

A Survey on Intelligent Sensor Network and Its Applications

Feng-Cheng Chang

Department of Innovative Information and Technology
Tamkang University
180 Linwei Rd., Jiaosi, Ilan 232, Taiwan
135170@mail.tku.edu.tw

Hsiang-Cheh Huang*

Department of Electrical Engineering
National University of Kaohsiung
700 University Road, Kaohsiung 811, Taiwan

*Corresponding author.
hch.nuk@gmail.com

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ABSTRACT. *With advances in technology, small form-factor sensors are feasible for various kinds of applications. The improvements on communication technology further make it practical to construct a wireless sensor network (WSN). In this paper, we review the works that are related to intelligent sensor network. Because there are no precise definitions of intelligent sensor network, we group them into two categories. One is to solve WSN issues with intelligent algorithms. The other is to design an intelligent application that incorporates sensor networks as the data sources. According to the categorization, the description of WSN issues, intelligent algorithms, and intelligent application technology are also provided in this article.*

Keywords: Survey, Sensor network, Intelligent algorithm

1. **Introduction.** In the past two decades, wireless communication and sensor technology have been actively developed. With advances in microprocessor and software architecture, it is expected that wireless sensor network (WSN) will be part of many future applications[1]. Depending on the level of integration, a WSN could be a mission-based standalone system or a supporting service to an application. The former is the study field of conventional WSN researches. The latter is a study field of modern network application design. It becomes popular due to several reasons, and one of them is the availability of smart phones. A smart phone is powerful in that sensors are embedded and small applications (apps) are installed. It is recognized that new types of applications are emerging due to the integration of sensors and apps. The concept of a smart phone can be generalized to a smart device. A smart device is capable of collecting data from the environment, processing the data to produce helpful information, and exchanging the information via network. The mobility of a smart device further extends the range of the applications. It allows the device to be located flexibly for collecting data precisely and timely.

In this paper, the efforts on intelligent sensor networks are reviewed. The rest of this paper is organized as follows. In Sec. 2, the concepts of intelligent sensor networks are described and categorized. In Sec. 3, the WSN issues and some intelligent algorithms

are studied. Then, some intelligent application scenarios is reviewed in Sec. 4. Finally, conclusions are provided in Sec. 5.

2. Intelligent Sensor Networks. There are no definitions of an intelligent sensor network. According to our survey, the combination of intelligent and sensor network falls into two categories. One is to solve the sensor network problems by intelligent methods. The other is to incorporate a sensor network to design an intelligent application.

The former category can be considered in two aspects: the sensor network problems and the intelligent methods. Sensor network problems are mostly related to wireless sensor networks (WSN). The reason is that wireless sensor network is designed to work in some extreme situations. Therefore, the deployment, the power consumption, the communication, etc are ad hoc, limited, and unstable. To make a sensor network deliver the information efficiently, the application specific requirements should be addressed and optimized. However, it difficult to precisely model the WSN issues due to various nonlinear environmental factors. Thus, it is unlikely to apply conventional linear tools to optimize the network. Using intelligent methods is an alternative to solve the nonlinear problems. There are a few developed methods such as neural network, fuzzy logic, and evolutionary algorithm. By applying one or more methods to a WSN problem, the optimal solution is likely to be found with the cost of computation complexity.

The latter category contains some emerging application scenarios. In a conventional program, the input data is provided by designed data sources or user input. There are a few limitations of the input scenario. For example, the input data are well-defined but inflexible; and the user is limited to use a computer console for entering the data. It is difficult to obtain various real-time responses from the user side. This situation is changed in recent years. With the popularity of smart phones, a user may use the phone as a new type of input device. The phone may deliver various kinds of information to the application, for example, the user input values (the typed or clicked values), the sensed environmental values (the GPS or the acceleration readings), or the behavioral parameters (the usage statistics in various aspects). An interesting property is that a user tends to feedback in near real-time when he carries a smart phone. The smart phone example can be extended to other smart devices such as the sensors and microprocessors in a vehicle. With the near real-time input data, the data model could be quite different from that in a conventional program. Therefore, the demand of developing intelligent methods to process the various kinds of sensed data in real-time is emerging.

The intelligent sensor network concepts are reviewed in the following sections. Solving sensor network problems with intelligent methods is provided in Sec. 3. Making an application intelligent with sensor networks is studied in Sec. 4.

3. Solution to Sensor Network Issues. In this section, the intelligent approaches to solve WSN problems are reviewed. In Sec. 3.1, the issues of WSN are described. In Sec. 3.2, the approaches to solve a non-linear problem intelligently are described. Then the applications of the intelligent methods to the issues are listed in Sec. 3.3.

3.1. Issues of Wireless Sensor Networks. A WSN is a set of autonomous devices that collects data from the environment [2]. The sensor nodes are typically organized in a distributed and ad hoc manner within a geographical area. A sensor node is resource-limited in terms of computation capability, power supply, storage space, and communication bandwidth. Therefore, it is impractical to perform all the computation collectively by the sensor nodes. The typical approach is that the sensor nodes are geographically grouped as clusters. Thus, a node sends the data by the help of its neighbors. The routing scheme reduces the transmission power of a single node. In each cluster, a node acts as

the cluster head for aggregating the data from the other nodes. Then, all the cluster nodes routes the data to the sink node. The sink node is also known as the base station which is a stable and powerful enough device as the gateway between the WSN and the application. The aforementioned communication scheme is based on a simple structure. More complicated structures, such as multiple base stations, are also possible depending on the scale of the application.

Although there are various kinds of WSN applications, they face to some common problems. Due to the distributed and ad hoc nature, the common WSN problems are described in the following sections.

3.1.1. *Deployment.* WSN is used in various applications, such as the agriculture monitoring [3][4], forest fire detection [5][6], volcano [7] and earthquake [8] measurements, and hazards detection [9]. The placement of the sensor nodes is an issue to a specific application. To cover the informational area for collecting data, some of the applications require precise design of the sensor locations. The optimal locations should be determined before the deployment of the devices. However, there are situations that predetermination is not feasible. For example, air-dropping a large number of sensors around a volcano make it impossible to deploy the sensors accurately. The issue is how to design the deployment of the sensors so that the application can receive the necessary information.

3.1.2. *Localization.* When all the sensors are deployed, a sensor requires the location information for optimally transmitting and routing the data. In many cases, the node location is part of the sensing information and is necessary for a location-aware application. There are various methods to make a sensor location-aware [10][11]. A high-end sensing device may use the GPS signals to determine its absolute location. For low-end devices, one of the methods is to use the reference points (e.g., base stations) as the locating signal sources [12]. A sensor use the arrival time of a signal from different base stations to estimate its relative location to the base stations.

3.1.3. *Sensor Fusion.* After determining the location of each sensor, the communications among the nodes start. Due to the large amount of sensors, voluminous data are generated in the WSN. If the raw data are transmitted directly, there are two coupled issues. On the one hand, high bandwidth is required, from a sensor node to the cluster head, and from the cluster heads to the base station. On the other hand, the more data a sensor transmits, the more power it consumes. As a constrained environment, it is not affordable for a WSN. Therefore, a common design is to pre-process the aggregated data at a fusion center (e.g., the cluster head) [13][14]. The goal is to obtain the condensed information and thus to reduce the transmission bandwidth to the base station.

3.1.4. *Energy Consumption.* A wireless sensor is usually designed to use battery power. For many WSN applications, it is not practical to replace the batteries. Therefore, a sensor should be designed to conserve power as much as possible. In the previous section, sensor fusion is the power conservation technique for cluster heads. For a sensor node, a smart routing strategy is required. One of the commonly used approaches is the hybrid of proactive and reactive routing method. This balance the required memory for the routing table and the on-demand computation of routes. There are other approaches such as the cluster-based routing [15] and power-balanced routing [16].

3.1.5. *Scheduling.* Yet another power conservation strategy is to schedule a node's activities. Typically a sensor node should only collect data periodically. This implies that a sensor node is not always in working mode. Instead, it could be put into sleep mode to greatly reduce the power consumption. The issue is how to design the schedule for

each node so that the overall WSN power consumption is minimized [17]. In addition, good scheduling may interleave the transmissions properly. The implication is reducing the collisions of the data packets. Some people view the scheduling problem based on the packet scheduling. By prioritizing packet transmission based on the data types, a sensor node can work more efficiently [18].

3.1.6. *Security.* Wireless networks expose the signals to the air. It is easy to eavesdrop or attack the transmitted data. Using cryptographic algorithms to protect the data is widely adopted in WiFi and mobile networks. However, encryption and decryption of data consume additional power. Depending on the application requirements, the security mechanism should be carefully designed so that the WSN achieves adequate security level with optimal power consumption [19][20].

3.1.7. *Quality of Service.* A WSN can be treated as a mission-based data service. The types of the sensors, the number of sensors, and the communication protocols are defined according to the application. Hence, the quality of service (QoS) is also application specific [21][22]. Several reviews presented that the QoS of a WSN should be carefully analyzed. It is common to include different QoS mechanisms in a WSN, and they should trade-off qualities among different aspects. Therefore, QoS is usually a multiobjective optimization problem.

3.2. **Intelligent Methods.** In this section, we briefly review the methods that are used to solve or optimize a WSN problem. The methods are grouped into three categories and are described in the following sections.

3.2.1. *Early Intelligent Methods.* There are intelligent methods developed by the conventional artificial intelligence field. They are mature and the effectiveness has been proven for quite a long time. The neural network, fuzzy logic, and game theory are described in the following paragraphs.

Neural network (NN) is one of the efforts to model the human brain structure. The biological neural system is very complex in that bio-chemical signals are exchanged in a sophisticated network of neurons. Each neuron is a processing unit that receives signals from the other neurons and transmit the processed signal to other neurons [2]. A neuron is then modeled as the weighted sum of the input signals followed by the activation function.

$$u_j = \Theta_j + \sum_{i=1}^n x_i W_{ji}$$

$$v_j = \Psi(u_j)$$

In the above equations, u_j is the aggregate result at neuron j . There are n input signals, and x_i denotes the signal from the i -th neuron. The W_{ji} represents the weighting factor for x_i at neuron j . The Θ_j is the bias of neuron j . The $\Psi(\bullet)$ function is a nonlinear activation function that simulates the computation inside a neuron. A popular structure of neural networks is shown in Fig. 1. The external input signal are processed by the input-layer neurons. The internal states (memory) are represented by the context-layer neurons. The results of input layer and context layer are merged in the hidden layer. The existence of the hidden layer implies that the network combines both the effects of the current input and the processing history. The results of the hidden layer are saved back to the context layer while triggering the output layer to produce the output signals.

Fuzzy logic is derived from set theory. The classical set theory is strict and does not allow ambiguity. However, human reasoning is not strict and may produce some result decorators like *many*, *most*, *roughly*, etc. To model the human reasoning with set

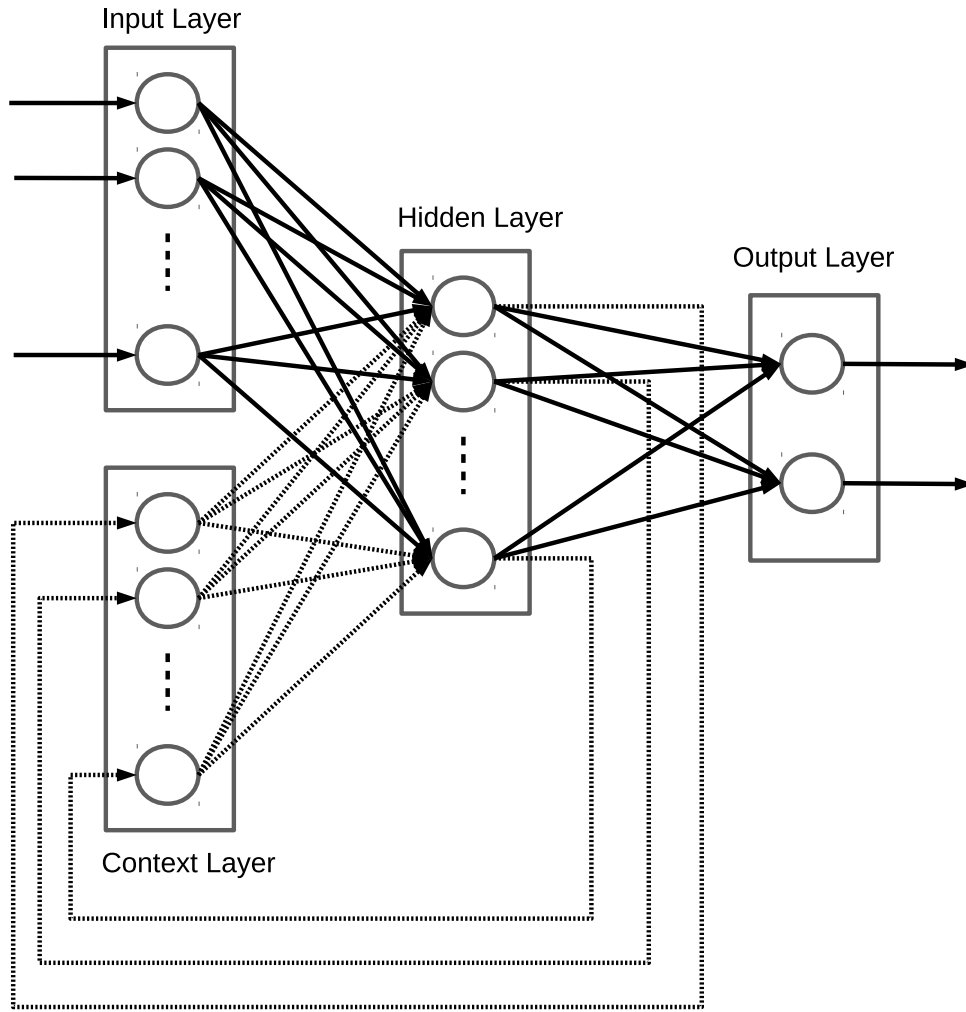


FIGURE 1. A popular neural network structure

operations, the concept of fuzzy logic was developed. In fuzzy logic, an instance could be a partial member of a fuzzy set. Typically we may describe an instance x as a member of a fuzzy set S with a relationship degree r . To resolve the fuzzy logic, a set of fuzzy rules should be defined by the expert. The inference engine then processes the input value based on the rules to determine the fuzzy set it belongs to. In a practical control system, all the input values and output values should be deterministic. Therefore, most of the fuzzy logic engines also include the conversion mechanism between fuzzy and non-fuzzy representations. Fuzzy logic is successful in many research areas such as control systems, communication systems, and pattern recognition.

Game theory is used for strategic decision making. More specifically, game theory is frequently used in an interactive, with several competing opponents, application. A game may take a number of rounds to finish. The goal is to maximize the probability of winning (or defending) the game. A game theory algorithm is based on the game model and the decision tree. Depending on the game state of each round, the algorithm computes the best approach to proceed to the next round. Game theory may include the bio-inspired methods (discussed later) due to the difficulty to determine the exact game model [23].

3.2.2. *Bio-inspired Methods.* Bio-inspired algorithms mimic how organisms solve the real-world problems [24]. There are a variety of bio-systems that can be used as the solution-finding mechanisms. In the following paragraphs, we introduce a few methods that falls in the evolutionary category and the swarm-intelligence category.

The most well-known method in evolutionary algorithms is the genetic algorithm (GA). Although there are many variants of GA, they are based on the common properties of GA [25].

Encoding: The solution is a vector that represents the chromosome. It has a counterpart representation that represents a list of genes. The typical method is to encode the vector as a sequence of bits.

Fitness Function: The function is used for evaluating how close a given solution is to the optimal one. This function implies the data model, and thus it should be carefully designed.

Selection: The selection mimics the natural live-or-dead mechanism of a chromosome. When a chromosome is selected for producing the off-springs, it effectively gains higher survival chance in the next generation. The strategy could be random, biased to fitter ones (e.g., the roulette wheel scheme), elite-based, or hybrid.

Crossover: After two chromosomes are selected, the crossover scheme controls how the off-springs are produced. The scheme could be single-point crossover or multi-point crossover. In some GA, a control parameter called crossover rate is used to decide whether to crossover or not for each crossover operation.

Mutation: After crossover operation, each gene on a chromosome is subjective to be flipped. This is called mutation. The probability of mutation is controlled by the mutation rate parameter.

GA is a mature method for solving various optimization problems. It is also proven that it converges eventually (if the fitness function is properly defined).

Swarm intelligence is based on the collective intelligence concept. A swarm intelligence algorithm creates a set of agents. Each agent performs simple computation locally and interacts with the other agents. The collaboration makes all the agents behaves as a group and show the impressive achievements. Popular swarm intelligence methods includes particle swarm optimization (PSO) [26], ant colony optimization (ACO) [27], artificial bee colony algorithm (ABC) [28], etc.

The PSO is suitable for searching the optimal solution in the given vector space. Each particle in PSO is composed with three vectors: one is its current position (p_i), another is the best position it has visited ($pbest_i$), and the other is its current velocity (v_i). To determine the optimality of a particle position, a fitness or cost function should be designed to estimate the distance of a particle to the optimal point. There is a shared information in the swarm, the best vector among all the $pbest_i$, denoted by $gbest$. In each iteration, a particle p_i moves from current position to the next position. The movement is attracted by the $pbest_i$ and $gbest$. To enable the exploration of the vector space, two random vectors r_1 and r_2 are employed when computing the acceleration toward the $pbest_i$ and $gbest$. The overall update process from iteration k to $k + 1$ is formulated as follows:

$$v_i^{(k+1)} = w \cdot v_i^{(k)} + c_1 \cdot r_1^\top \cdot (pbest_i^{(k)} - p_i^{(k)}) + c_2 \cdot r_2^\top \cdot (gbest^{(k)} - p_i^{(k)})$$

$$p_i^{(k+1)} = p_i^{(k)} + v_i^{(k+1)}$$

There are three scalar control parameters: w represents the inertia of the particle, c_1 represents the cognitive acceleration toward its best experience, and c_2 represents the social acceleration toward the global best point. The PSO method is applied to many problems, such as power systems and WSN [26][29].

The ACO mimics the ants searching for food. The goal is to find the optimal path from the source node to the target node in a given graph. The graph represents the state of the problem. Initially an ant randomly chooses a path. If the path connects the source and the target, the ant updates the attraction factors along all the traversed edges. For the subsequent iterations, the probability to choose a path is affected by the attraction factors. In the end, the optimal path is the one that attracts most of the ants to traverse. The ACO is popular to optimize combinatorial problems, such as traversing, scheduling, and routing problems [29].

3.2.3. Machine Learning Methods. The concept of machine learning (ML) was part of the early artificial intelligence (AI). The research focused on making computers learn from data. Nowadays, ML and AI have been evolved into two different research fields. ML methods are mostly based on statistics and probability theories; AI methods are mostly based on symbolic and logical approaches. Therefore, the common property of the ML methods is producing the result based on the known training data that are used to construct the probability model. Machine learning methods falls into three categories:

Supervised Learning: The learning is guided by the supervisor. The goal is to learn the general properties from the training process.

Unsupervised Learning: The learning is not guided by an external entity. The algorithm should resolve the criteria to end the learning.

Reinforcement Learning: The learning process is not guided by a supervisor. Instead, the algorithm interacts with the environment to determine whether it is close to the optimal training result.

Machine learning methods have been successfully applied to many optimization and classification problems [30], including the deployment, routing, and power problems of WSN [31].

3.3. Intelligent Solution for Sensor Networks. In this section, we review some of the researches that solve the WSN issues by using the intelligent methods.

Deployment: :

- In [32], the NN is setup on top of the WSN. Based on the learning result, the coverage of the WSN is obtained.
- In [33], a fuzzy-based coverage detection is employed. Each node periodically sends heartbeat signal to the neighbors and estimates the coverage. When an uncovered area is detected, the proper node moves toward it to increase the coverage of the WSN.
- In [34], co-evolutionary PSO is proposed as an alternative to optimize the dynamic deployment algorithm.
- In [35], sensor deployment is modeled as data clustering problem. The optimal solution is obtained by using ABC.
- In [36], ABC is applied to a WSN with mobile nodes. The goal is to maximize the coverage while minimize the tour distance of a mobile node.

Localization: :

- In [37], the time difference of arrival (TODA) information is the input data. The output of the NN is the location (x,y) of the sensor node.
- In [38], a feed-forward NN is used to process the input Received Signal Strength (RSS) and determines the location of the node.
- In [39], the genetic simulated annealing algorithm is employed to estimate the location of a node.

- In [40], the localization issue is solved collaboratively by the nodes. The optimal location estimation is done by PSO in real-time.

Sensor Fusion: :

- In [41], the data fusion process is achieved by using NN . The NN structure is three-layer (input, hidden, and output, without the context layer).
- In [42], ML techniques are employed to predict the state of the monitored wagon. With the prediction capability, not only the task of each sensor is simplified but also the number of sensors is reduced.

Energy Consumption: :

- In [43], the base station uses an NN to determine the best set of cluster heads for saving transmission power. Each input is a vector consisting of the node residual power and the node position.
- In [44], a survey on optimizing energy consumption with NN is presented.
- In [45], cluster head election is determined by a neural network. The NN reads the coverage information of the competing nodes and elects the proper cluster head.
- In [46], a fuzzy-based simulation model is proposed for estimating the lifetime of a WSN. The input is based on the battery power, sleep time rate, and transmission time rate.
- [47], a fuzzy inference engine is used in each node for determining the efficient routing. The result is the increase of the WSN lifetime.
- In [48], fuzzy logic method is adopted to help the routing of the data. The goal is to consume the nodes' power evenly so that the overall lifetime of the WSN is maximized.
- In [49], a fuzzy-based clustering method is proposed. With the optimal clustering, the lifetime of the WSN is prolonged.
- In [50], an improvement of the LEACH protocol is achieved by using fuzzy logic.
- In [51], GA is used for calculating the optimal cluster under the constraint of energy harvesting WSN. The goal is to find the energy-efficient routing structure according to the harvested energy from the environment.
- In [52], a multiobjective GA optimization is used to reduce the power consumption under the application specific constraints.
- In [53], a fault node recovery algorithm is proposed. The algorithm incorporate GA to find the optimal set of functional nodes to replace the nonfunctional nodes.
- In [54], PSO is employed to optimize the hierarchical clustering in WSN. The goal is to maximize the lifetime while minimizing the number of active cluster heads.
- In [55], the number of disjoint connectivity covers of a WSN is maximized by ACO. The target result is to cover the sensing range in a power-efficient manner.
- In [56], ABC optimization is used for determining the routing in a WSN. The result also shows that the lifetime is prolonged.
- In [57], the efficient routing design is optimized by ML. With the optimization, the energy consumption is also reduced.

Scheduling: :

- In [58], a multiobjective optimization method is proposed for sleep scheduling. The method is fuzzy based and it compares the performance with a genetic based method.
- In [59], the scheduling problem is optimized by using ACO. The goal is to achieve efficient energy coverage.

- In [60], each node in WSN is modeled as an ant. The ACO algorithm is then applied to schedule the wake/sleep cycle of a node.

Security: :

- In [61], a secure scheme of WSN is proposed. GA is applied to the clustering process. It also considers the energy-efficient encryption in the clusters.
- In [62] and [63], the secure routing issue is addressed. The method is to prefer the high-credit nodes and then routes the data securely. The optimal routing is computed by the ACO method.
- In [64], the method of detecting anomaly (a sensor node is compromised) is proposed. It is based on ML techniques to detect the intrusions.

Quality of Service: :

- In [65], a localized decision making with fuzzy logic is proposed. The goal is to report the sensed event by the most proper sensor node so that reduce the false alarms.
- In [66], fuzzy logic is used for selecting the forward error control scheme to reduce the transmission errors.
- In [29], the topology maintenance issue is optimized by PSO and by ACO. The two approaches outperform the conventional methods.
- In [67], the task allocation issue in WSN is addressed. The PSO method is used for allocation of tasks on the nodes. The goal is to make the WSN optimally deliver the computation result.
- In [68], the ACO method is used for clustering and routing. The distance to base station and the energy of a node are considered in the heuristic function to enhance the result.
- In [69], the efficiency of routing that affected by the changing transmission power is addressed. The ACO method is used to adaptively determining the routing path whenever the WSN power state is changed.
- In [70], the optimization method is applied to determine the cluster head. It treats a cluster as the hive and each node as the bee. The methods simulates the queen bee selection process. The result queen bee is the cluster head.

According to the review, we learned that the intelligent methods are frequently applied to optimize energy consumption, routing, and quality of service. In fact, the balance among several related aspects should be considered when optimizing a WSN. Thus, the application of intelligent methods is implicitly a multiobjective optimization problem. The conventional intelligent methods are still very useful for some of the WSN issues. Swarm intelligence based methods seem to be more generic to all the WSN problem areas. Machine learning is not applied as frequently as the others. However, it is still promising in solving the WSN issues in the application level.

4. Intelligent Applications with Sensor Networks. In this section, intelligent applications that incorporate sensor networks are reviewed. As mentioned in Sec. 2, this type of applications could be viewed as an evolution of traditional data processing programs. Therefore, the properties of the applications are described in Sec. 4.1. Then the applications and the related technology are reviewed in Sec. 4.2.

4.1. Properties of Intelligent Applications. According to [71], there are five technology areas that helps the supply chain applications evolves to be more intelligent: mobility, Internet of Things, big data, new forms of predictive analytics, and cloud computing. The mobility of smart devices helps the application to collect near real-time data from the user. A smart device may embed different kinds of sensors to obtain physical readings. It may

also collect data from an installed program (e.g., an app on a smart phone), which represents the behavior of the user. With the limited computation capability of the smart device, the application is responsible for obtaining the preliminary information. The information may be produced as a stream depending on the type of the measured data. In the traditional data collecting process, it is difficult to achieve real-time due to the lack of mobility. The application waits for the feedback from the user, obtains non-real-time data, and analyzes the delayed (and sometimes biased) data.

The Internet of Things (IoT) concept is that everything could be part of the Internet. A thing could be physical or virtual, and communicates through the Internet. In short, the IoT converges all the data sources on the Internet. Smart devices, tagged objects, and all the other identifiable objects are associated with the Internet. An application may collect data by specifying the identifications, and communicates to the object if applicable. In this scenario, the mechanism for producing and transmitting the raw data is hidden behind the thing-level. As long as a thing is associated to the Internet, it may exchange information with the other things via the Internet. The transparency of the data exchange extends the availability of sensed data.

The widely available Internet-connected mobile devices is a new challenge. The combination of mobility and IoT indicates that constantly produced real-time data streams are available on the Internet. The huge amount of real-time data (volume and velocity) and the various kinds of sensed data (variety) meet the 3V property of the big-data concept. Big data is not usable unless it is properly processed. However, the usability is based on the application domain and there is no universal processing method.

In the supply chain domain, new predictive analytics should be developed. Traditionally, data are collected and analyzed for decision support. The methods are based on linear optimization and simple rules-based processing. However, it is known that supply chain problems are not linear and complex. It could be solved by some other sophisticated methods. As mentioned before, the mobility allows the application to obtain near real-time data. This implies that the data model should be modified. Otherwise, the mismatch of the data and model would invalidate the prediction results. In addition, the high-volume and high-speed properties require new algorithms to produce the results efficiently. The property is based on the supply chain problems but it is also applicable to many modern network applications.

Even the new predictive analytics are developed, it is not easy to process big data in-time. A commonly recognized approach to solve this problem is to incorporate the cloud computing technology. Cloud computing is the concept of providing computational resources on the Internet. It was proposed to address some software issues such as the computational power, the availability, the reliability, etc. An application may use cloud services to store and process the big data, and achieve stable and in-time computation results.

4.2. Intelligent Applications and Technology. There are variety of applications with sensor networks. Some studies are listed below:

- The survey [1] provides the review of application categories.
- The survey [72] focuses on the sensor as a service (SaaS) with big data applications.
- The research [73] reviews the technology of multimedia streaming in WSN.
- In [74], the described intrusion detection technique can be applied to a normal network as a network security application.
- Sensor network can be deployed underwater, such as [75].

There are variety of applications with sensor networks. It is difficult to cover all the researches. In this section, we focus on a few application scenarios that require sensor networks as the automatic input devices.

One scenario is the health care domain [76][77]. The monitoring devices (the sensors) could be implanted into the body or worn on the surface of the body. It is obvious that they should be wireless so that the interference to the daily life is minimized. The sensors transmit the readings to the monitoring service (may through a proprietary network), the service then relays the data to the server or cloud storage. On the server side, continuous analysis of the readings could be performed, and alerts are triggered when abnormal events are detected. The data processing could be on the remote server or partially at home [78]. The implementation may be dedicated devices, powerful embedded systems, and/or Internet web services [79][80][81].

Another scenario is the sport and training. An example is the BikeNet [82]. The service collects various kinds of data of the cyclists and the environments, including some features

- The cycling performance readings — deriving the fitness measurements;
- The pollution level, noise level, roughness, etc — deriving the environment and experience mapping.
- The service allows disconnected operation, i.e., a client uploads the data only when a stable Internet connection is available.

There are some studies about the ad hoc network of a cycling group. When it is designed to combine with some Internet services, it creates the value-added opportunities. For instance, the network sends the location information to the location-aware service, and the service responses the food or restaurant information [83] to the cyclists.

The other scenario is the environmental monitoring for scheduling and safety. An example is monitoring the crowd of people in a theme park. Some of the data may be obtained from the automatic sensing devices such as the infrared cameras and body movement detectors. Some of the data may be obtained from the customers such as the reservation request for a facility. These input values form a continuous stream of voluminous data. Based on the big data, real-time analysis for optimal scheduling is critical [84]. The other example is the fire detection sensors in a building. When a fire event is detected, the application suggests the evacuation paths for the people. Due to the dynamics of fire, the evacuation paths should be continuously updated in real-time according to the sensor readings [85].

5. Conclusions. In this paper, we review the intelligent sensor network with two viewpoints. One is to solve or optimize the wireless sensor network (WSN) issues by intelligent algorithms. The other is intelligent applications that incorporate sensor networks as the data sources. For the former category, we review the issues of WSN and some popular intelligent algorithms. Then a brief list of related literature is provided. For the latter category, it is not easy to cover all the application-specific researches. Therefore, we addresses a few survey articles and a few application scenarios with the related literature.

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