure and the fuzzy sensor position should be optimized in regarding of the query, WSN and environment status. Together with fuzzy sensor's assignment its knowledge base should be changed. When cluster head function is delivered inside cluster of nodes from one fuzzy sensor to other fuzzy sensor than knowledge base with cluster head functions of first fuzzy sensor should be send to second fuzzy sensor.

When user requests about some attribute from particular fuzzy sensor and this fuzzy sensor has no rules to compute it, then the request should be send to the nearest fuzzy sensor where necessary knowledge base was located. E.g., for monitoring of dynamic object (goal) moving or other changes of goal parameters the positions of fuzzy sensors responsible for this monitoring can change and data fusion methods must be transmit to the fuzzy sensor responsible for this monitoring and located near the goal at the moment of data request.

The suggested approach consists in moving up of fuzzy sensor with data fusion rules to the event point and in hierarchical data processing inside this fuzzy sensor. At first fuzzy sensor should get the necessary physical data and then compute the users' inquiry answer. Computing procedure for inquiry answer starts from fuzzy sensor with data fusion rules, than distributes across WSN. The universal character of these algorithms by production rules allows to simplify these procedure by transmission only rule's parameters instead of program code.

Thus fuzzy distributed knowledge base for distributed data base query processing has the following properties:

- It functions as distributed expert system.
- Knowledge in production form can be transmitted between nodes.
- Knowledge base for inquiry answer can be send in fuzzy sensor together with the inquiry
- Special language is used for knowledge base transmission between nodes.

Knowledge-based program of data fusion uses parallel computing algorithms and destines for the whole WSN and not only for certain fuzzy sensor.

Until now middleware was rarely designed for wireless networks support. Most middleware systems were for enterprise networks. Some of then focuses on how to control quality of service adaptation in middleware architecture, and the quality of service is specified by fuzzy rules and membership functions [15] an can be realized by fuzzy sensor. But there are already some projects underway that aim to develop middleware for WSN, such as [1, 3, 4, 5, 6, 7, 8, 9, 16]. Cougar [1], for example, adopts a database approach where sensor readings are treated like "virtual" relational database tables. An SQL-like query language is used to issue tasks to the WSN. The Smart Messages Project [7] is based on agent-like messages containing code and data, which migrate through the sensor network. NEST [8] provides so-called microcells as a basic abstraction. They are similar to operating system tasks with support for migration, replication, and grouping. SCADDS [4] is based on a paradigm called Directed Diffusion, which supports robust and energy-efficient delivery and in-network aggregation of sensor events. Project AGILA [16] envisions a new paradigm for programming and using sensor networks where applications consist of special programs called mobile agents that can migrate their code and state from one node to another as they execute. Mobile agents offer an unprecedented level of flexibility by allowing fluid applications to spread throughout the network and to intelligently position themselves in the optimal location for performing their task, whether it be detecting an intruder or tracking a wildfire. By allowing new agents to be dynamically injected, a pre-existing network can be re-tasked.

However, most of the projects are in an early stage focusing on developing algorithms and components for WSN [2], which might later serve as a foundation for middleware. Moreover, most of the current results are based on simulations or small-scale experiments in laboratory settings. The suitability for large-scale networks still has to be proven.

There are several models of fuzzy databases, which can be easily, generalized as WSN fuzzy database in the fuzzy sensor friendly domains.

Applying fuzzy logic to databases has been an active research area since the 80's. The most important issues are the enhancement of existing data models for representing uncertain and/or imprecise data (fuzzy data), the extension of current database languages to handle fuzzy queries, and the use of fuzzy inference to deduce answers to questions in fuzzy expert database systems [11, 12].

Active databases, which incorporate Event-Condition-Action rules into the conventional (passive) databases, have been investigated by many researchers over the past decade [13, 14]. They provide the capability to react to database (and possibly external) stimuli, called events, without user intervention. Fuzzy triggers model combines fuzzy logic features with active database capabilities to provide a high-level view of data stored in a database was proposed in [10].

In spite of the fact that knowledge representation with fuzzy production rules is quite natural and simple procedure, it suppose rather slow interface with the user for rules and membership function acquisition. Besides the resulted knowledge base usually needs validation and verification. A learning pattern that corresponds to expert opinion about desired measurement process can greatly accelerate this process. So the nearest goal is using beside fuzzy sensor neuro-fuzzy networks (embedded in one node or distributed among several nodes of WSN), genetic algorithms and artificial immune systems. These models can control by adaptation and learning of fuzzy sensor for optimization such hierarchical processes as data clusterization, filtration, aggregation, association and fusion. These possibilities will increase the effectiveness in static and dynamic object monitoring, monitoring of environments, buildings and industry processes. Besides they will be able self-learning simultaneously with control of basic processes – data and knowledge transfer inside WSN, energy saving, defense of WSN from attacks. For the case of heterogonous WSN functions dedicated nodes should realize the most part of soft computing methods.

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