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Conceptual Framework for Integrating a Wireless Sensor and Control Network into a Robotics Course for Senior Students of Mechanical Engineering Technology

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Conceptual Framework for Integrating a Wireless Sensor and Control Network into a Robotics Course for Senior Students of Mechanical Engineering Technology

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Abstract

Modern robotics is a field that integrates mechanical, electrical, computer and information systems. However, students of Engineering Technology, especially Mechanical Engineering Technology (MET), are facing two dilemmas when taking robotics courses because technology programs mainly focus on hands-on skills and there are fewer fundamental robotics-related courses in the MET curriculum than in electrical engineering technology.

In order to improve the performance of the student in robotics program of MET, an educational framework based on using a wireless sensor and control network (WSCN) was devised and employed in the senior-level robotics course “Sensor and Actuator Applications in Robotics”. This framework has two advantages over the former teaching methodology. First, it is low cost and used to facilitate conceptual education with popular and affordable mechatronics devices (Arduino development kit, sensors, wireless communication modules, actuators, etc.). Second, the devised ready-to-use framework avoids exposing the students to complicated algorithms and appropriately balances the students’ time between theory and practice, thus letting them focus more on the applications of robotics. Therefore, both the students and instructors can take advantage of the limited number of class hours to develop sophisticated projects. During the implementation, the course was redesigned based on pre-class survey results and the assessment of the students’ abilities. Subsequently, the students were instructed to familiarize themselves with basic sensors and actuators, the Arduino development kit and c-based programming with Arduino Integrated Development Environment (IDE). Then, the framework was implemented into the course. Over the course of the semester, a series of homework and projects were assigned. Through these assignments, the students were able to build practical devices within the framework. This framework enhanced the students’ understanding of the fundamental concepts, and the practical applications inspired the students’ interest in this course, which also improved their performance.

1. Introduction

Robotics is becoming one of the most attractive majors in the Colleges of Technology because of the advantages in respect of applications, jobs, and prospects. Therefore, more and more Colleges of Technology have or are planning to create robotics program. Usually, as an interdisciplinary field, the robotics programs are provided by either Computer Engineering Technology or MET. However, students of Engineering Technology, especially MET, are facing two dilemmas when providing robotics courses:

(1) Technology programs mainly focus on hands-on skills and there are fewer fundamental robotics-related courses in the MET curriculum than in electrical engineering technology. One of the educational goals in MET is to cultivate future technologists rather than researchers. Therefore, the traditional manufacturing-based classes dominate the degree pathway of the MET program.

Therefore, this configuration impairs the students' deeper understanding of the concepts and theories required by robotics.

(2) The limited number of robotics class hours constrain the extended application and practice of the knowledge related to robotics. Since the knowledge related to the control and electrical circuit is relatively weak, the students are assumed to refresh the mind with more class hours. Unfortunately, the degree path has been packed with many classes which focus on the hands-on work.

In order to find an appropriate method to overcome the above problems, an educational framework based on using a WSCN was devised and employed in the senior-level robotics course "Sensor and Actuator Applications in Robotics".

2. Conceptual Framework for Integrating a Wireless Sensor and Control Network

2.1. Inspiration

Nearly all MET programs at the colleges of Technology are in the transition from the traditional manufacturing-based priority to the modern autonomous-control-based one. Take a look at the degree pathway in the MET Department at the New York City College of Technology[1], the baccalaureate-level courses mainly focus on the mechanical system design, mechanics, dynamics, and simulation. Therefore, the students lack the systematical training in the area of electrical and computer engineering technology. So, it is necessary to find a way to open the students' horizon of interdisciplinary knowledge.

In addition, the students' skills involving robotics are weak. A question-based survey (in form of self-evaluation) is administered before a senior-level robotics class which is named as "Sensor and Actuator Applications in Robotics" (There are 54 students in this class). The questions in the survey are listed in Table 1. Every question has 0 (unknown), 1 (poor), 2 (fair), 3 (good), 4 (very good), and 5 (excellent) scores (from the weakest to the strongest) to represent the level of their skills. A statistic result of this survey (Average score) is shown at the end of each question. According to the survey result, it is very clear that the students have little knowledge related to the embedded system design. Unfortunately, the knowledge of embedded system design is so essential to the robotics that the robotics experiments cannot be implemented without it[2]. Therefore, it would be an appropriate practice if an integrated embedded-system-development platform is employed in the robotics class. Certainly, the desired platform should be flexible to expand and fool-free usage for the students.

In order to find such a platform, a "conceptual framework for integrating a WSCN is designed.

2.2 Basic structure

2.2.1 Principles

In practice, the traditional sensing and controlling methodologies are enriched by various wireless manipulation networks[3]. The proposed framework is built up from the basic wireless sensor network (WSN) topology. A typical WSN configuration with a PC server can be found in Figure 1. There are four main components which include sensor field (composed of many sensor nodes), sink node (gateway or other interface devices), network (usually is the internet) and PC server.

Sensor nodes sense the interested physical information based on the specific applications. Following that, the physical information is converted into a serial of raw data. Then, the raw data is passed to the local intelligent electronics devices (IEDs) to process. After that, the processed data is sent to the sink node. The sink, in turn, passes the corresponding instructors to the sensor nodes according to the received information. The main characteristics of the WSNs can be generalized as[4]:

a) Network topology is specified based on the users' requirements;

b) Applications are diverse based on the sensors varieties in sensor field;

c) Traffic characteristics is relatively unique based on the protocols used in the whole network;

d) Available resources extremely depend on the architecture of the network.

The sensors on sensor nodes can be low-power (for instance temperature sensor) or high-power sensing devices (for example high-voltage current transformer). The embedded processors integrated on the sensors are used to process data and realize communication between the sensor nodes and the sink nodes through the communication modules. In addition, the embedded processors, the communication modules, the power source modules and the sensors are combined into an IED. This IED is used to administer the interaction between the clients (sensor nodes) and the servers (PC server).

Moreover, the WSN should have a specific information model based on the communication protocols in order to improve the interoperability among the sensor nodes[5]. As shown in Figure 2, the information of real world is sensed by the sensors. Then, the sensor nodes are taken as a serial of logical nodes with corresponding physical information. The physical information is processed, classified and normalized into various data classes of an information model. The information model complies with the seven layers of the Open System Interconnection (OSI) model. More details about the OSI model can be found elsewhere[6].

After the WSN is built-up, the interfaces used to communicate with the actuators are integrated into the WSN[7]. The embedded processors will control the actuators according to the information provided by the sensor network. The basic layout of a WSCN can be found in Figure 3. All the remote controlling and sensing work are implemented via a wireless network. The embedded processors will be equipped with the peripheral circuits and various interfaces of communication and control.

2.2.2 Affordable and easy to use conceptual framework of wireless sensor and control network

The desired platform for robotics class in MET should be affordable while being functional. Most Colleges of Technology especially the public Colleges are struggling during seeking the financial support from both government and industrial agencies. Many students in these colleges are also constricted by the financial conditions of their families. Therefore, to find economic but practical components is thumped up during fabricating the conceptual framework of WSCN. Certainly, the core component of this platform should be an embedded system development kit (ESDK)[8]. There are many ESDKs in the market. The very popular ESDK for the beginners is Arduino Microcontroller board (the price is less than $20). In addition, an Arduino Microcontroller board has enough resources to provide interfaces for the wireless access points of sensors and actuators which are used in the projects of robotics class. Therefore, the Arduino Microcontroller board is chosen as the embedded controller.

Up to the wireless transceiver IC, there are many options based on specific applications[9]. Generally, there are five popular ways to realize wireless communication between the sensors & actuators and the embedded-processor-based controllers[10]. These wireless ways are designed via different wireless protocols.

First wireless communication way is WiFi. One of the popular ICs of WiFi is ESP8266 WiFi module based on ESP8266 system-on-chip. The outstanding advantage of ESP8266 is its computational power on board. Therefore, it can be used to harness the sensors and actuators automatically. The specification of ESP8266 can be found elsewhere[11,12].

Table 1 Survey used to evaluate students' skills

Mechanical Design Aspects:		Embedded System Development Aspects:	
➢ Autodesk AutoCAD:		➢ Basic Knowledge	
• Overall Skills:	4.2	• Analog/Digital Circuit:	3.2
➢ Autodesk Inventor:		• Integrated Circuit:	0.8
• Overall skills:	4.1	• Operating System:	1.2
• Part making:	4.4	➢ Programing Language/Scripts:	
• Assembly:	4.3	• C/C++:	1.2
• Speed:	3.8	• Java:	0.9
➢ SolidWorks:		• Python:	0.6
• Overall Skills:	4.3	• HTML:	0.8
• Part making:	4.5	➢ Developing Tools	
• Assembly:	4.2	• Arduino:	3.2
• Speed:	3.9	• Raspberry PI:	0.8
➢ MasterCAM:		• PLC:	1.3
• Overall Skills:	4.4	➢ Simulation/Sketching Software	
➢ ProE:		• LabView:	1.2
• Overall Skills:	1.1	• Matlab:	4.2
• Part making:	1.5	• Protel:	0.0
• Assembly:	1.3	• Proteus:	0.0
• Speed:	1.1	➢ Algorithm:	
➢ Other Mechanical Software:		• Formalization:	3.1
• Please specify		• Implementation:	2.9
		• Algorithmic analysis:	0.7
		➢ Other Programming Skills	
		• Please Specify:	

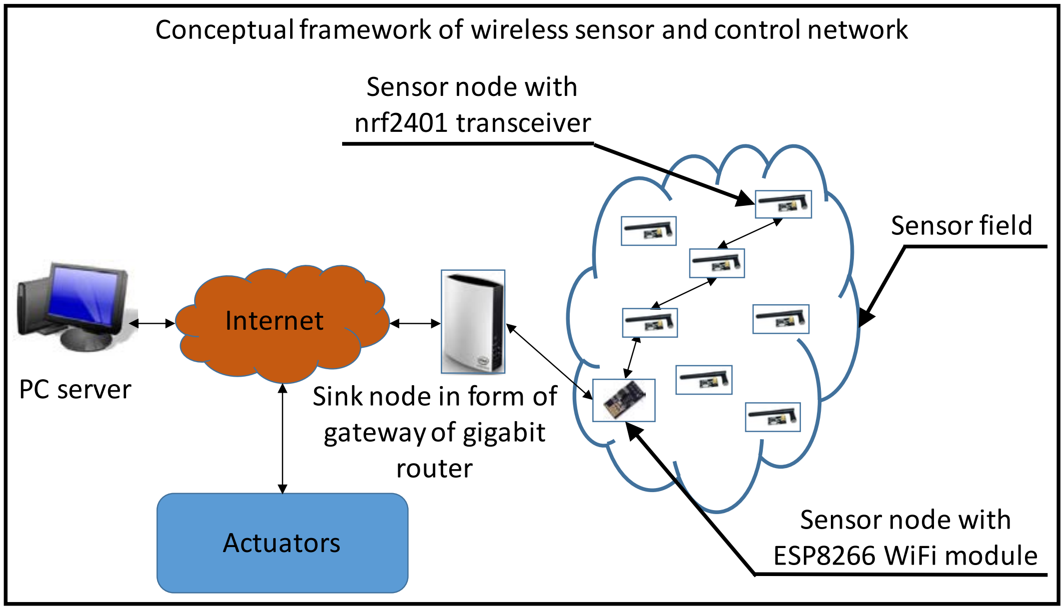


Figure 1: A PC server-based wireless sensor network topology

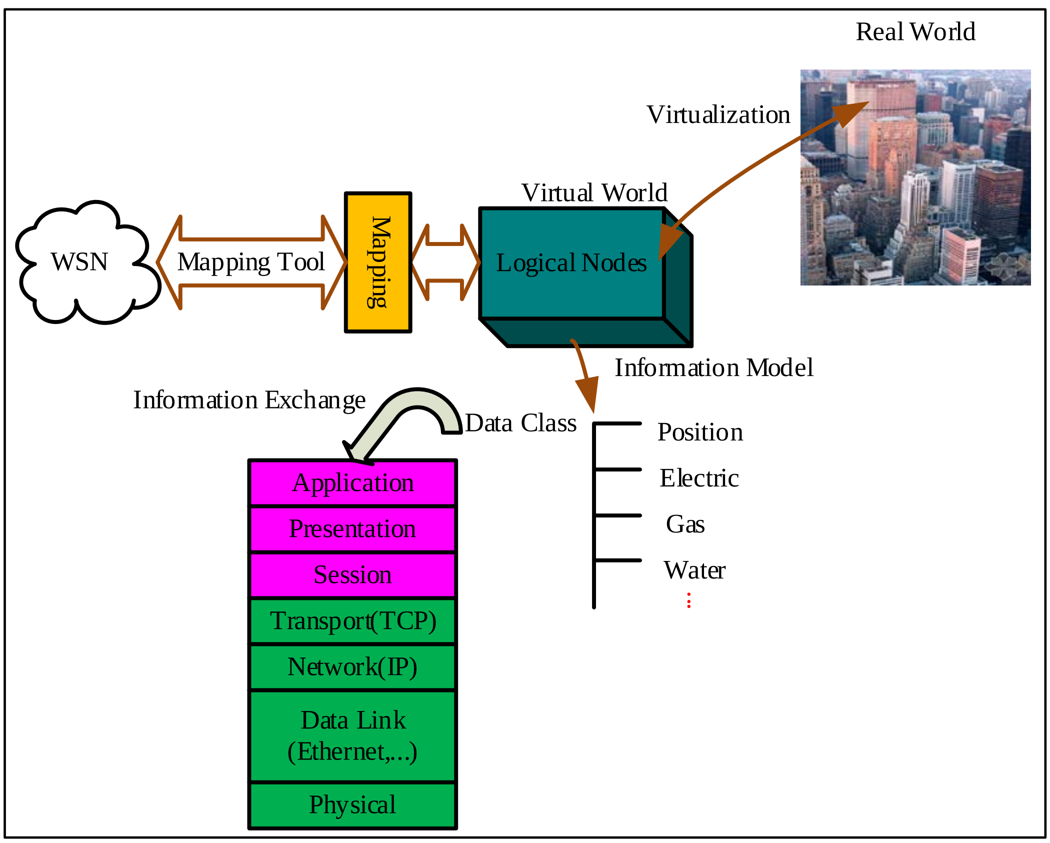


Figure 2: Information model for facilitating interoperability

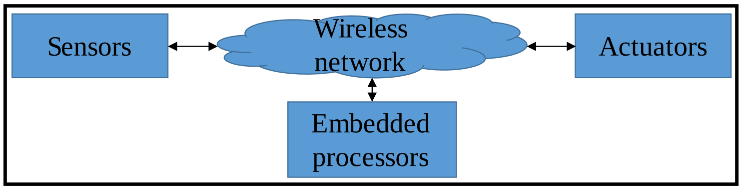


Figure 3: Wireless sensor and control network layout

The second way is Bluetooth. Bluetooth is a low energy wireless communication way with lower latency. With the release of Bluetooth 4.0, the range and stability of Bluetooth have been improved. The common Bluetooth modules are EZ-BLE and EZ-BT Bluetooth Modules. More details of these modules can be found elsewhere[13,14].

The third way is Zigbee. Zigbee is designed for personal area networks and it is based on IEEE 802.15.4 standard. Zigbee is typically used in the low data-transmission-rate cases which have strict constraints on the battery life and security. The materials related to Zigbee can be found elsewhere[15,16].

The fourth way is the Global System for Mobile communication (GSM). GSM is a digital mobile telephony system and the most popular cell phone standard[17].

The fifth way is radio frequency (RF). The common solutions for RF include 433MHZ (for example, DRF1278F module[18]) and 2.4GHZ (for example, nrf24l01 transceiver [19]) transceivers.

After a compromise among the applications, performances and cost, nrf24l01 transceiver and ESP8266 WiFi module are taken as the wireless transceivers. Firstly, nrf2401 is an economical option for local wireless access points. A nrf2401transceiver is only $1. It can be used in point to point communication between sensors, actuators, and controllers. At the same time, nrf2401 can mimic a Bluetooth transceiver to generate a stable communication path between receivers and senders. Secondly, the ESP8266 WiFi module is powerful to realize the communication via the internet. It is an efficient and economical way to provide a very compact “Internet of Thing” solution. The final conceptual framework of WSCN is shown in Figure 4. The sensors are equipped with nrf2401 transceiver, and these sensor nodes only acquire data and transmit data locally. The acquired data is finally passed to a gigabit router via a sensor node combined with ESP8266 WiFi module. The actuators are operated and controlled via internet according to the data acquired from sensor field.

3. Course Design

The “Actuators and Sensors Applications in Robotics” is a senior level course in MET program. The objective of this course is to let the students learn different types of actuators and sensors; be familiar with their working principles; following that the students can integrate common actuators and sensors into the projects of robotics.

In this class, the Arduino MEGA 2560 board, sensor and actuator kit are selected to implement the hands-on experiments. In the first class, a survey (in the form of self-evaluation) used to evaluate the students’ skills is administered. The details of this survey have been introduced in the part of 2.1. Through the survey, the students’ strength and weakness in respect of robotics are apparent: strong in the area of traditional mechanical subjects but weak in the areas of control related topics (refer to Table 1). In order to let the students overcome the difficulties posed by the control knowledge, the fundamental theories of control are given in class. Then, let the students practice these theories through a serial of experiments of sensors and actuators. In addition, the students lack the experience of programming with C/C++. So, the C/C++ programming classes are given. After the students master the basic grammar and the structure of C/C++, they are required to use Arduino intelligent development environment (IDE) to compile and upload programs which are used in the embedded system experiments.

After 7 weeks, the students are separated into different groups (4 students in one group) to create different projects. The students firstly propose their projects. Then, the conceptual framework of WSCN is given to the students. The students use this framework to create their own applications according to their proposals. After one more 7-weeks work, the final projects are presented and exhibited. In order to assure the justice of the grading work, the students evaluate the projects between each other. The final grade is the average of all the evaluations.

4. Projects by employment of Conceptual Framework of Wireless Sensor and Control Network

There are 14 projects in the class. These projects include remote control car, automatic curtain, intelligent sprinkler system, smart building, digital door lock, drone, automatic cat food feeder, wireless motion-activated light; floor cleaning robot, smart rice-cooker, automatic food chopper, robotic arm, crane, and quadcopter. Finally, some of these projects are combined into one large project: smart building. The smart building project fully employs the conceptual framework of WSCN to realize remote access and control to the appliances and the interior environment of the building. A diagram of this project is shown in Figure 5.

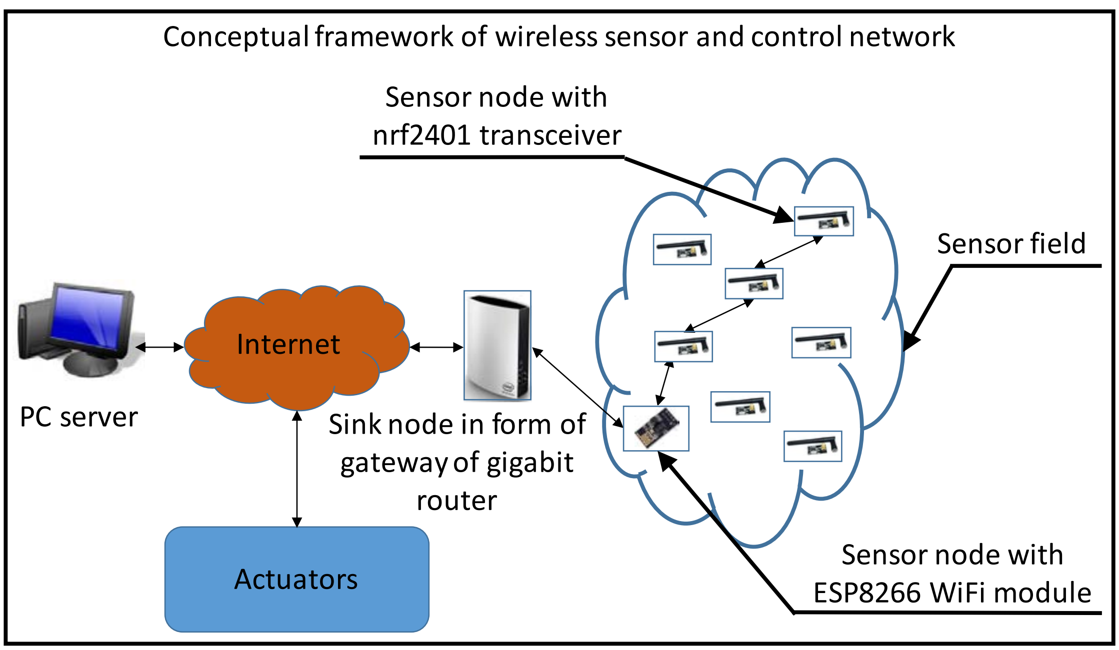


Figure 4: Conceptual framework of wireless sensor and control network

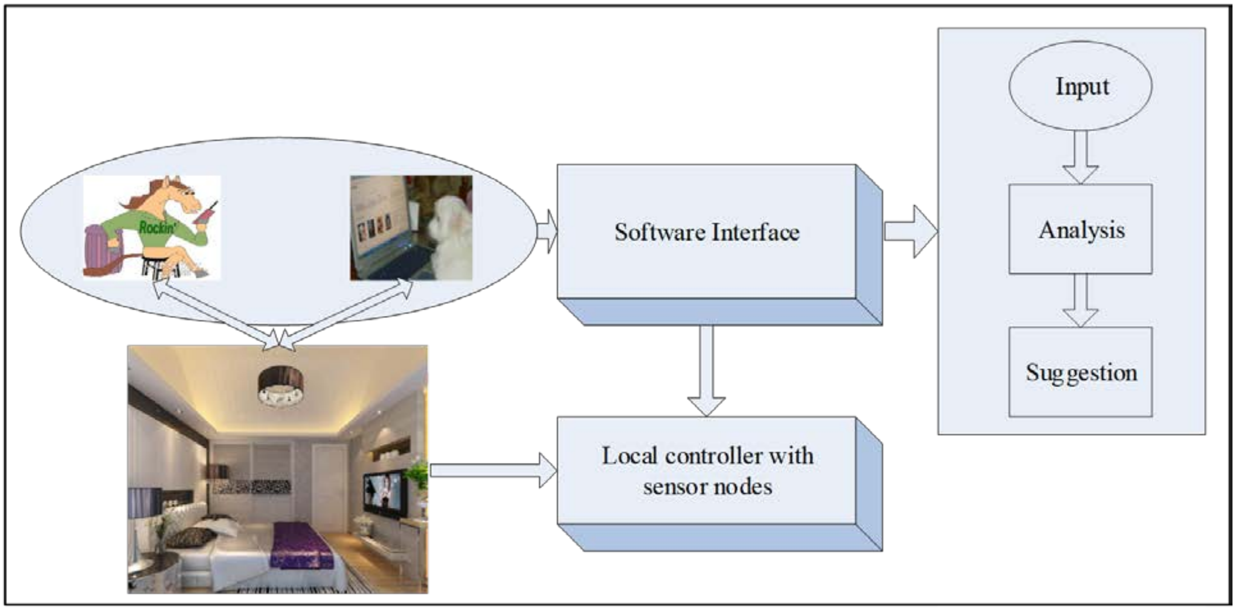


Figure 5: Diagram of smart building

In this large project, a 12 inch × 12 inch × 12 inch cardboard box is taken as a miniature house model as shown in Figure 6. In the house, sensors and actuators are laid out. Outside of the house, the intelligent sprinkler system and the digital door lock are used to increase the complexity of the project.

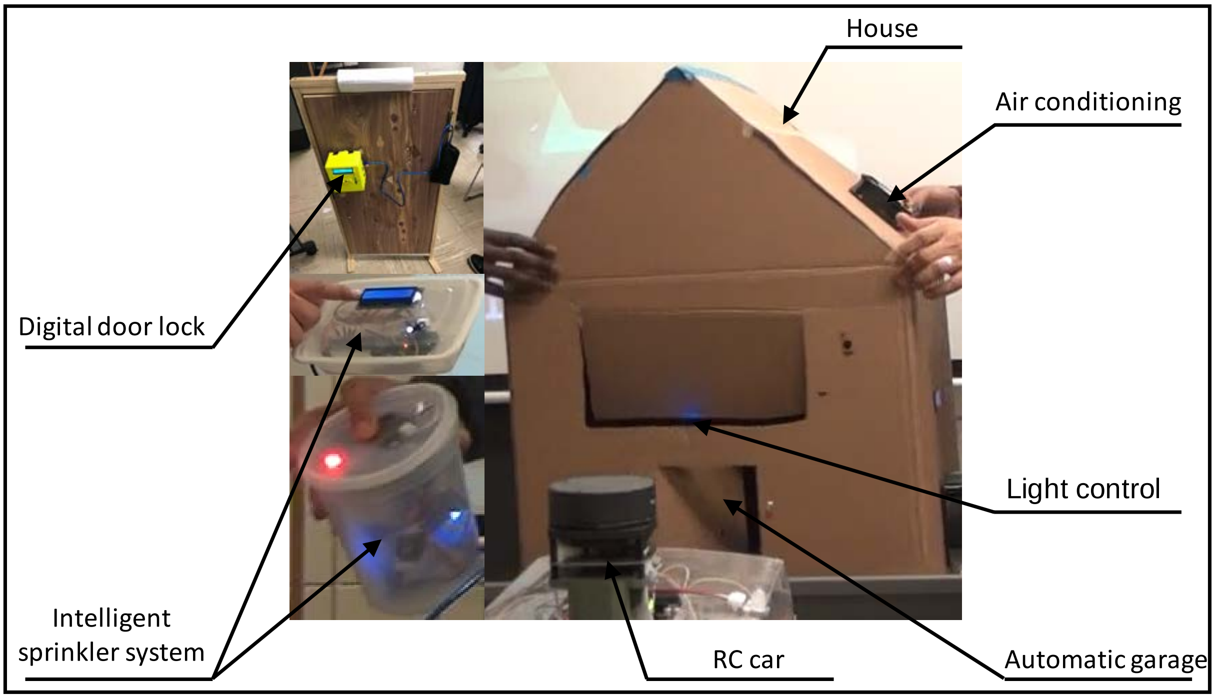


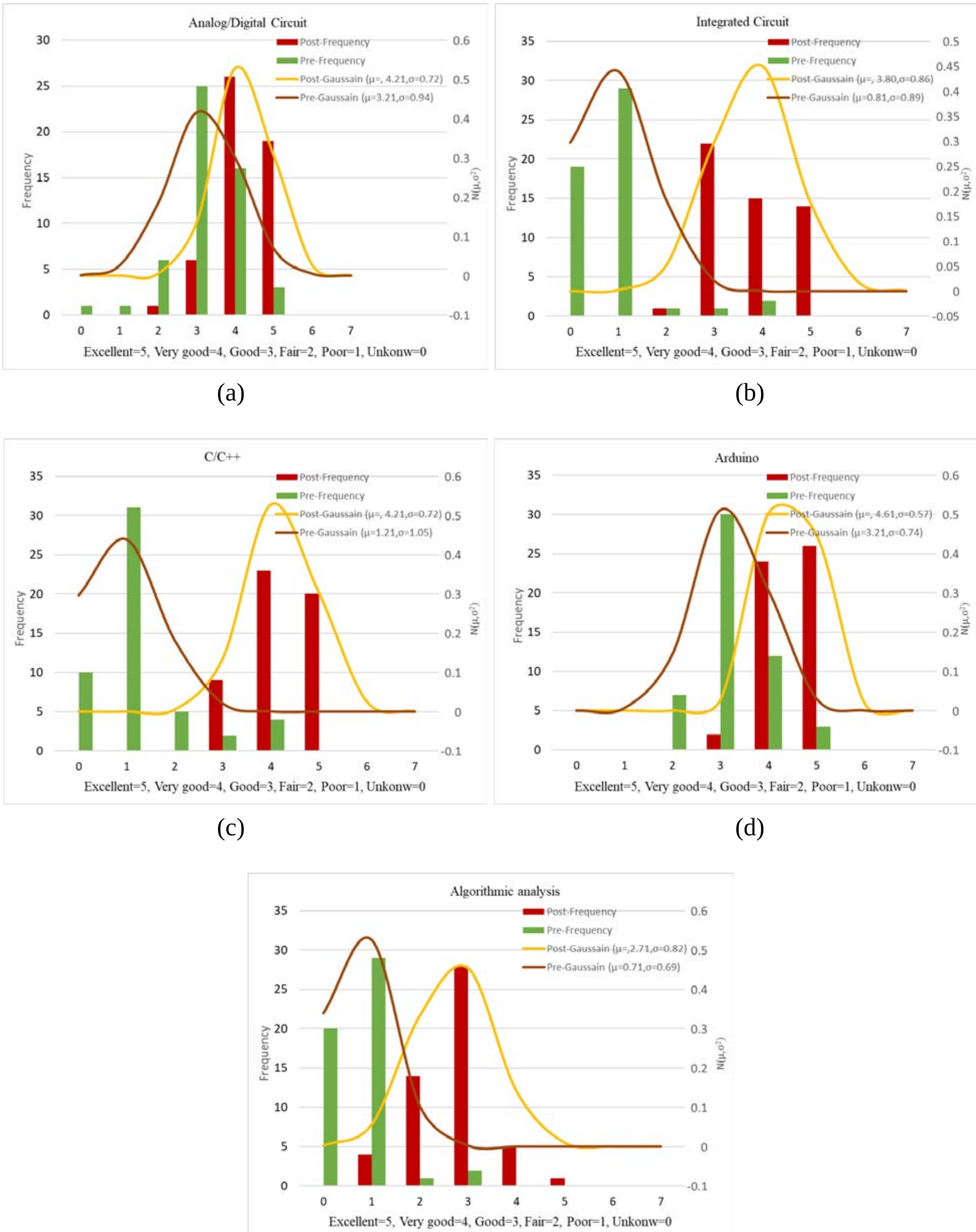
Figure 6: Smart building exhibition in class

5. Evaluation of Students' Performance

In order to learn the performance of the conceptual framework of WSCN, a post-class survey was administered. In this survey, only the robotics skills are asked. In addition, the same questions as the pre-class survey are given. 52 of the 54 participating students provided feedback. A result can be found in Table 2. By comparing Table 1 and Table 2, there is a great improvement in respect of analog digital circuit, integrated circuit, C/C++, Arduino, and algorithmic analysis. In order to demonstrate the differences between pre-survey and post-survey, a serial of graphs is given as shown in Figure 7 (a) through Figure 7 (e). The standard deviations of all the items shown in Figure 7 are relative low since the students in the observed class are enough that the self-evaluation results can be taken as an important metric to evaluate the outcomes of the mentioned class. Therefore, a conclusion can be drawn that the students' skills are enhanced by the proposed method.

Table 2: Post-class survey results

Embedded System Development Aspects:		➢ Simulation/Sketching Software	
➢ Basic Knowledge		• LabView:	1.4
• Analog/Digital Circuit:	4.2	• Matlab:	4.3
• Integrated Circuit:	3.8	• Protel:	0.0
• Operating System:	1.4	• Proteus:	0.0
➢ Programing Language/Scripts:		➢ Algorithm:	
• C/C++:	4.2	• Formalization:	3.5
• Java:	0.8	• Implementation:	3.1
• Python:	0.7	• Algorithmic analysis:	2.7
• HTML:	0.7	➢ Other Programming Skills	
➢ Developing Tools		• Please Specify:	
• Arduino:	4.6		
• Raspberry PI:	0.9		
• PLC:	1.5		



(e)

Figure 7: Comparison by statistic analysis

6. Conclusions and future work

In this paper, a conceptual framework for integrating a WSCN into a robotics course for senior students of MET was introduced. The first step in the development of an educational approach used in this robotics class was to conduct an assessment of the affected students by administering a pre-class survey. Based on the result of this survey, the course was redesigned while developing the conceptual framework of WSCN. Subsequently, the students were instructed to familiarize themselves with basic sensors and actuators, the Arduino development kit and c-based programming with Arduino IDE. After the students had mastered the usage of the hardware and software, the framework was implemented into the course. Over the course of the semester, a series of homework and projects were assigned. Through these assignments, the students were able to build practical devices within the framework. At the end of the class, a post-class survey was administered. After the comparisons of the results from two surveys, a conclusion can be drawn that the conceptual framework of WSCN is helpful to improve the students' performance in respect of robotics technology. First, the framework enhanced the students' understanding of the fundamental concepts; second, the practical applications inspired the students' interest in this course and then improved their performance.

Although the educational approach is not perfect, it still represents a new way for the robotics class of MET at the College of Technology. It holds certain promise, especially if the method can be improved by administering more classes. In future, the WSCN will be integrated into other platforms involving virtual laboratory [20] and virtual proctor [21] which have been developed by the authors. Besides these, the techniques including Simultaneous tracking [22] and reconstruction, real-time 3D reconstruction [23] and parallel computing [24] will be introduced and applied in the class projects. These works can provide students an opportunity to participate the activities featured with cutting-edge techniques, can let the students broaden their horizon of knowledge, can enhance their professional skills and make them more competitive in future job market.

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