Design and Application of a Platform of Wireless Sensor and Control Network in Robotics Course of Mechanical Engineering Technology

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***Abstract*— Robotics is one form of interdisciplinary field which involves the tight integration of mechanical systems, electrical systems, computer systems, and information systems. However for students enrolled in the Engineering Technology programs, especially the Mechanical Engineering Technology (MET) program to learn robotics, they are confronted with two difficulties: (1) limited number of fundamental robotics-related courses, (2) limited robotics course hours. In order to help the students of MET to overcome these two difficulties, a wireless sensor and control network (WSCN) platform is designed and employed. This platform has two advantages: affordable and foolproof. Therefore, students can avoid exposing themselves to complicated algorithms. They can focus on the applications of robotics to develop sophisticated projects. Before introducing WSCN,, the existing entry-level robotics course was redesigned based on the pre-class survey results and the assessment of the students' abilities. Subsequently, the students were instructed to familiarize themselves with the basic sensors and actuators, the Arduino development kit and the c-based programming. Then, the platform was implemented in the course. In addition, a series of homework and projects were assigned. Through these assignments, the students were able to design practical projects using the platform. It was proven that the platform enhanced the students' understanding of the fundamental concepts, inspired the students' interest in this course, and improved their performance in the robotics classes.**

Keywords—robotics, WSCN, MET, education

I. Introduction

Robotics is becoming one of the most attractive majors at the Colleges of Technology because of the advantages in respect of applications and future careers [1]. In addition, the field of robotics has been broadened significantly by a number of new topics including additive manufacturing [2], automation [3], internet of things [4], virtual reality [5], etc. Therefore, more and more Colleges of Technology have had robotics programs, or they are planning to create robotics programs. As an interdisciplinary program, the robotics program is usually provided by either Computer Engineering Technology or MET [6]. However, the students of MET are facing two dilemmas when they are taking the robotics courses:

(1) MET program mainly focuses on the hands-on skills. In addition, there are fewer fundamental robotics-related courses in the MET program than in the electrical engineering technology program [7]. One of the educational goals in MET is to cultivate future technicians rather than researchers. Therefore, the traditional manufacturing-based classes dominate the degree pathway of the MET program. This configuration consequently impairs the students' understanding of the concepts and theories of robotics.

(2) The course hours of robotics are limited, and this fact constrains the extended application and practice of the knowledge related to robotics. Since the knowledge related to the control and electrical circuit is weak, it is necessary for the students of MET to take more time to refresh their minds. Unfortunately, the degree path has been packed with many traditional mechanical engineering classes and the hands-on work. So, it is impossible to spare time for the fundamental knowledge of robotics.

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

II. Platform of Wireless Sensor and Control Network

A. Inspiration

Nearly all MET programs at the Colleges of Technology are in the transition from the traditional manufacturing-based programs to the modern autonomous-control-based ones. Take a look at the degree pathway in the MET Department at the CUNY New York City College of Technology, the baccalaureate-level courses mainly focus on the mechanical system design, mechanics, dynamics, and simulation [8]. Therefore, the students of MET lack the systematical training in the area of electrical engineering, computer science, and information system. So, it is necessary to find a way to expand the students' horizon with respect to interdisciplinary knowledge. In addition, the students' skills for developing the projects of robotics are weak. A question-based survey of self-evaluation is administered in the robotics class in which there are 54 students. The questions in the survey are listed in Table

I. 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 result of the survey, 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 [9]. 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 foolproof to use and flexible to expand for the students.

In order to meet these requirements, a platform of WSCN is designed and applied in class.

TABLE I 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:	

B. Basic structure

1) Principles

In practice, the traditional sensing and controlling methodologies are enriched by various wireless manipulation networks [10, 11]. The proposed platform is built up from the basic wireless sensor network (WSN) topology. A typical WSN configuration with a PC server can be found in Fig. 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 a 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 instructions to the sensor nodes according to the received information. The main characteristics of the WSNs can be generalized as [12]:

(1) The network topology is specified based on the users' requirements;

(2) Applications are diverse based on the types of sensors in the sensor field;

(3) Traffic characteristics are relatively unique based on the protocols used in the whole network;

(4) 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. At the same time, these processors 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 on which the sensors from different manufacturers are attached [13]. As shown in Fig. 2, the information of the 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. Then, the physical information is converted 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 [14].

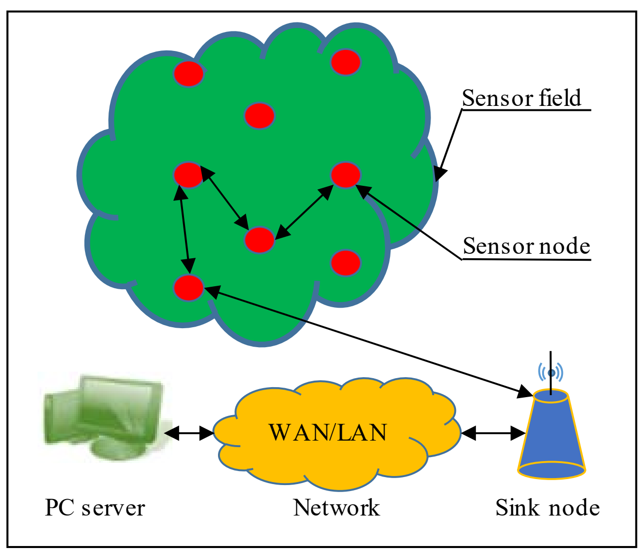


Fig. 1: A PC server-based wireless sensor network topology

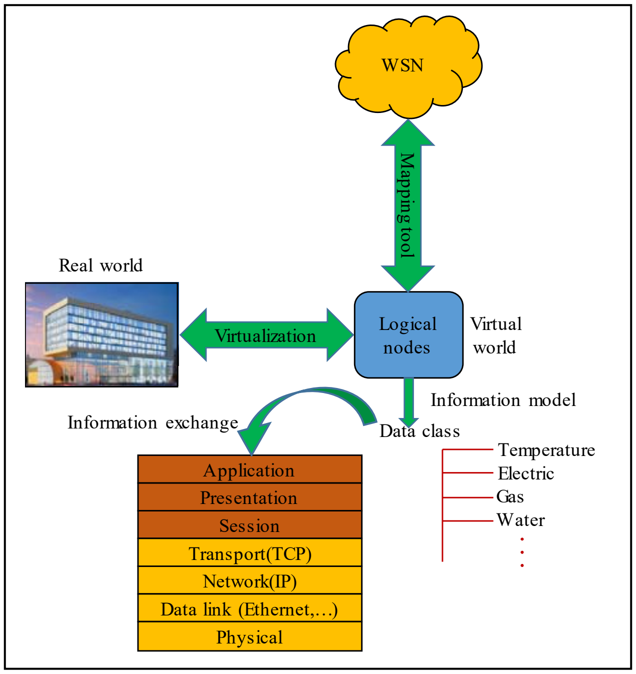


Fig. 2: Information model for facilitating interoperability

After the WSN [15] is established, the interfaces used to communicate with the actuators are integrated into the WSN. 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 Fig. 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 which are used to do communications and control.

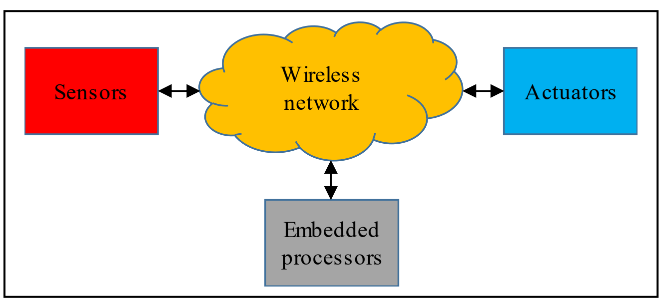


Fig. 3: Wireless sensor and control network layout

2) Affordable and easy-to-use platform of wireless sensor and control network

The desired platform for robotics classes in MET should be affordable, foolproof and functional. Most Colleges of Technology, especially the public Colleges, are struggling during seeking financial support from both the government and industrial agencies. Many students in these colleges are also constricted by the financial conditions of their families. Therefore, to find the economic but practical components is thumped up during fabricating the platform of WSCN. Certainly, the core component of this platform should be an embedded system development kit (ESDK) [16]. 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 ESDK.

Up to the wireless transceiver IC, there are many options based on the specific applications [17, 18]. Generally, there are five popular ways to realize wireless communication between the sensors & actuators and the embedded-processor-based controllers. These wireless ways are designed via different wireless protocols.

First wireless communication way is WiFi [19]. One of the popular ICs of WiFi is the 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 [20].

The second way is Bluetooth [21]. Bluetooth is a low energy wireless communication way with lower latency. With the release of Bluetooth 4.0 [22], 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 [23].

The third way is Zigbee [24]. Zigbee is designed for personal area networks and it is based on IEEE 802.15.4 standard [25]. 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 [26, 27].

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 [28].

The fifth way is the radio frequency (RF) [29]. The common solutions for RF include 433MHZ (for example, DRF1278F module [30]) and 2.4GHZ (for example, nrf24l01 transceiver [31]) transceivers

After a compromise among the applications, performances and cost, nrf24l01 transceiver and ESP8266 WiFi module are taken as the wireless transceivers. First, 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 the receivers and senders. Secondly, the ESP8266 WiFi module is powerful to realize communication via the internet. It is an efficient and economical way to provide a very compact "Internet of Thing" solution. The price of an ESP8266 WiFi module is only $2, and cheaper in wholesale. The final platform of WSCN is shown in Fig. 4. Here, each sensor is equipped with an nrf240 transceiver. In addition, all the sensor nodes as shown in Fig. 4 are only used to acquire data and transmit data locally [32].

The acquired data is finally passed to a gigabit router via a sensor node combined with the ESP8266 WiFi module. The actuators are operated and controlled via internet according to the data acquired from the sensor field.

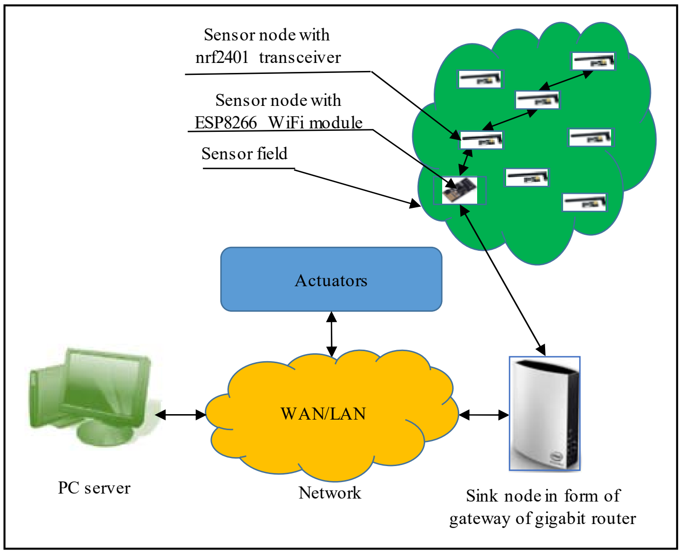


Fig. 4: Diagraph of the platform of wireless sensor and control network

III. Course Design

The course of "Actuators and Sensors Applications in Robotics" is a senior level course in the 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; and theories. Following that, the students can integrate common actuators and sensors into the projects of robotics.

In this course, the Arduino MEGA 2560 board, sensors, and actuators kit are selected to implement the hands-on experiments. In the first class, a survey (in the form of self-evaluation) is administered to evaluate the students' skills. The details of this survey have been introduced in the part of II-A. Through the survey, the students' strength and weakness in respect of robotics are obtained: they are strong in the area of traditional mechanical subjects but weak in the areas of control-related topics (refer to Table I). In order to let the students overcome the difficulties with respect to the control knowledge, the fundamental theories of control are introduced in the first 3 classes. 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 platform of WSCN is given to the students. The students use this platform 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.

IV. Projects by Employment of Platform 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 platform of WSCN to realize remote access to and control the appliances and the interior environment of the building. A diagram of this project is shown in Fig. 5.

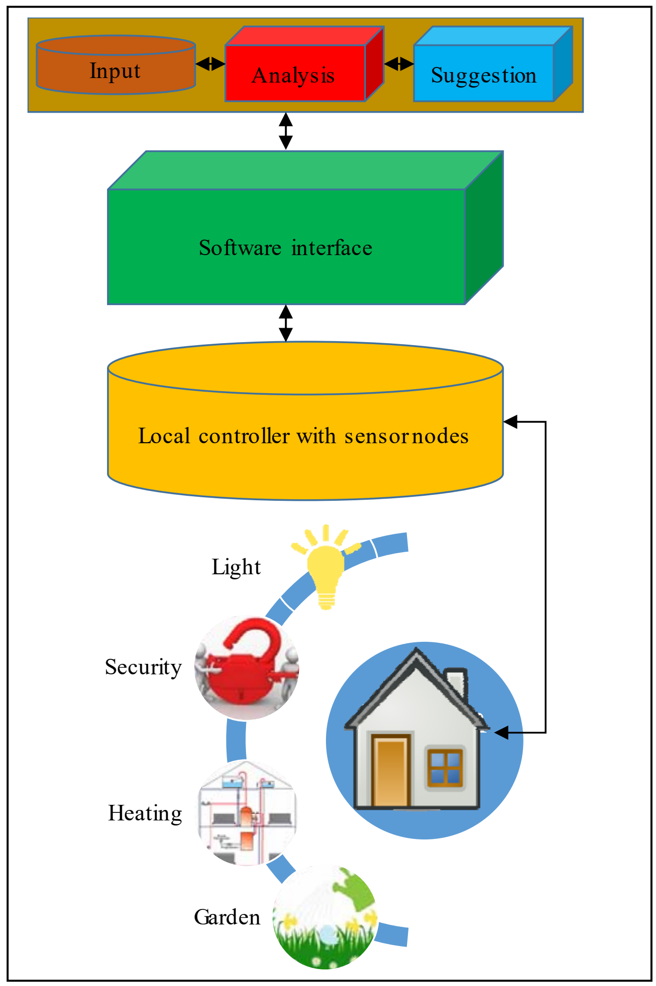


Fig. 5: Diagram of a smart building

In order to decrease the cost of the project as low as possible, a 12-inch × 12-inch × 12-inch cardboard box is taken as a miniature house model as shown in Fig. 6. In the house, various sensors and actuators are laid out which include thermosensors, light sensor, chemical sensors, DC motors, stepper motors, and servo motors. Outside of the house, the intelligent sprinkler system and the digital door lock are used to increase the complexity of the project.

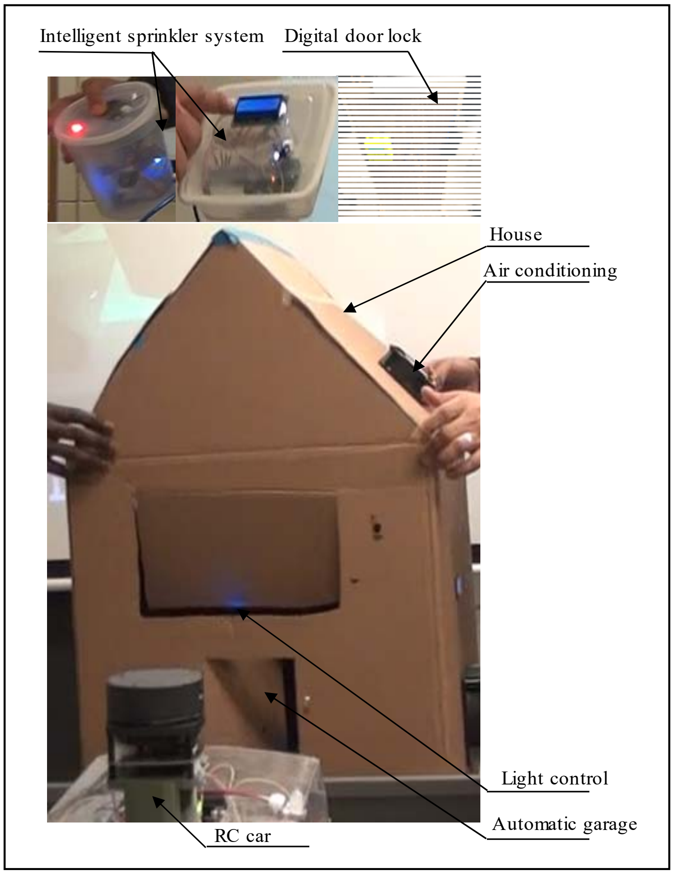


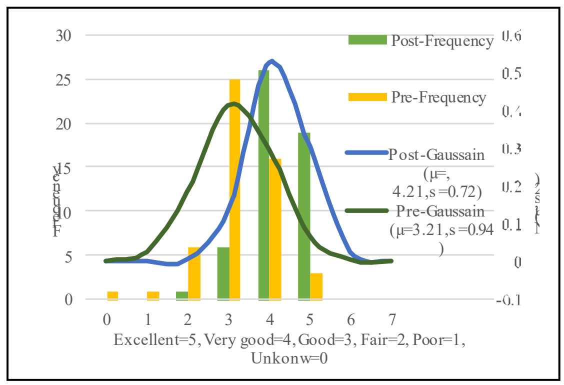
Fig. 6: Smart building exhibition in class

V. Evaluation of Students' Performance

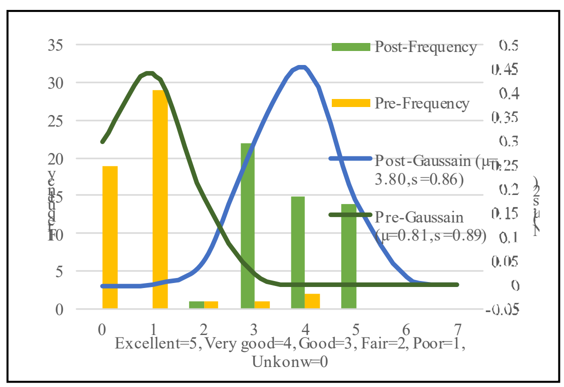
In order to learn the performance of the platform of WSCN, a post-class survey was administered. In this survey, only the robotics skills are asked. In addition, the same questions as the pre-class survey are given. 52 of the 54 participating students provided feedback. A result can be found in Table II. By comparing Table I and Table II, there is a great improvement with respect to the 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 are given as shown in Fig. 7 (a) through (e). The standard deviations of all the items shown in Fig. 7 are relatively low since the number of students in the observed class is enough that the results of self-evaluation can be taken as an important metric to evaluate the outcomes of the mentioned class [33]. Therefore, a conclusion can be drawn that the students' skills are enhanced by the proposed platform.

TABLE II SURVEY USED TO EVALUATE STUDENTS' SKILLS

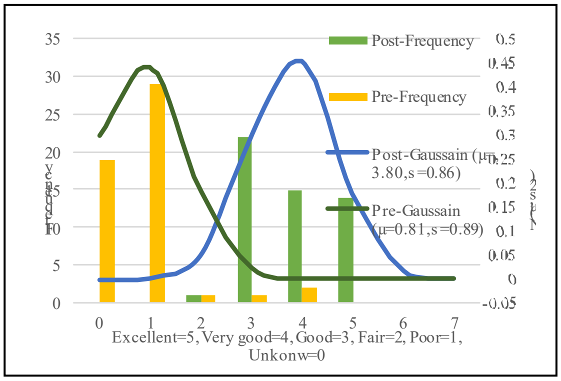
Embedded System Development Aspects	
➢ Basic Knowledge	
• Analog/Digital Circuit:	4.2
• Integrated Circuit:	3.8
• Operating System:	1.4
➢ Programing Language/Scripts:	
• C/C++:	4.2
• Java:	0.8
• Python:	0.7
• HTML:	0.7
➢ Developing Tools:	
• Arduino:	4.6
• Raspberry PI:	0.9
• PLC:	1.5
➢ Simulation/Sketching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



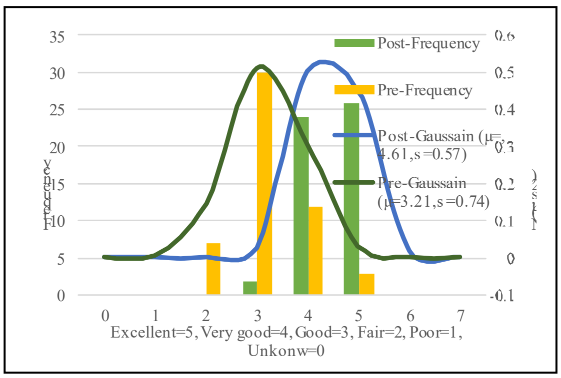
(a) Analog/digital circuit



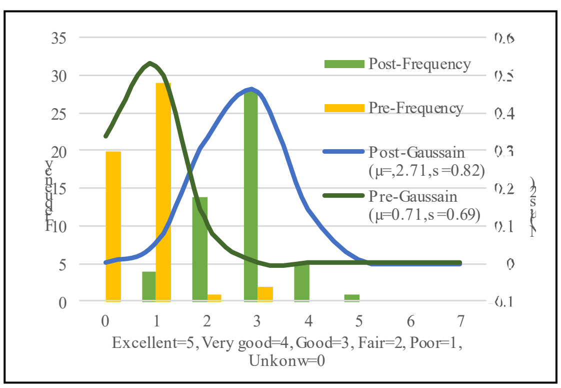
(b) Integrated circuit



(c) C/C++



(d) Arduino



(e) Algorithmic analysis

Fig. 7: Comparison of statistical analysis

VI. CONCLUSIONS AND FUTURE WORK

In this paper, a platform of WSCN was designed and employed in a robotics course for senior students of MET. During developing the platform, the first step was to conduct an assessment of the students by administering a pre-class survey. Based on the result of this survey, the course was redesigned. Subsequently, the students were instructed to familiarize themselves with the 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 platform was introduced to the class. At the same time, a series of homework and projects were assigned. Through these assignments, the students were able to build practical projects with the proposed platform. 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 platform of WSCN is helpful to improve the students' performances in respect of robotics technology. First, the platform enhanced the students' understanding of the fundamental concepts; second, the practical applications inspired the students' interest in this course and then improved their performances.

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 the future, the WSCN will be integrated into other platforms involving virtual laboratory and virtual proctor which have been developed by the authors. Besides these, the techniques including Simultaneous tracking and reconstruction, real-time 3D reconstruction and parallel computing 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 the future job market.

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