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Model Based WSN System Implementations Using PN-WSNA for Aquarium Environment Control in a House

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1. Introduction

Ubiquitous computing architectures are implemented for cognitive sensor networks. Wireless sensor networks cooperating with cognitive science and artificial intelligence are used to develop cognitive sensor networks (Shenai et al., 2008). Therefore, a cognitive sensor network is generally represented as a closed loop control system (Ruiz et al., 2008), where the feedback data is collected from remote sensor nodes. At the same time, the control approaches are desired to deal with regulations of desired operation scenarios and sensor feedbacks.

Wireless sensor networks (WSN) (Romer et al., 2004; Akyildiz et al., 2008) are developed using autonomous sensor nodes (Dalola et al., 2009) to collect remote sensor data for decision systems with low power consumptions and failure tolerable mechanisms. In general, the WSN system can be applied to the factory automation (Zhuang et al., 2008), intelligent diagnosis (Zhuang et al., 2008), intelligent monitoring and control systems (Sridhar et al., 2007), smart home (Suh et al., 2008), etc. Practically, the challenging issues for developing WSN systems are large amounts of coding and program maintenance efforts for various sensor oriented applications as well as interdisciplinary integrations of domain engineers and WSN engineers.

For the first issue, diverse control and decision scenarios in a WSN system are developed for different sensor nodes. The coding and maintenance for large scale WSN systems would be huge challenges. The second issue is the problems of interdisciplinary integrations. Coding for sensor nodes is a challenge for domain engineers who are not familiar with programming. According to aforementioned challenging issues, model based system implementation approaches are proposed to eliminate the efforts for programming native codes with cross compilers.

In order to perform model based implementation approaches, several discrete event dynamic system (DEDS) modeling approaches are surveyed, such as finite state machine (FSM) (Avnur et al., 1990), unified modeling language (UML) (Manasseh et al., 2010) and Petri net (PN) (Murata et al., 1989; Kuo et al., 2009). The Petri net (Murata et al., 1989) was proposed by C.A. Petri. A PN model may model the system using events and conditions. Events are represented as transitions; conditions are represented as places. Arcs are used to describe pre- and post-conditions between places and transitions. In general, an autonomous sensor node can be also described as conditions, events, and their relationships. Sensor events are generated in terms of the changes of sensor conditions.

Although the PN is suitable for modeling a WSN, the ordinary PN is not applicable due to the lack of interfaces and intercommunications. Therefore, the Petri net based wireless sensor node architecture (PN-WSNA) (Kuo et al., 2009) is selected in this book chapter to model an aquarium environment control in a house. Interface functions are desired for collecting sensor data and controlling actuators. Intercommunication functions provide wireless data exchanges among different autonomous sensor nodes. In our approach, the PN-WSNA system is composed of a PN-WSNA kernel program and a PN-WSNA management program. The PN-WSNA kernel program is developed as an inference engine which is implemented inside the sensor node. The PN-WSNA kernel program is responsible of receiving and interpreting PN-WSNA models, collecting sensor data from analog and digital channels, intercommunication between sensor nodes, PN model inference, decision making, and controlling actuators.

In this book chapter, the Petri net based wireless sensor node architecture (PN-WSNA) (Kuo et al., 2009) is used to construct an aquarium environment control system in a house. This aquarium environment control system demonstrates the modelling and implementation procedures for two PN-WSNA sensor node systems, where one sensor node is deployed for aquarium environment control and the other one is desired for entrance counting system. The entrance counting system counts the people in a house. The aquarium environment control system acquires the data from temperature sensor and dissolved oxygen sensor as well as the people number collected from the entrance counting system. Meanwhile, the light, heater and pump are also activated using the sensor node. As a consequence, the aquarium environment control system is capable of autonomously controlling the temperature and dissolved oxygen concentration in a desired condition. In addition, the light can also be controlled in terms of the presence of people in a house.

2. PN-WSNA Definitions

In this book chapter, the PN-WSNA is developed by inheriting the definitions of the ordinary PN. In order to deal with real-time sensor data acquisitions, intercommunications and actuator controls, additional interface and intercommunication places are defined based upon the ordinary PN for practical cognitive sensor network applications. In addition to the interface and communication places, periodic executions of the system are also defined using timed transitions. The sensor data is further categorized as high enable and low enable situations. Therefore, the PN-WSNA structure is a eleven-tuple, $PN-WSNA = (P, P_s, P_{ci}, P_{co}, P_a, T_0, T_t, T_H, T_L, I, O)$ structure; where P is a finite set of normal places; P_s is a finite set of

sensor places; P_{ci} is a finite set of receiver places; P_{co} is a finite set of transmitter places; P_a is a finite set of actuation places; T_0 is a finite set of immediate transitions; T_t is a finite set of timed transitions; T_H is a finite set of high-enable transitions; T_L is a finite set of low-enable transitions; I is the input function; and O is the output functions. The PN-WSNA graphical definitions are shown in Fig. 1. The PN-WSNA definitions are further elaborated as follows.

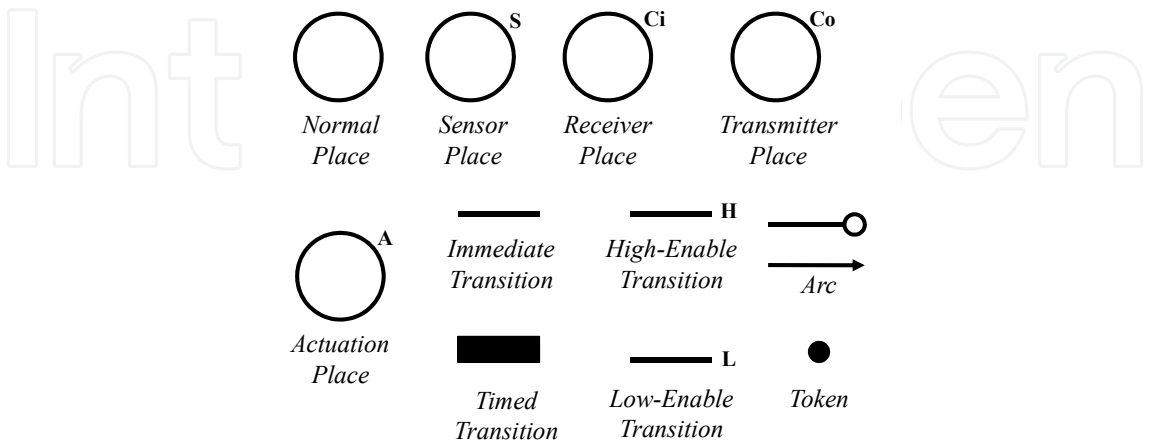


Fig. 1. PN-WSNA graphical definitions.

- I. Place: $P = \{p_1, p_2, p_3, \dots, p_n\}$: P is a finite set of places, $n \geq 1$, and it is denoted a circle. Places of the PN-WSNA are refined as normal places, sensor places, receiver places, transmitter places, and actuation places. Brief introduction is defined as follows. Detailed definitions may refer to (Kuo et al., 2009).
- a. Normal places: the definition of a normal place is the same as the place defined in the ordinary PN. Tokens in normal places may represent the corresponding status, condition, command, etc.
 - b. Sensor places: A sensor place is desired for data collections. For a PN-WSNA, the sensor place may collect sensor signals in terms of analog value (0 – 3 V), binary digits (0 and 1), or serial communication packets (0 – 255) manners, and the sensor data of a place (p_i) is denoted as $\eta(p_i)$. A sensor interface is required to be corresponded to an analog-digital-converter (ADC) address, a generalized input-output (GIO) address or the universal asynchronous receiver /transmitter (UART). Because the PN-WSNA does not define the color token (Kuo et al., 2003), the sensor status is eventually represented as “high” or “low” status. Hence, a threshold value is defined for the sensor place to divide the analog value into “high” or “low” status, and the threshold value of a place (p_i) is denoted as $\phi(p_i)$.
 - c. Receiver and transmitter places: With the PN-WSNA, a receiver place and a transmitter place can be combined as a communication pair, and they appear in different sensor node models. Hence, the transmitter place is a sink place (Kuo et al., 2009); and the receiver place is a source place (Kuo et al., 2009).
 - d. Actuation places: The actuation place play similar roles to transmitter places; however, the token in an actuation place are converted as actuation signals to control peripheral devices. As a consequence, an actuation place is a sink place, any token in an actuation place may directly control peripheral devices and then the actuation place releases this token.

II. Transitions: $T = \{t_1, t_2, t_3, \dots, t_m\}$: T is a finite set of transitions, $m \geq 1$, and it is denoted a bar.

Transitions of the PN-WSNA are further refined as immediate transitions, timed transitions, high-enable transitions, and low-enable transitions. Detailed definitions are illustrated as below:

- a. Immediate transitions: the definition of an immediate transition is the same as the transition defined in the ordinary PN, and it can be used to model events and decisions.
- b. Timed transitions: the definition of a timed transition is similar to the transition defined in the ordinary PN; however, tokens in the input places of a timed transition do not deliver to its output places directly. Instead, a fired transition keeps these tokens until a predefined elapsed time is expired. Therefore, an elapsed time factor is further defined for the timed transition.
- c. High-enable and low-enable transitions: high-enable and low-enable transitions are defined for sensor places. Basically, high-enable and low-enable transitions serve as output transitions of a sensor place. They must be appeared in a pair configuration; hence conflicts of these transitions are happened. The firing of conflict high-enable and low-enable transitions depends on the sensor data and threshold value defined in the input sensor place. A high-enable transition is fired when the sensor data is greater than or equal to the threshold value defined in the input sensor place; and a low-enable transition is fired when the sensor data is less than the threshold value defined in the input sensor place.

III. In a PN-WSNA model, the places and transitions follow the rules of $P \cap T = \emptyset$, and $P \cup T \neq \emptyset$.

IV. Token, marking and initial marking: tokens are quantitative representations of bag set in places. The marking is denoted as μ , which represents the token distributions in all places of a PN-WSNA model. μ is a $q \times 1$ column vector, the j -th element of μ indicates the number of tokens in place j . Note that q is a nonnegative integer, and it is equal to the number of places in a PN-WSNA model. The initial marking (μ_0) is defined for the marking of system startup.

VI. Input, output functions, enabling and firing: input and output functions are defined via directed arcs graphically, and they are represented as $I(p_i, t_j) \rightarrow N_{i,j}$ and $O(p_r, t_s) \rightarrow N_{r,s}$, respectively. $N_{i,j}$ and $N_{r,s}$ are nonnegative integers, and they defines the pre- and post-conditions of the PN-WSNA models. In this study, directed and inhibited functions are further defined. A transition (t_j) is said to be enabled when (1) satisfies.

$$\prod_{i=1}^k (I(p_i, t_j) - N_{i,j}) > 0 \quad \text{and} \quad \prod_{i=1}^k (I(p_i, t_j) - N_{i,j}) < 0 \quad (1)$$

where $i = 1$ to k , and k equals the number of input places of t_j ; $p_i \in$ input places of t_j with directed arcs.

At the same time, an enabled transition is not necessarily to be fired because of the conflict situations. The conflict exists when the number of enabled transitions for a place is greater than unity. With a conflict situation, only one of the enabled transitions can be fired. For the PN-WSNA, conflict transitions are resolved in terms of the following approaches.

- a. Immediate and timed transitions: Random selections of an enabled and conflict transitions are desired for immediate and timed transitions because of identical token and transition characteristics.
- b. High-enable and low-enable transitions: to resolve the conflict situations of a pair of high-enable and low-enable transitions, the sensor data, $\eta(\text{pi})$, and threshold value, $\varphi(\text{pi})$, are evaluated for the same input place (pi). A high-enable transition is fired if (2) satisfies.

$$\eta(\text{pi}) \geq \varphi(\text{pi})$$

(2)

Meanwhile, a low-enable transition is fired if (3) satisfies.

$$\eta(\text{pi}) < \varphi(\text{pi})$$

(3)

3. PN-WSNA Based Aquarium Environment Control System

3.1 System Descriptions

To verify the proposed PN-WSNA approaches, an aquarium environment control system is implemented. Fig. 2 shows the facilities used in this experiment. An aquarium is the major environment for this study. A dissolved oxygen meter (with type: DO-5510 from Lutron Co. Ltd.) is used for measuring the dissolved oxygen concentration and the temperature as well in the water. In addition, two infrared human motion detection sensors are used for detecting the entry and exit of visitors. In case of insufficient dissolved oxygen concentration in the water, a pump is activated for increasing the dissolved oxygen. The pump stops when the dissolved oxygen concentration satisfies the setting conditions. On the other hand, in case of low temperature in the water, a heater is also activated for increasing the temperature in the water. Similarly, the heater stops when the water temperature satisfies the setting conditions. It is noted that hysteresis ranges are desired for the activation and termination conditions with respect to their threshold values.

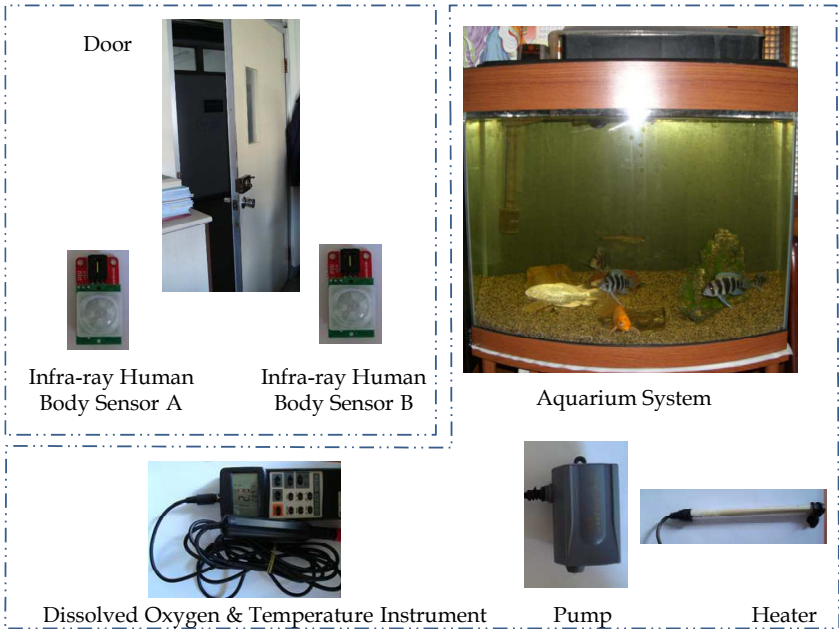


Fig. 2. PN-WSNA model construction architecture.

Two sensor nodes are cooperated to control the proposed aquarium system. PN-WSNA models are implanted inside two sensor nodes to autonomously control aquarium environment system. Fig. 3 shows the architecture this system, respectively. The functions in our system are elaborated as follows.

1. Dissolved oxygen control: The concentration of dissolved oxygen is important for aquarium environment. In general, adequate concentrations of dissolved oxygen depend on the species of fishes. In our system, concentrations of dissolved oxygen are desired for our experiment with 4.5 mg/l. The value of concentration of dissolved oxygen is collected from dissolved oxygen sensor. This sensor can transmit the packets of concentration of dissolved oxygen and temperature via RS-232. In here, an AVR micro-controller is used to collect the data, and then converted it into analog signals (DAC) to meet the interface requirements of the PN-WSNA (ADC). The signal would be transmitted in to Mote-1 via ADC port. If the sensor value is less than 4.5 mg/l, the pump will switch on for increasing concentration of dissolved oxygen. On contrary, if the sensor value is greater than 5.0 mg/l (0.5 mg/l hysteresis range), pump will switch off. The control scenario is shown in Fig. 4.
2. Temperature control: The working process of temperature is similar to concentration of dissolved oxygen. The lower threshold of temperature is 25°C; and the upper threshold of temperature is 27°C. The corresponding action is used to turn on / off the heater. The control scenario is also shown in Fig. 4.
3. Light control: Light control in our system depends on the number of visitors in the house. Counting the number of visitors is realized by comparing the rising edges of two Infra-ray human detection sensors. The control scenario is also shown in Fig. 4.

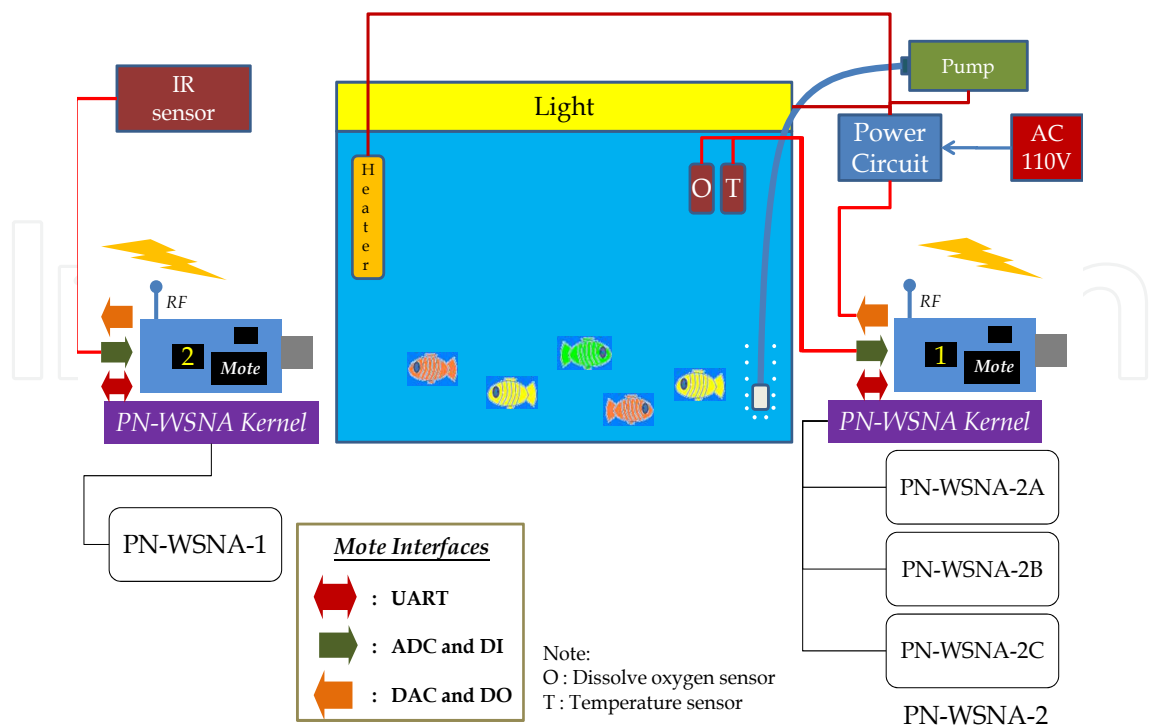


Fig. 3. System architecture of the proposed aquarium system.

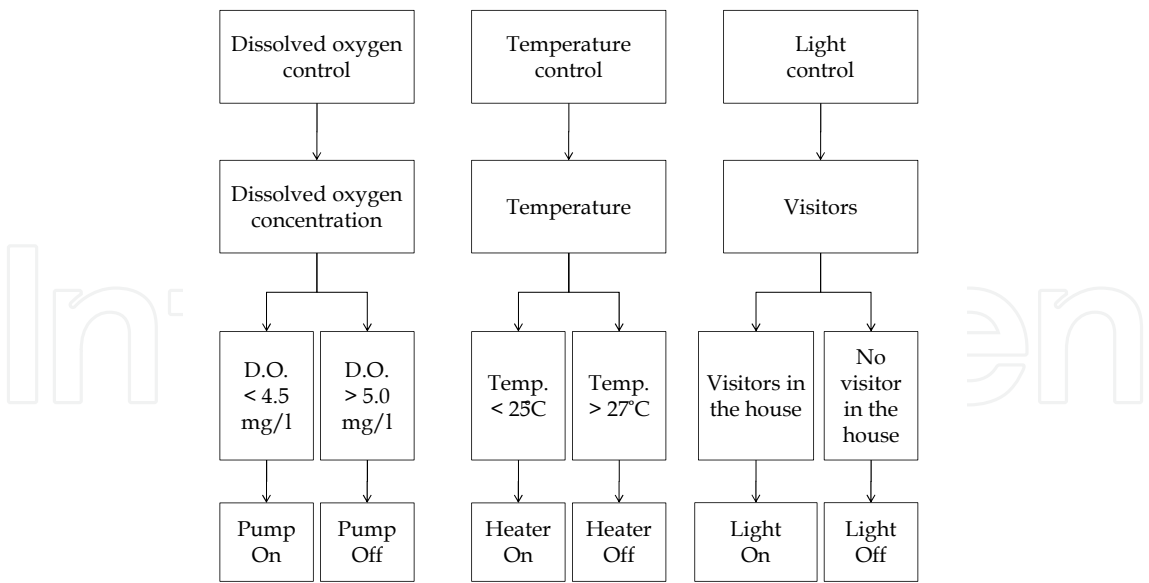


Fig. 4. System operation control scenario.

3.2 PN-WSNA Integrated Development Environment

In order to construct the PN-WSNA models, an integrated development environment (IDE) for constructing the PN-WSNA model is developed. The WSN developer may construct their domain-based PN-WSNA models by using the IDE, and then simulate the PN-WSNA models using the IDE to verify their models before these models are deployed. The PN-WSNA system is composed of the PN-WSNA kernel program and a PN-WSNA management server. Fig. 5 shows the PN-WSNA system implementation architecture. The management server is composed of an IDE which provides a graphical user interface for the domain engineers to construct or modify their PN-WSNA models. At the same time, the databases are also constructed for recording the PN-WSNA models and route tables of sensor nodes. The route tables are used to explore a specific route path for delivering PN-WSNA models to a remote mote in terms of wireless media.

On the other hand, the kernel program is implanted inside a sensor node. In addition, radio frequency (RF) interface with Zigbee protocol (IEEE 802.15.4) as well as physically connected interfaces of UART, ADC, DCA, digital input (DI) and digital output (DO) are also available for cognitive sensing and controls. It is noted that the PN-WSNA IDE is realized using the Microsoft visual C++ and the nesC (Avvenuti et al., 2007) program is used to implement the kernel program.

The PN-WSNA IDE is a plug-and-play model construction environment. Fig. 6 shows the proposed IDE, and the toolbar icons are used for model constructions, editing, revisions, manipulations, run-time simulations, model drawing auxiliaries as well as model deliveries. Detailed descriptions of the tool bars and algorithms for implementing the PN-WSNA inference engine are referred to (Kuo et al., 2009). Finally, the interface functions are coded within the kernel program. Fig. 7 shows the I/O, ADC, DAC and communication interfaces of PN-WSNA motes. The mote is capable of collecting sensor status and actuating the actuators using the sensor interface. At the same time, PN-WSNA motes may also

communicate with each other to deliver tokens among different PN-WSNA motes so that distributed decisions can be achieved.

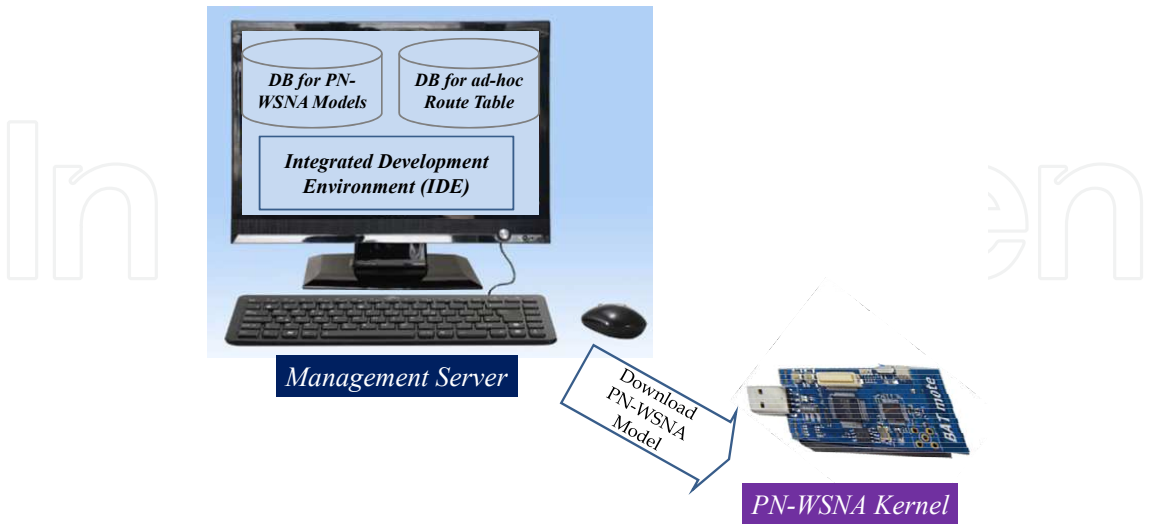


Fig. 5. PN-WSNA model construction architecture.

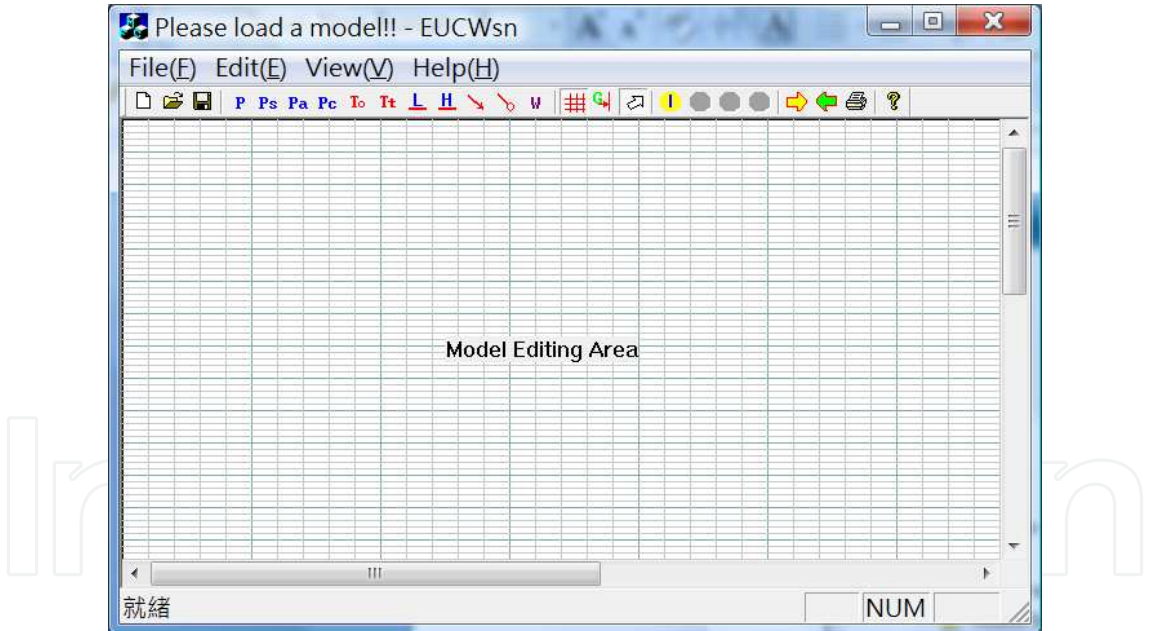


Fig. 6. PN-WSNA IDE workspace.

3.3 PN-WSNA Models

In this subsection, the PN-WSNA models for the proposed aquarium system are presented. These PN-WSNA models are implemented using two PN-WSNA motes. Two motes are communicated via the Zigbee for the delivery of tokens in the corresponding communication places. The proposed overall PN-WSNA architecture was shown in Fig. 3, where PN-WSNA-1 is desired for the entrance counting system using a PN-WSNA mote;

and PN-WSNA-2 is desired for the temperature, dissolved oxygen concentration, and light control system using another PN-WSNA mote.

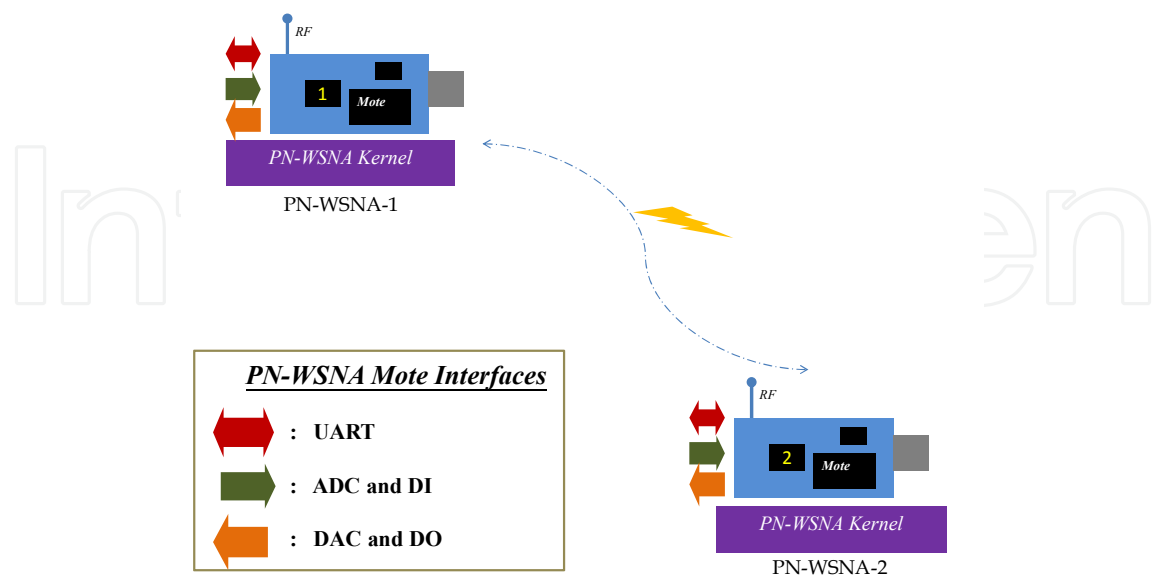


Fig. 7. Interfaces of PN-WSNA motes and their communications.

The first PN-WSNA model (PN-WSNA-1) is an entrance visitor counting and light control system. Fig. 8 shows this model. It is can be classified into three parts, including rising edge detections of two infrared human motion detection sensors, event sequence determinations and light control command generations. For the rising edge detection of an infrared human motion detection sensor, two conditions are considered for pulses generated from each infrared human motion detection sensor including the signals from low-to-high and high-to-low TTL voltage level. The second part is desired for recognizing activated event sequences of two infra-ray sensors (A and B). When infra-ray sensor A is activated first, it means a visitor entering the house. Contrarily, if sensor B is activated first, it means a visitor exiting the house. The last one part is to determine the total number of visitors. If the number of visitors is greater than or equal to one, a command with “turning on the light” is generated; otherwise, a command with “turning off the light” is generated. Because the light is installed a far away mote (PN-WSNA-2), two communication places are desired to transmit the tokens for these light control commands in PN-WSNA1.

For the rising edge detections of two infrared human body sensors model, two similar sub-models are shown first in the left-hand side of the Fig. 8. P001 and P010 indicate the availability of each sensor. T001 and T011 are timed transitions for periodic sampling of the sensors. P003 and P012 indicate the ready signals of sensors A and B, respectively. When the sensor places are ready, the sensor data will be attached within the corresponding places. T002 and T012 are low-enable transitions; T003 and T013 are high-enable transition, and they are used to percept sensor data as high or low status. P004 and P013 indicate the conclusions of low-enable transitions of T002 and T012; P005 and P014 indicate the conclusions of high-enable transitions of T003 and T013. T005, T007, T015 and T017 have the higher priority compared with T004, T006, T014 and T016. It is noted that, the places P006, P007, P015 and P016 are safe (i.e., boundedness with unity token) to keep the current high/

low level status of the sensor. Once the high and low status are both detected (i.e., both P006 and P007 have tokens), the system detects a high/ low level change event. At this moment, the T009, T010, T019 and T020 are used to detect the rising or falling edge event of the sensor in terms of its current level (sensor place P009; the same sensor as P003). For example, if a level change event is detected and its current level is high, then the rising edge from a low-level to high-level voltage would be concluded. It is noted that, only the rising edges (T010 and T020) are used in this project.

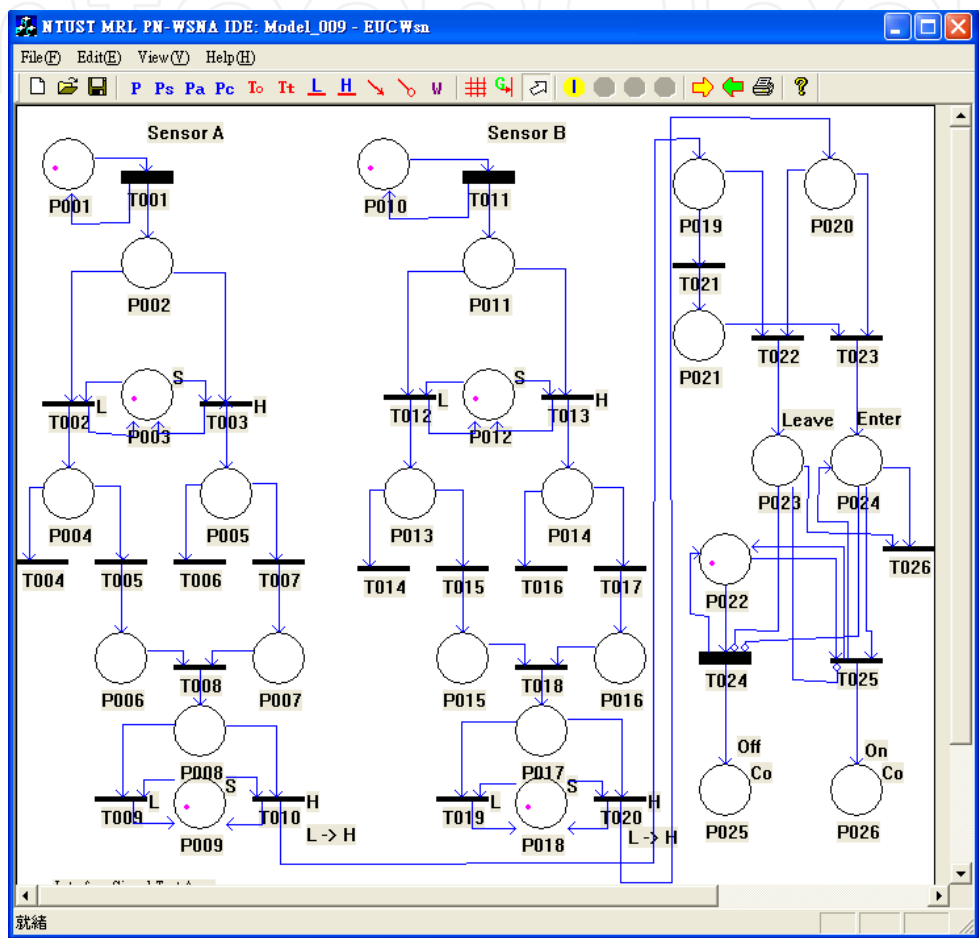


Fig. 8. PN-WSNA model for entrance visitor counting and light control system.

The second part covers the places of P019 - P021 and the transitions of T021 - T023. P019 and P020 represent the rising edges of sensors A and B, respectively. The token arriving sequences determine the entering and exiting events of visitors. If a token arrives at P019 and there is not any token in P020, then the system detects a visor passing through sensor A first. In this situation, the token would enable and fire T021, and then the token enters P021. Once, a token arrives at P020 the T023 will be enabled and fired. As a consequence, a token will be released to P024. On the other hand, a leaving visitors can also be defined similarly. For the case of leaving visitors, token(s) will enter P023.

The remaining part is the light control system. In this sub-model, the tokens in P024 indicate the total number of visitors in a home. The token number would be decreased if a visitor

leaves the home (P023). Therefore, the third part of this model realizes such a scenario. If there is no visitor in the home, inhibit arcs from P023 and P024 with respect to T024 would not be inhibited. In this situation, the token in P022 would periodically enable and fire T024 and then the token enters to the transmitter place P025 for delivering tokens to another mote. For another situation, if any visitor is in the home, token(s) would be appeared in P024. Inhibit arc from P024 for T024 would inhibit the activation of T024. For this situation, the token would enable and fire T025, and then the token enters to the transmitter place P026 for delivering tokens to another mote. Other situation is the case of leaving visitors. In this situation, token(s) would be appeared in P023 and P024 as well. Because of using inhibited arcs, the token will enable and fire T026 only.

The second PN-WSNA model (PN-WSNA-2A) is desired for temperature control in our system, as shown in Fig. 9. For conventional temperature control systems, the threshold is setting for turn on and off to modulate the temperature. In order to reduce the switch turn on and off frequency, a hysteresis temperature is desired. In our PN-WSNA, high-enable transition and low enable transition are created. The activation thresholds are defined using specific values. Because of the conflict between high-enable transition and low enable transition, the only one transition would be enabled by comparing the sensor data. In order to create the hysteresis voltage range, two threshold values for upper and lower bounds are desired in this model.

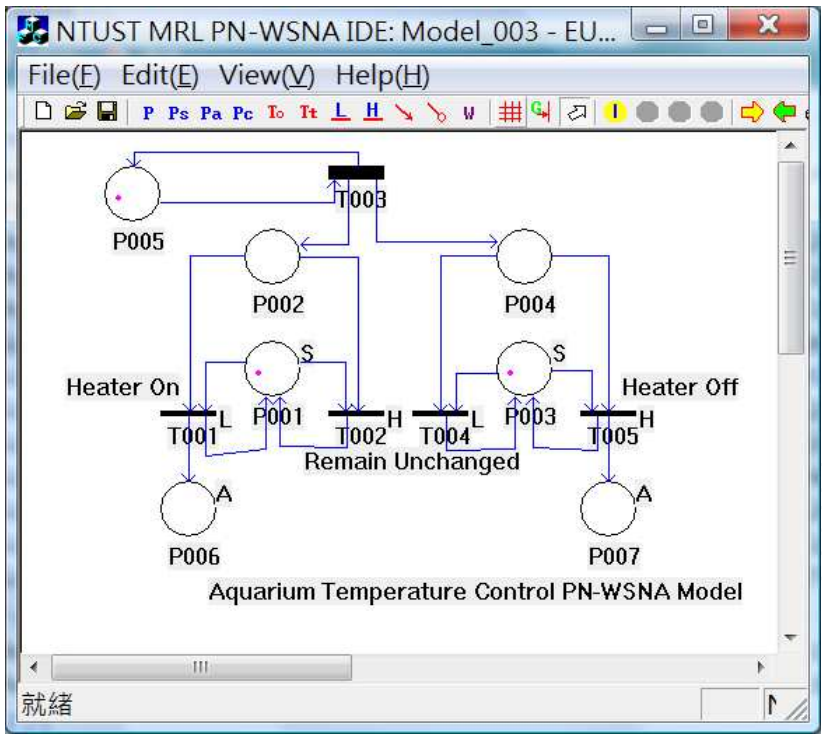


Fig. 9. PN-WSNA model for temperature control.

Two sensory places with the same sensor device and signal as well as two high-enable transitions and low-enable transitions are used in our approach. In this model, P005 indicates the availability of aquarium system. P002 and P004 indicate the ready signals of the temperature sensor. P006 and P007 is the actuation place for turning on and off of the

heater. Three tokens are initially assigned to these places for the initial marking. A timed transition (T003) is desired for the periodically sampling and control of this model. If the firing time of T003 is expired, a token in P005 will initiate a decision process. T001 and T004 are low-enable transition; T002 and T005 are high-enable transition, and they are used to percept sensor data as high and low status. Specially, the two different thresholds are defined in the sensory place P001 and P003 for hysteresis ranges. The threshold in sensory place P001 is the lower one. Hence, if data in sensory place P001 is below the threshold, the transition T001 is enabled and then the corresponding actuation place will turn off the heater. The activation of then sensory place P003 is similar with sensory place P001. Therefore, the two thresholds for control the heater is done by aforementioned process. On the other hand, the PN-WSNA model for dissolved oxygen (PN-WSNA-2B) is similar to the temperature model, and it just needs to adjust the threshold of sensory places as specific values. Then, this model can turn on and off of the pump in terms of actuation places.

The last PN-WSNA model (PN-WSNA-2C) is desired for communication between two motes so that the lighting device at a remote mote can be controlled. P001 in PN-WSNA-2C is corresponded P026 in PN-WSNA-1; and P002 in PN-WSNA-2C is corresponded P025 in PN-WSNA-1. Once the receiver place P001 receives a token and then the token would enable fire T001. This token will be released to actuation place P003. The corresponding action of P003 is “turning on the light”. The activation process of P004 is similar to P003 and the corresponding action of P004 is “turning off the light”. Fig. 10 shows the model of PN-WSNA-2C.

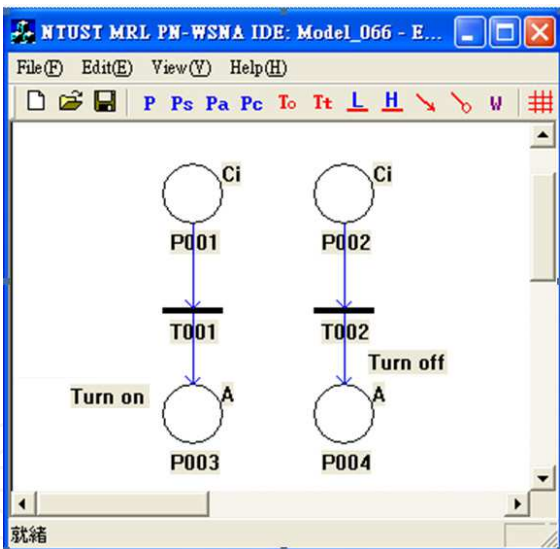


Fig. 10. PN-WSNA model for mote communication and control the light.

4. Experiments and Discussions

In this section, the experiment is proposed and discussed. At first, the initial marking of PN-WSNA-1 was shown in Fig. 8. Tokens are initially paaeared in the sensory places (P003, P009, P011 and P018) and the normal places (P001, P010 and P022). In here, an experimental example is proposed to describe the control procedures of light control system. A time chart of sensor signals with respect to two infrared human motion detection sensors of this experiment is shown in Fig. 11.

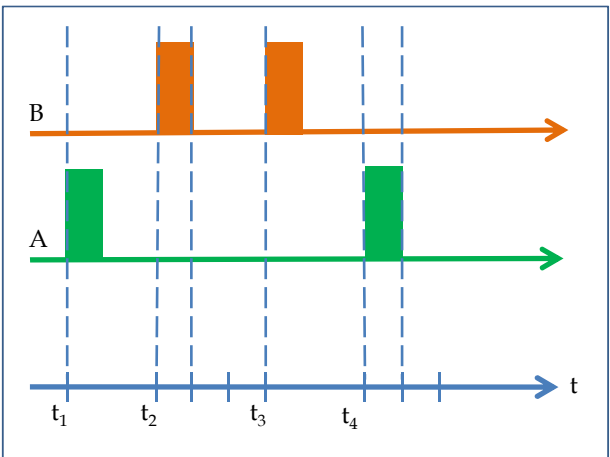


Fig. 11. Time chart of sensor signal

Initial signals of sensor A and B are both in low states before the time t_1 . For the sensor A, when time transition T001 is fired, the token enters P002. After token is appeared in P002, the sensory place P003 would enable and fire low-enable transition T002, and then the token enters P004. After that, T005 will fire and then the token transmits to P006. For the setting of safeness, the number of token in P006 is one maximally. The procedures of sensor B are the same as sensor A. The inference of PN-WSNA model for this part is shown in Fig. 12 (a) and Fig. 12 (b).

At the moment of t_1 , a high-level signal is generated from sensor A, and then high-enable transition T003 would be fired. The token would consequently enter P007, as shown in Fig. 12 (c). At that time, T008 is fired, and then the token enters P008, as shown in Fig. 12 (d). Because the signal is in a high state, signal from sensor A would enable and fire high-enable transition T010, and then the token enters P019, as shown in Fig. 12 (e). As a consequence, the token in P019 represents a low-to-high rising edge signal is detected, as shown in Fig. 12 (f). After an edge signal is detected from sensor A, token would enter to P021 for waiting edge signal which comes from sensor B, as shown in Fig. 13.

At the moment of t_2 , a high-level signal is generated from sensor B. Similar procedures will be executed, and consequently deliver a token to P020. In this situation, the sequence of sensory A and B are that A comes before B. Therefore, T023 is fired, and then the token enters P024 for presenting a visitor entering in the house. After that time, T025 is enabled and fired, and then the token enters the transmitter place P026 to send the command with “turning on the light” to mote-1. The inferences of PN-WSAN model is shown in Fig. 14.

W At the moment of t_1 , a visitor leaves the house, and then the corresponding signal of sensory B is activated first. In this situation, T022 is fired and then generates a token for presenting a visitor leaving the house. Then the token in P023 and P024 would be released accordingly. The inferences of PN-WSAN model is shown in Fig. 15.

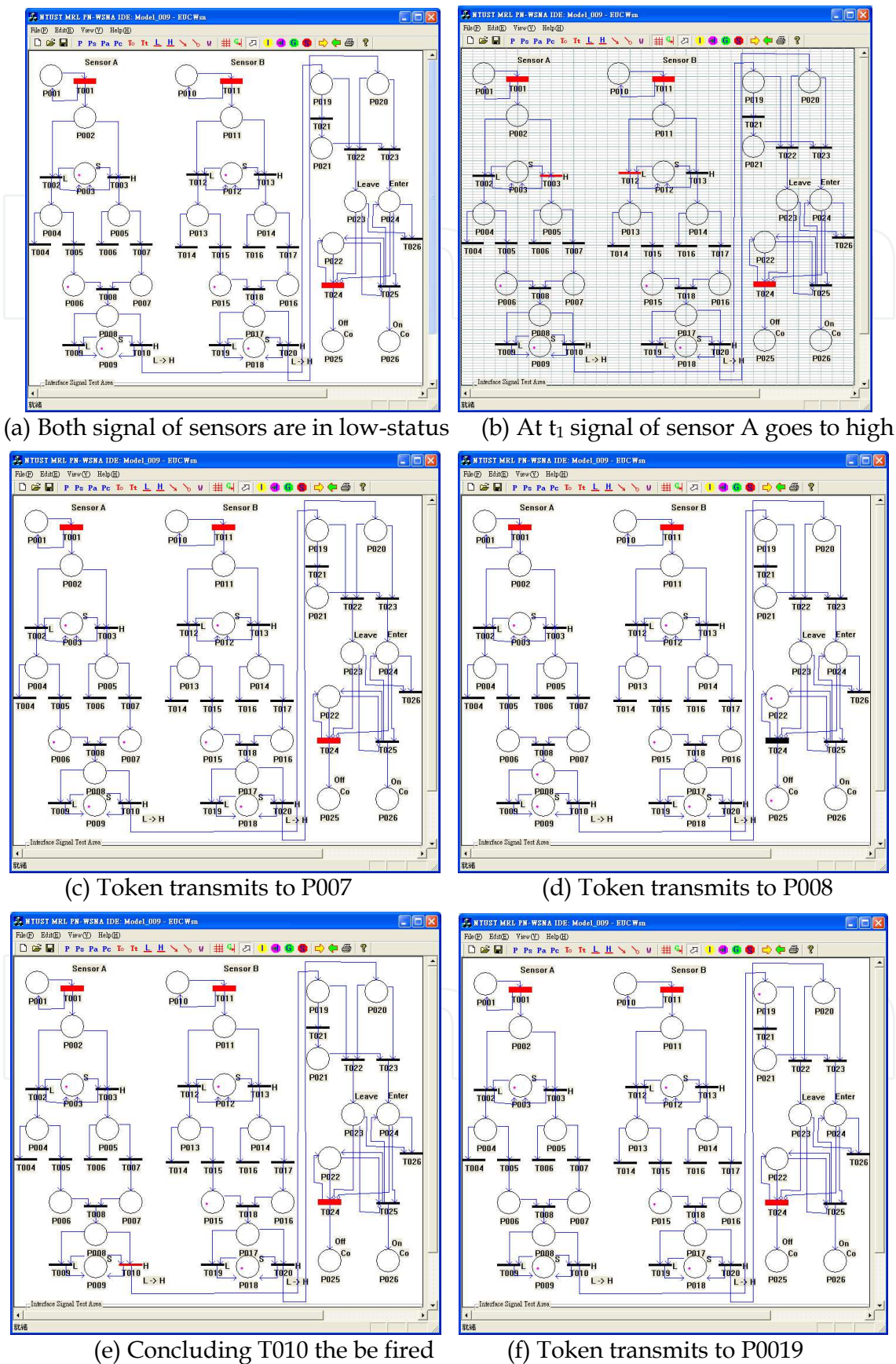


Fig. 12. Decision procedures of sensor A's signal (from low-to-high).

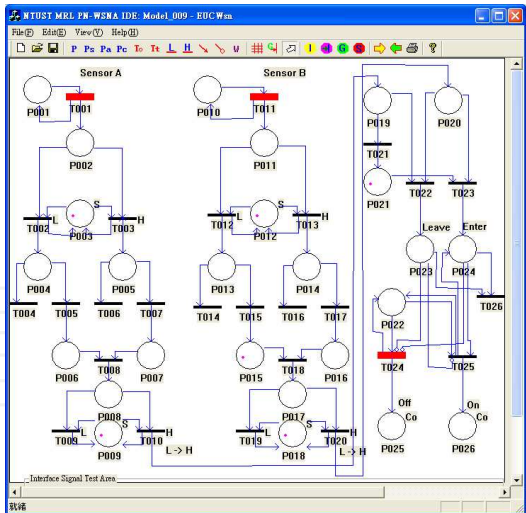


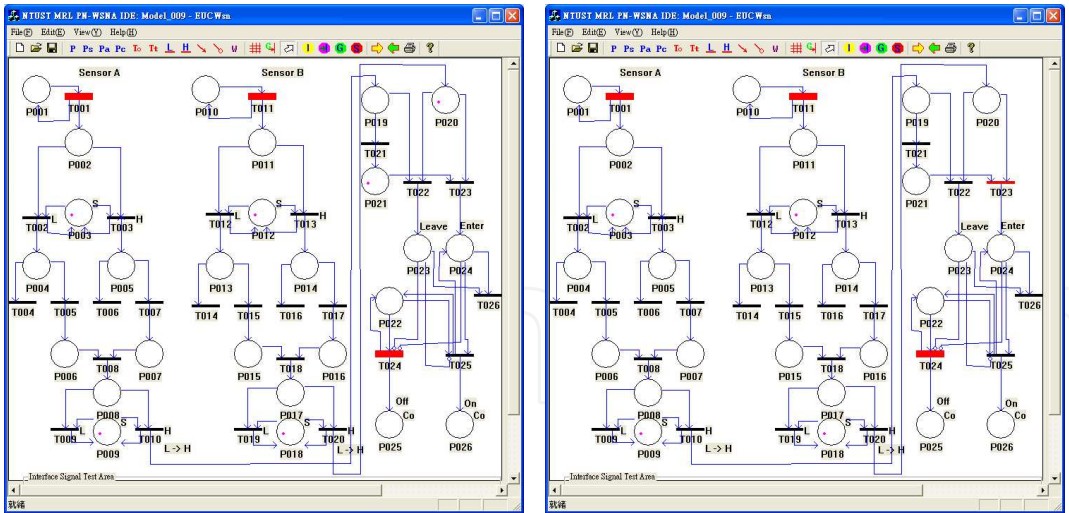
Fig. 13. Concluding rising edge status of sensor A.

5. Conclusions and Future Works

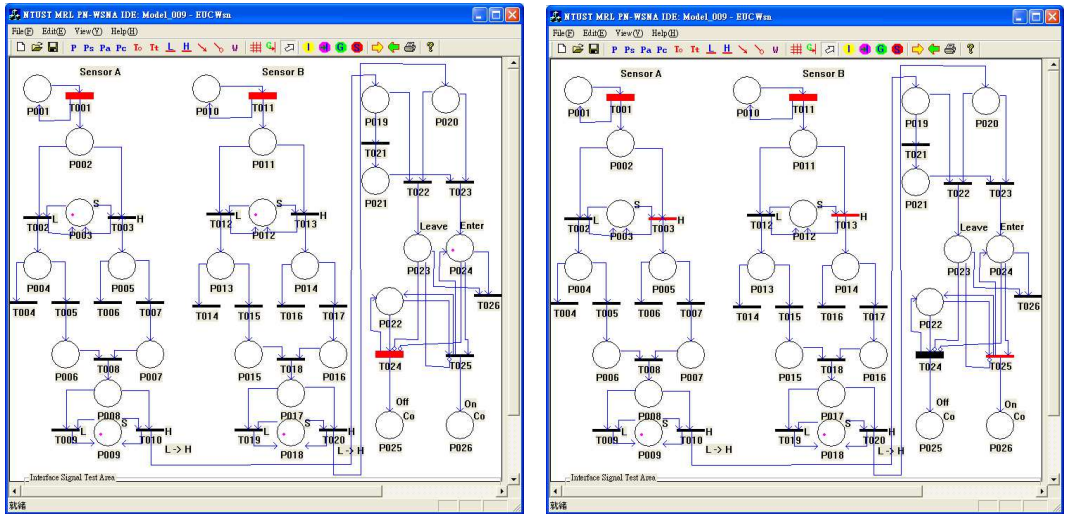
In this book chapter, the PN-WSNA is used to construct an aquarium environment control system in a house. The major advantages of using PN-WSNA are to use a model based WSN realization approach so that the coding efforts from domain engineers can be significantly reduced. In addition, the control scenarios can be verified in terms of the PN-WSNA simulations before the sensor algorithm are deployed. This book chapter use an aquarium environment control system to demonstrate the modelling and implementation procedures for two PN-WSNA sensor node systems, where one sensor node is deployed for aquarium environment control and the other one is desired for entrance counting system. Two PN-WSAN motes are communicated using the communication places of the PN-WSNA. The aquarium environment control system acquires the data from temperature sensor and dissolved oxygen sensor as well as the people number collected from the entrance counting system. Meanwhile, the light, heater and pump are also activated using the sensor node. In the future, the PN-WSNA will be used to construct more complicated WSN system to demonstrate the powerful modelling and control capability of the PN-WSNA.

6. Acknowledgement

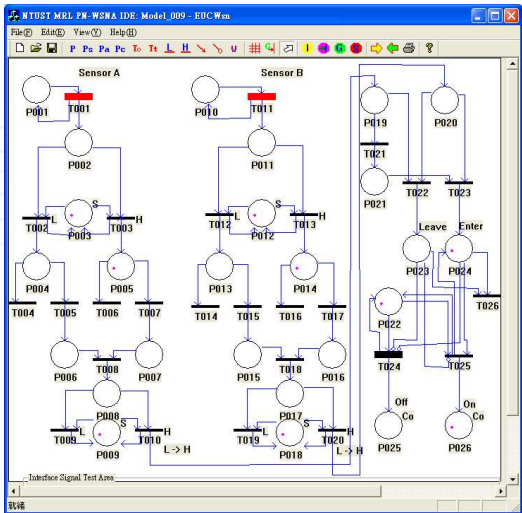
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(a) Rising edge detected from sensor B (P020) (b) A->B sequence determined



(c) Token enters to P024 (d) T025 enable fire



(e) Token enters to P026

Fig. 14. Concluding status of A->B sequence determinations.

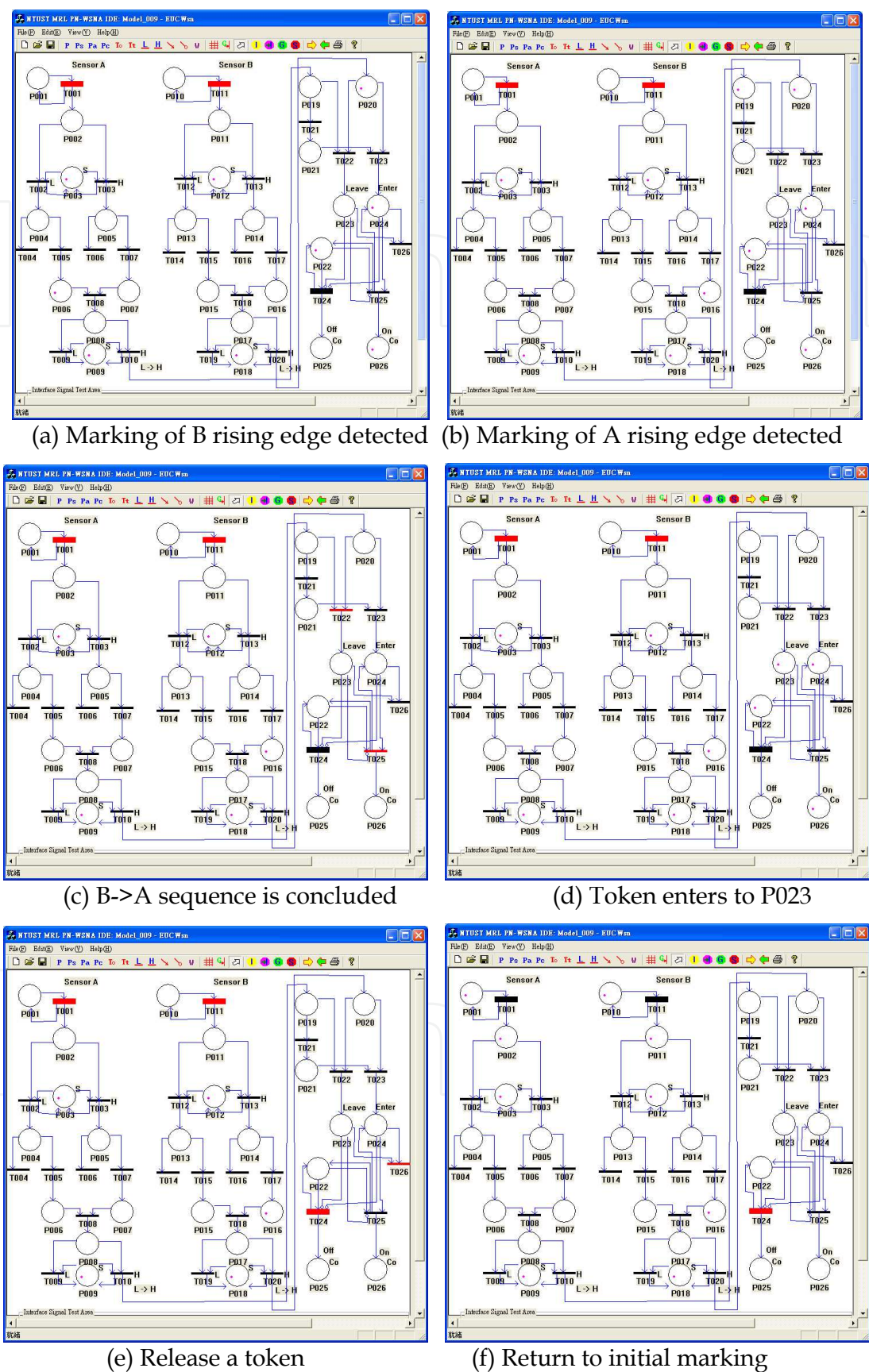


Fig. 15. Concluding status of B->A sequence determinations.

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Wireless Sensor Networks: Application-Centric Design

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Over the past decade, there has been a prolific increase in the research, development and commercialisation of Wireless Sensor Networks (WSNs) and their associated technologies. WSNs have found application in a vast range of different domains, scenarios and disciplines. These have included healthcare, defence and security, environmental monitoring and building/structural health monitoring. However, as a result of the broad array of pertinent applications, WSN researchers have also realised the application specificity of the domain; it is incredibly difficult, if not impossible, to find an application-independent solution to most WSN problems. Hence, research into WSNs dictates the adoption of an application-centric design process. This book is not intended to be a comprehensive review of all WSN applications and deployments to date. Instead, it is a collection of state-of-the-art research papers discussing current applications and deployment experiences, but also the communication and data processing technologies that are fundamental in further developing solutions to applications. Whilst a common foundation is retained through all chapters, this book contains a broad array of often differing interpretations, configurations and limitations of WSNs, and this highlights the diversity of this ever-changing research area. The chapters have been categorised into three distinct sections: applications and case studies, communication and networking, and information and data processing. The readership of this book is intended to be postgraduate/postdoctoral researchers and professional engineers, though some of the chapters may be of relevance to interested master's level students.

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