Adaptive Sensing based on Fuzzy System for Wireless Sensor Networks*

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Abstract. Wireless sensor networks (WSN) are used by various application areas to implement smart data processing and ubiquitous system. In the recent research of parking management system based on wireless sensor networks, adaptive sensing of WSN is not considered where the effective implementation of these distributed computing devices affects the performance of the over-all reliability of the parking management system. This paper proposes an adaptive sensing using the proposed fuzzy wireless sensor implemented in the ubiquitous parking management system. The fuzzy inference system is encoded in the sensor devices for efficient car presence detection. A rule base adaptive module is used to change the fuzzy set values from wireless sensors based on the rules specified by an expert. The prototype implementation of the proposed fuzzy wireless sensors is done in a ubiquitous parking management system simulator.

1 Introduction

Wireless sensors have been popularly researched on the field of healthcare, military, environmental monitoring and others [1]. These wireless sensor networks (WSN) are characterized by low-cost, limited-power, small sized, specific or multiple functional and wireless communicating device that smartly processes data and real-time information. The concepts and techniques of WSN to solve the problems on diversity in various applications are mostly studied by researchers. Most performance issues of WSN rely on the protocols and architecture [2]. Communication protocols of WSN are crucial on providing reliable information from source to destination. Efficiency in energy consumption is also considered like implementing power-aware methods that removes unnecessary links to provide longer time operations. It is also important to consider adaptation of sensor reading based on changes of the physical environment. Extreme conditions like having dramatic changes of weather in the area where sensors are deployed can affect significantly the accuracy of sensor readings.

This paper proposes an adaptive sensing using the proposed fuzzy wireless sensorfor the ubiquitous networks of parking management system. The proposed ubiquitous parking management system is consisted of three separate layers of hardware

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and software components. This paper focuses on the efficiency of ubiquitous network by using fuzzy wireless sensors. The proposed fuzzy wireless sensor is designed to process the raw data of the sensor in the fuzzy inference system for efficient car presence detection. Moreover, a rule base adaptive module is proposed which transmit the new values to each sensor for adapting the environment of parking area. The fuzzy wireless sensor is implemented in the ubiquitous parking management system simulator.

2 Related Works

Parking management system using WSN are popular studies of research. This method implements WSN to sense the presence of the car and monitors the location of cars. Relevant services like car locator system, parking negotiator and other ubiquitous application in parking system rely on sensing procedure to provide the basic input variable for parking system management. However, adaptive methods are needed to be considered. The following subsections are related works basis on designing the adaptive system of the fuzzy wireless sensor.

2.1 WSN-based Parking Management Systems

Current studies in smart parking system are efficient implementation of WSN. Wireless sensor networks are used for automatic vehicle car parking [3] where wireless sensors and infrareds are used for the positioning to enhance the accuracy of positioning. The positioning and error correction procedures are calculated by the vehicles, and forwarded to the server by WSN. A car parking monitoring system using WSN is proposed [4]. Low-cost wireless sensors are deployed into a parking field which detects and monitors the occupation of the parking lot area. The status of the parking field detected by sensor nodes is reported periodically to a database via the deployed wireless sensor network and its gateway. The database can be accessed by the upper layer management system to perform various management functions, such as finding vacant parking lots, auto-toll, security management, and statistic report. In [5], describe results of a simulation where reports from wireless sensor nodes are passed from car-to-car in order to achieve scalable dissemination of information regarding parking spaces. An analysis of link characteristics in the car-park scenario is studied [6]. The experiments show unexpected reliability patterns which have a strong influence on MAC and routing protocol design. It concludes that the presence of the cars being sensed can cause significant interference and degradation in communication performance and link quality has a high temporal correlation but a low spatial correlation. A comparison of data from different sensors for improvements to WSN in parking management system is presented [7]. An RFID-based car parking system is proposed which is improved by designing a middleware [8]. The design of the previous researches does not include adaptive methods in the parking environments. Adaptive design where variables from the environment are considered for adapting new configuration in the sensor to read the inputs correctly is not considered.

2.2 Fuzzy Inference System

Fuzzy inference system is based on the concept of fuzzy logic and fuzzy sets, which was conceived by Lotfi Zadeh [9]. It is presented as a way of processing data by allowing partial set membership rather than crisp set membership or non-membership. Fuzzy logic is one of the earliest concept using fuzzy sets where most fuzzy controllers benefit this technique because of the it's smooth transition to transfer the another fuzzy set and the way it handles its imprecise values [10]. Figure 1 shows an example of a fuzzy inference system.

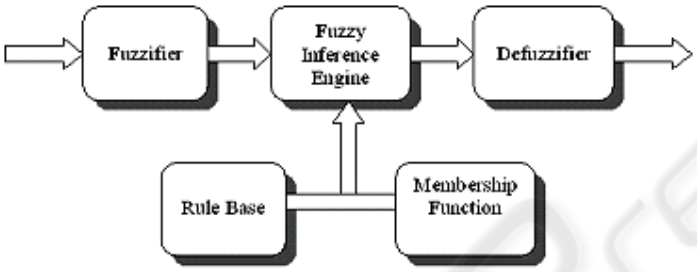

Fig. 1. The component and procedure of fuzzy inference system.

A fuzzifier is an interface for the input where maps the numeric input to a fuzzy set and it maps the premises of the fuzzy rules from the rule base. The fuzzy inference engine applies the inference mechanism to the set of rules using the membership function. Lastly, the crisp value is determined by the deffuzifier. The fuzzy inference system in Figure 1 is efficient in classification of data in terms of speed. Non-linear methods can be more accurate method but computational costly. The improvements in accuracy of the fuzzy logic classifiers are recent studies nowadays to accurately classify variety of data. In this study, the FIS is used to classify input sensors like illuminance and temperature in detecting the car presence.

3 Fuzzy Wireless Sensors

This paper proposes the integration of fuzzy system in the sensing module of a wireless sensor device and called fuzzy wireless sensors. The application which the proposed fuzzy wireless sensor is implemented is the WSN-based parking management system. The architecture of the proposed ubiquitous parking management system is shown in Figure 2. The architecture consists of three layers: ubiquitous network, middleware and application services layers. In the ubiquitous network, represents the physical networks of different sensor devices and computers communicating in the wireless environment. The components in the middleware layer are transparently executing for the efficiency on managing data from the ubiquitous network layer. The previous study uses the hybrid-middleware which uses a peer-to-peer technique [8] while it is currently improved by proposing a multi-agent system communication

model for the middleware for efficient interaction and serves efficiently the ubiquitous network and application services and will be presented in a different paper. Interaction of clients and application services are handled by the middleware layer. Users and administrators do not need to know the configuration on how to find, where to find and how to manage the resources but transparently executes the services. The application service layer is consisted of services for ubiquitous parking management system. The efficiency of the ubiquitous network relies on the reliable communication and well-designed distribution of tasks of the devices in wireless environment.

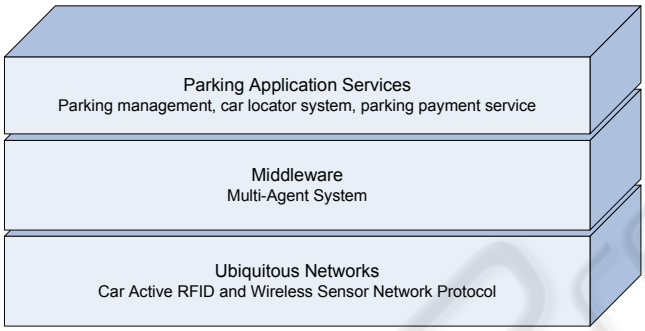

Fig. 2. Framework for the ubiquitous parking management system consisting of three layers; application services, middleware and ubiquitous network

3.1 Rule Base Adaptive Module of FWS

Wireless sensor devices are used for the car presence detection. A sensor module is consisted of several sensors like light, temperature and humidity to process in the fuzzy inference system (FIS). The fuzzy set concept was conceived by Lotfi Zadeh is mostly used by intelligent controllers because the way it handles imprecise values and smooth transition of changing fuzzy values. The FIS is composed of fuzzifier, fuzzy rules and defuzzifier. Fuzzifier is an interface for the input where maps the numeric input to the fuzzy sets and fuzzy rules. FIS applies the inference mechanism to the set of rules using the membership function. Lastly, the crisp value is determined by defuzzifying method. This paper proposes the fuzzy wireless sensor where the FIS is encoded inside the module of the wireless sensors device shown in Figure 3. The inputs of a single sensor module are processed by FIS and send the output value to sink node. The FIS of the proposed fuzzy wireless sensor adapts the rules from adaptive rule base module in the sink node. Aside from the sensor that detects car presence, there are additional sensors assigned to sense the changes in the environment of car parking area. The inputs from these sensors are processed on the adaptive rule base module to change the FIS value of each fuzzy wireless sensor. Rules from the module are configured by expert base on the parking environment where weather conditions that can affect the sensor readings are considered.

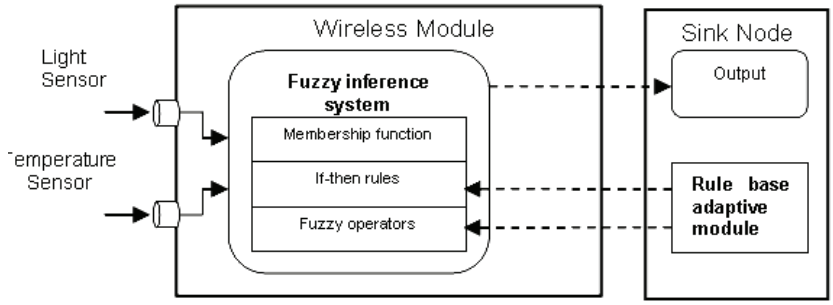

Fig. 3. The proposed fuzzy wireless sensor consists of fuzzy inference module.

Procedure of the FIS. This research uses the sensor inputs (S_i) in a single module to process in the FIS. The S_i, refers to sensor input value, where i is the index of the input. The values gathered at the same time, t_n={ S_1, S_2,…, S_i}, and processed in the FIS to determine the presence of the car represents as c. Two input parameters are defined for the fuzzy rules of the FIS shown in Table 1.

Table 1. Fuzzy rules used in the proposed fuzzy wireless sensor.

Rule	Temperature (S_1)	Luminance (S_2)	Car Presence (C)
1	Low	Dark	Not present
2	Medium	Dark	Not present
3	Low	Medium-bright	Not present
4	Medium	Medium-bright	Present
5	High	Medium-bright	Present
6	Medium	Bright	Present
7	High	Bright	Present

The S_1 and S_2 both have three linguistic values while the candidate has two linguistic values. The presence of the car is determined by processing the S_1 and S_2 in the FIS and then the value of the center of gravity, c_i, is determined to decide the state of the car presence. The car presence function, *CarPresence*(c_i), is consist of input variables, input(c_i), state(present, absent), boundary(0.5), and returns the state. Equation 1 shows the conjunction of two variables process in minimum function used for mapping the rules in Table 1. Equation 2 calculates the deffuzzified value of a rule and Equation 3 presents the boundary condition to decide the state.

$$\mu_j = \mu_{A \wedge B}(x) = \min\{\mu_A(x), \mu_B(x)\} \tag{1}$$

$$c_i = \frac{\sum_{j=1}^{r} \mu_j \cdot s_j}{\sum_{j}^{r} \mu_j} \tag{2}$$

$$f(c_i) = \begin{cases} present & if\ c_i < boundary, \\ absent & if\ c_i > boundary \end{cases} \tag{3}$$

Adaptation of FIS. Extreme conditions in the car parking area could vary the values of the sensor readings. In this paper, an adaptive module for the proposed fuzzy sensors is implemented to adjust the values in the FIS. Fuzzy values are reconfigured based on the rules from the adaptive module of the sink node shown in Figure 3. The new configuration of the FIS correctly processes the inputs. Rules are defined by expert based on the conditions of the car parking where R=$\{R_1, R_2, \ldots, R_k\}$.

$$R_k = IF\ S_1\ is\ A_1\ AND, \ldots, AND\ S_k\ is\ A_k\ then\ \Sigma_k \tag{4}$$

The outcome of the rule in Equation 4 (Σ) consists of fuzzy sets center value (σ_l) and expressed by $\Sigma=\{\sigma_1, \sigma_2, \ldots, \sigma_l\}$. These values are sent in wireless transmission method. Each center value is used to calculate the fuzzy sets shown in Equation 5. The x is the index and, A, B, C are the minimum, center and maximum values of fuzzy set x, respectively. The procedure of Equation 5 is done in the proposed fuzzy wireless sensor.

$$\begin{aligned} B_x &= \sigma_x; \\ A_x &= \begin{cases} C_{\min} & if\ x = 1, \\ \sigma_{x-1} & else \end{cases}; \\ C_x &= \begin{cases} C_{\max} & if\ x = last\ index \\ \sigma_{x+1} & else \end{cases}, \end{aligned} \tag{5}$$

4 Implementation in UPMS

Our design of the ubiquitous parking management system (UPMS) uses wireless sensor motes which is a 2.4 GHz IEEE 802.15.4 compliant RF transceiver. The primary model of WSN uses a flooding technique and focuses on the adaptive sensing function. The proposed fuzzy wireless sensor and rule base adaptive module is implemented in the ubiquitous parking system simulator. The FIS of the fuzzy sensor is coded and designed in nesC, which is a programming language for wireless sensors, and the rule-base adaptive module is programmed in Java. This paper focused on the flexibility of the program to interact with other program and is the main reason of using Java.

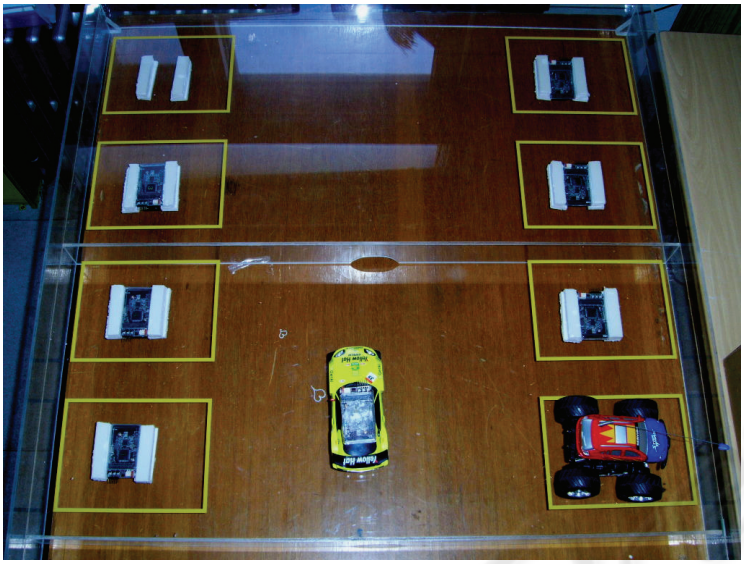

Fig. 4. The ubiquitous parking management system simulator with wireless sensors nodes and car model.

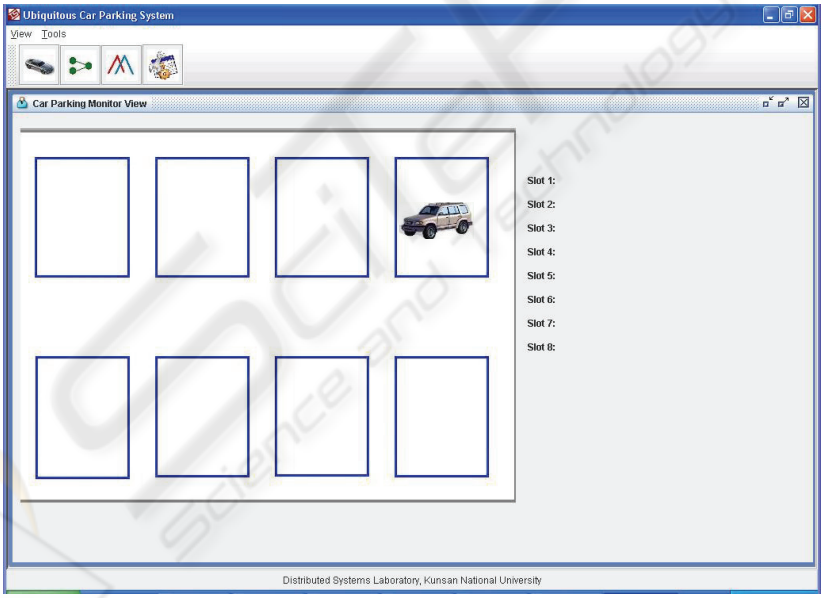

Fig. 5. The parking program simulator displays the output from the platform.

The interaction of the parking simulator is presented in Figure 4 and 5. In Figure 4, a car parked in a slot and is detected by the fuzzy wireless sensor under the slot. The values from sensor reading are processed in the FIS of the proposed fuzzy wireless sensor. The car parking platform is consisted of 8 slots embedded with wireless sen-

sors. A sink node is used in communicating with the wireless sensors and gathering of the data from sensor readings. In Figure 5 is an output display from the car parking platform. The output value from fuzzy wireless sensor is sent directly to the sink node. The output display is updated every second and the values are stored in the database. Also, the rule base adaptive module is executing at the same.

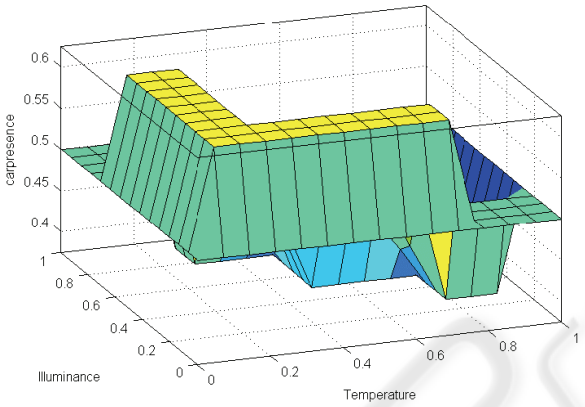

Fig. 6. The graphical presentation of membership function transitions for the illuminance and temperature to detect the car presence.

The fuzzy system from wireless sensors classifies the input from sensors and in Figure 6 presents the transition of membership values to classify the car presence based on illuminance and temperature. Our approach is scalable and classifies more input values compared to other research like using magnet sensors [6] which only used one sensor to detect car presence. It is also possible to use non-linear system to solve the classification problem on car presence detection but computational costly to perform in sensor devices. This also means using more input sensors obtains accurate readings from sensors. Moreover the adaptive module is design to adjust the readings and provide new pattern of detecting the presence of car.

5 Conclusions and Future Works

This paper proposes the adaptive sensing using fuzzy wireless sensor to implement the efficient ubiquitous networks in the parking management system. The proposed fuzzy wireless sensor is designed to process the raw data of the sensor using fuzzy inference system for efficient car presence detection. Moreover, an adaptive module is presented to adapt on new rules set by an expert. The proposed fuzzy wireless sensor is implemented in the ubiquitous parking management system simulator.
The future work will be defining the functions of application services and middleware components of the UPMS. Improvements on communication protocols for the fuzzy wireless sensor will be considered and also, additional ubiquitous devices needed to be implemented are the next topic.

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