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RFID-enabled Real-time Mechanical Workshop Training Center*

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Mechanical workshop training is important in engineering education, which often faces challenges such as the management of a large number of teaching resources, manual and paper-based data collection and the low efficiency and effectiveness of teaching operations. This paper proposes an RFID-enabled Engineering Workshop Training Center (EWTC) by first integrating the Teaching by Examples and Learning by Doing (TELD) principle to enhance the teaching efficiency and effectiveness. "Teaching by examples" allows the students to "see and then remember", while, "Learning by Doing" allows students to "do and then understand". Secondly, EWTC uses RFID (Radio-Frequency Identification) technology to convert various resources into smart teaching objects (STOs), which are connected by wireless networks in order to collect real-time information in an intelligent ambience. Finally, it adopts the Service-Oriented Architecture (SOA) model to develop the system architecture to use the real-time RFID data for facilitating different users' operations and behaviors. A real-life case study illustrates how the RFID-enabled EWTC rationalizes a typical mechanical workshop training item in a university. By qualitative analysis, the daily operations of typical end-users, such as teaching supervisors, tutors and students are reengineered and improved into a pedagogical level that is real-time, optimal and specific. A set of statistics implies the upgrade of EWTC in quantitative analysis.

Keywords: RFID; real-time; mechanical workshop training; TELD; engineering education

1. Introduction

Workshop training is a very important part of mechanical engineering education. It aims to teach students through structured facilities, such as equipment, software, etc. to acquire and equip themselves with a better skill set before joining industry [1]. Typically, students are required to undertake workshop training in the use of hand tools, use of a lathe, drilling, milling, welding, turning, etc. After that, students may familiarize themselves with engineering tools, equipment, and techniques as well as gaining actual experience of the different work roles that they are likely to encounter once they become professional engineers [2].

Mechanical workshop training is often carried out in a virtual or real-life environment. A training program plays a critical role in helping students to familiarize themselves with: working ambiences, such as warehouses and fabrication workshops; engineering terms, including the names of tools and basic workshop equipment; and techniques used in the manufacture of mechanical components [3, 4]. In addition, skilled mechanical engineering tutors commonly work closely with students in the environment to teach the appropriate operations and procedures.

However, mechanical workshop training currently faces several challenges. First, compared with other courses, it is closely associates with practical operations, so that a large number of teaching resources are involved, some of which are specific to the topic, such as equipment, materials, teaching examples, assessment standards, etc. [5]. This large involvement increases the difficulties in planning, executing and controlling operations across its processes. Secondly, manual and paper-based operations dominate in this area [6]. Data collection and information sharing tend to be incomplete, inaccurate and untimely. Reports and decisions based on these data are usually unreal and unreasonable. Finally, the preceding two challenges lead to inefficient and ineffective management during workshop training. Information gaps and inconsistencies commonly cause many issues in engineering training, such as unfulfilled programs, untraceable processes and unpredictable evaluations.

To tackle these challenges, the Teaching by Examples and Learning by Doing (TELD) strategy has been proposed and adopted in engineering education [7, 8]. TELD reflects the ancient philosophy introduced by Confucius of "I hear and I forget. I see and I remember. I do and I understand".

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"Teaching by Examples" enables the students to "see and then remember", while "Learning by Doing" allows them to "do and then understand".

The efficiency and effectiveness of TELD may be enhanced by better information sharing. To this end, RFID (Radio-Frequency Identification) technology and web-based solutions are widely used and reported. RFID technology has been applied to: a multidisciplinary undergraduate studies project to create a remotely controllable laboratory system; an experiential learning approach based on Plato's four forms of awareness; and a learning system to provide personalized learning services, etc. [9–13]. Web-based courses in engineering education can be divided into several categories. First is distance education, which provides web-based services for a large number of students [6, 14, 15]. Second is the experimentation system that caters for different items such as automatic control, electric circuits and programming, etc. [16, 17]. Third is the collaborative learning that enables a group of students to fulfill a project or a course using a variety of coordination methods [18–20]. However, the applications of RFID and web technologies to mechanical workshop training are scarcely found in literature.

This paper introduces an RFID-enabled real-time mechanical workshop training center (RT-MWTC) to apply the TELD principle to workshop training with the assistance of RFID and web technologies. Several research questions are involved.

- How can we deploy RFID devices in workshops to suit the operations and processes of mechanical engineering workshop training? For example, what, where and how can we deploy RFID readers in the workshop to capture the training data? We developed a specific RFID reader and worked out a systematical approach to collect real-time data as well as to facilitate users' operations.
- How can we design a binding relationship between various teaching resources such as equipment, materials, toolings and participants? For example, to which materials and toolings should the RFID tags be attached? We proposed a set of systematic tagging schemes to bind different objects so that they can be uniquely tracked and traced.
- How can we transform the raw real-time RFID data captured from the workshop to useful information to assist in various end-users' training operations? We established a graphical approach for guiding different end-users to facilitate their operations in engineering workshop training. It contains three levels. They are: student-level, tutor-level and teaching supervisor-level.

The rest of this paper is organized as follows. Section 2 demonstrates the overview of RFID-enabled RT-MWTC in terms of the RFID-enabled real-time workshop training ambience and key services. Section 3 introduces a real-life case to report how typical end-users fulfill their daily operations in the RFID-enabled RT-MWTC. Improvements in terms of qualitative and quantitative aspects are also illustrated. Section 4 concludes this paper by describing innovations and future work.

2. Overview of RFID-enabled RT-MWTC

As shown in Fig. 1, the overall framework of RFID-enabled RT-MWTC is divided into several parts. These are: smart teaching objects (STOs), a real-time control system (RT-CS), a real-time engineering workshop training platform (RT-EWTP) and a database service.

STOs are the teaching objects involved in the engineering workshop training, made smart by equipping RFID devices. STOs reason and interact with each other to create an intelligent environment in the workshop. Therefore, they can be tracked and traced within the ambience. They carry some critical information that will be updated at different locations. They are able to acquire, receive and distribute the information in EWTC via wireless connections.

The purpose of RT-CS is to manage the STOs in the workshop. C/S (Client/Server) technology is used because of its distributed computing ability through an Intranet. RT-CS uses polling mode to manage the data transfer between RFID readers and computers. Therefore, data collection becomes real-time and complete.

The purpose of RT-EWTP is to facilitate the different users' (e.g. tutors' and students') teaching

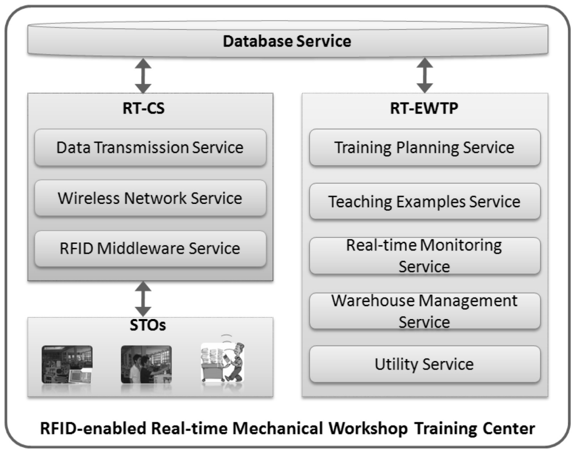

Fig. 1. Overview of RFID-enabled RT-MWTC.

and learning operations and behaviors within the network (e.g. Internet). RT-EWTP uses SOA (service-oriented architecture) to design and development in order to achieve a SaaS (Software as a Service) delivery model.

An SQL server 2005 is used and designed as a database service that is intended to tackle two challenges. First is the data operation (e.g. update, insert, etc.) within several different systems. Second is massive real-time RFID data from the workshop. An event-driven method and real-time stored procedure are used in the database service to overcome the above two challenges [21]. The former, based on event operations, is used to achieve data query, inserting and updating, etc.; the latter, relying on various functional parameters, is used to process the massive RFID data in real-time.

2.1 RFID-enabled real-time workshop training ambience

This section describes how to deploy the RFID devices systematically in workshops to create a real-time ubiquitous training ambience. Fig. 2 gives a deployment roadmap for this purpose.

First, RFID readers are deployed at the entrance of each workshop and individual pieces of equipment. The entrance reader is to check the students' authority to use the workshop and capture their attendance information; this will be fed back to the back-end system in real-time for arranging the equipment. The monolithic information is displayed through an LED screen in the middle of the workshop. The reader deployed at the equipment is for students and tutors to obtain training plans, instructions and technical pictures as well as to report on training data. In order to achieve this, RFID readers that have several functional modules for different teaching activities have been specifically designed and developed. For example, the display module is to show the information that the user requires. The RFID module is for reading and writing tags. The data input module is for entering training data through a keyboard and the wireless communication module is for sending and receiving data between readers and wireless devices. Those with RFID readers are called active STOs and are able to detect the passive STOs, which are deployed by tags.

Secondly, RFID tags are deployed on various teaching objects in different schemes. For critical components, an item-level tagging scheme is used because they should be uniquely tracked and traced. For minor materials, a tray-level or pallet-level scheme is adopted. This means that RFID tags are attached to the trays or pallets that carry minor materials. For tutors and students, they are tagged with RFID-based ID cards. Once the teaching objects have been tagged, they become passive STOs and carry on some critical information that relates to the workshop training. The information will be updated by downloading and uploading from the database at different locations, according to the predefined training logics.

Thirdly, wireless connection devices are deployed in the workshop. 433 MHz wireless communication is adopted for three reasons. First, it is challengeable

Fig. 2. Deployment of RFID devices in workshops.

to wiring on the workshop given the equipment layout. Second, it is selected through cost–benefit analysis. Some available approaches such as Wi-Fi, Bluetooth and Zigbee are taken into account. 433 MHz is acceptable and its bandwidth with 50 kHz is qualified to avoid electromagnetic interferences in this application. Third, the network is easily deployed and its devices have relative low power consumption.

Fourthly, the operation of the RFID devices is based on the reengineered workshop training processes. First, students pat their ID cards on the reader at the workshop entrance to verify their authority to enter as well as to register their attendance. Second, they read their ID cards again at each workstation (training area with equipment) to obtain the training plans, tasks, instructions, technical pictures and evaluation standards. Third, they report on training data while they are performing the tasks via a data input module. Finally, they pat their student cards to register that they have completed the tasks and automatically log out of the system. Within the operations, all the information is collected and used for purposes such as visibility, traceability and evaluation.

2.2 Key services

After establishing RFID-enabled intelligent workshops, a rich set of key services are designed and developed in RFID-enabled RT-MWTC to manage and control the users training operations. They are encapsulated as a rich set of services in RT-CS and RT-EWTP respectively.

2.2.1 RT-CS

RT-CS includes several key services. They are: the RFID middleware service, the wireless network service and the data transmission service.

The RFID middleware service is responsible for controlling the RFID devices in terms of switching the readers on/off, configuration of parameters and so on. It enables hardware maintainers to monitor the statuses of RFID devices and to control the data write/read activities in real-time. This service provides a set of tools to define the STOs' operational logics and teaching operations in training processes. In addition, this service also executes the update of RFID readers.

The wireless network service is responsible for controlling wireless network devices, such as base stations, transmission frequency, channels, etc. It enables hardware engineers to supervise the wireless devices in real-time. It includes several tools to configure the wireless devices as well as some visibility tools to real-time display their working statuses. Therefore, all the reactions of STOs can be captured and reflected on these tools.

The data transmission service is responsible for controlling the data transmission within the RFID-enabled EWTC. It involves three levels of control. The first is data transmission between readers and tags. The High Frequency (HF) RFID tags and readers are adopted, since they are already widely used on most occasions in GDUT for access control. Second is data transmission between readers and computers. A 433 MHz wireless connection standard is used. Third is data transmission between computers and server. An Intranet-based database connection is used. This service enables the data analyst monitor the data transmission between different parties in real-time.

Due to data transmission at inhomogeneity levels, a specific protocol is established. This protocol is based on TCP/IP standards and contains three data structures: for tag, reader and middleware. The tag data structure includes start and end flags, reader address, step ID, data contents and check code. The reader data structure is almost the same as the previous one, except for the addition of several control flags such as CID, STEP, LIMIT, MIN, MAX, and VALUE. These flags are used for controlling data reliability and accuracy. Middleware data structure relates with the database through a tag index, which is obtained when a reader reads a tag. The index set the connection with various data so as to differentiate between tutors, students, materials, etc. Low-density parity-check (LDPC) code is used in the structures to handle the noise over the transmission channel [21].

2.2.2 RT-EWTP

Five critical services are included in RT-EWTP and are described in detail below.

1. The Training Planning Service (TPS) is responsible for making workshop training plans according to the teaching programs. Its main users are teaching supervisors. TPS provides a set of explorers to guide, standardize and facilitate their planning operations. Different operations, objective functions and corresponding solution algorithms are developed as web services. As a result, they can be easily be chosen by users to meet different situations because different classes, training items and semesters have diversified criteria.
2. The Teaching Examples Service (TES) realizes the principle of teaching by examples through the web-based component. Its key users are tutors from different training workshops. It provides plenty of explorers for them to establish teaching examples, which are divided into a few levels of difficulty, such as simple, medium and complex. Therefore, the level can be

selected by the individual student according to his or her own skills. It aims to improve their engineering abilities step by step in practice training.

3. The Real-time Monitoring Service (RMS) is responsible for organizing and displaying various data (e.g. RFID captured data) in real-time in a meaningful and graphical way. It enables teaching supervisors and tutors to monitor and control training processes, equipment statuses, as well as student attendance. RMS is based on a simple but significant principle, which is "what you see is what you do and what you do is what you see". Thus, the teaching activities and operations are seamlessly entwined with information flows. That creates a closed-loop within the entire management of the engineering workshop training.
4. The Warehouse Management Service (WMS) is responsible for managing various materials and toolings that are used at the students' learning by doing stage. Critical materials and toolings are tagged by RFID tags and are located in a specific area in the warehouse. Therefore, their movements can be tracked and traced and their consumption can be monitored in real-time. In this case, the counting, picking and replenishing are much easier than paper-based operations. WMS enables warehouse keepers to manage the frequently used consumables in a more efficient and effective way. In addition, e-forms are used for applications for purchasing, replenishing and transferring the assets.
5. The Utility Service caters to various services for assisting in RT-EWTP providers to customize and deploy this system. These services include: an account management service, role definition service, authority service and configuration service. The account management service is responsible for maintaining the user profiles, such as updating information, password change, etc. The role definition service works as a user classifier that determines which one will be categorized into which role group. The roles include: administrator, regulatory body, teaching supervisor, tutor, student, warehouse keeper, etc. The authority service is responsible for determining which role possesses what authority to access what functions in this platform. The configuration service mainly manages the platform configuration, such as system style, database type and its connection settings, etc.

3. Case study

3.1 About the university

This research is motivated by a real-life case that comes from Guangdong University of Technology (GDUT), whose engineering training center is the only functional entity in the Guangzhou Higher Education Mega Center (HEMC). It provides more than fifteen types of engineering training services for over 10 000 undergraduate students from GDUT and about 5000 students from the other universities in HEMC. These services include the training of the lathe-hand, driller, milling, welding, etc, which are located in different workshops, all of which take up an area of over 10 000 m^2. Fig. 3 shows the processes in GDUT. There are four stages which are illustrated in detail in the below.

Stage 1. Establish personal training objectives
Educational establishments such as GDUT establish the objectives of personal training according to

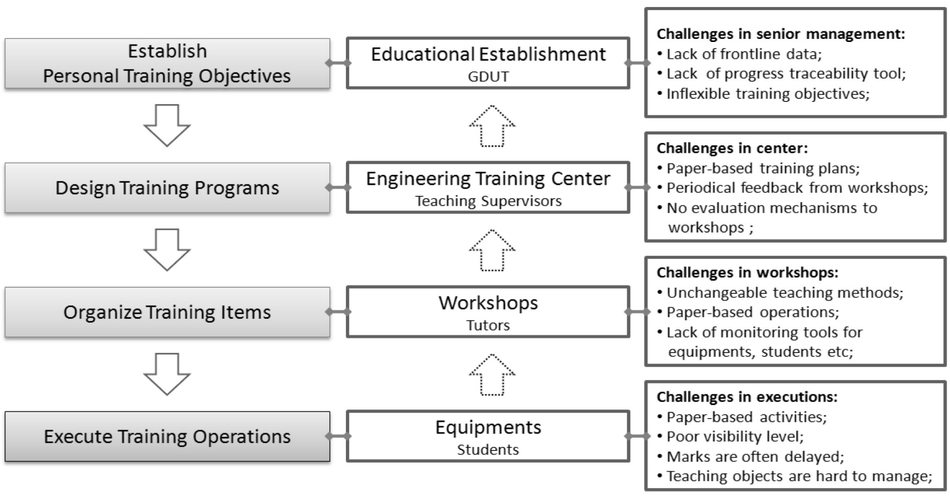

Fig. 3. Training processes in GDUT for using lathes.

the requirements for graduation. The objectives are closely related to the practical requirement of engineering ability from industrial parties. Therefore, GDUT has a large number of facilities managed by a center for the students to improve the capacity of their engineering practice.

Stage 2. Design training programs
The engineering training center is responsible for managing the training facilities that are located in different workshops according to their functions. The teaching supervisors in the center should design different training programs, given the previous objectives. The programs include a set of training items, evaluation standards, etc. and will be distributed to different workshops for guiding their training teaching operations.

Stage 3. Organize training items
Different workshops equipped with different equipment can organize different training items. Tutors in different workshops are responsible for establishing teaching examples with associated technical pictures. This aims to provide suitable teaching examples for a variety students at different engineering training levels.

Stage 4. Execute training operations
The training operations are carried out by students using a variety of equipment. During the processes, students follow the examples established by the tutors and learn corresponding engineering technology through carrying out practical operations on the equipment. This means students can gain knowledge by performing real-life tasks on their own. It aims to improve their engineering skills ultimately to meet the requirements of industry.

3.2 Current challenges

Within the above four-stage processes, several challenges currently confine the teaching efficiency and effectiveness in lathe workshop training. They are mainly come from four directions, as follows.

1. Challenges in senior management: First, the senior decision makers (e.g. training supervisor) lack the information from the frontline engineering training sites (e.g. workshops). The information is accumulated in various training workshops, causing myriad of isolated islands within GDUT. For example, a great deal of information cannot be given to the high-level decision-making entities on time from the workshop areas such as workstations. It is impossible for training supervisors to make precise and practical decisions on a real-time basis. Secondly, there is no efficient traceability approach to monitor the teaching progress. Therefore, GDUT is suffering a lot from the "blind-eyes management", which means that it is hard to track and trace various training items, especially when there is a disturbance, such as equipment break down, in the workshops. Thirdly, the above two challenges result in inflexible training objectives in GUDT. Therefore, the engineering training in GDUT is unable to keep up with the rapid development of engineering technologies in real-life industry because the objectives updates and modification are time-consuming and have high labor costs.
2. Challenges in engineering training center: The paper-based operations dominate in the engineering training center. For example, training plans are made by teaching supervisors using some rudimentary tools, such as Word and Excel, and printed out in multi-copies. The paper-based plans are distributed to tutors, students, warehouse keepers, etc. and are finally collected by specific secretaries who input the data into a computer. In this way, high-level bodies can get periodical feedback from various workshops. However, these feedbacks are liable to be incorrect, incomplete and untimely. As a result, evaluation mechanisms are difficult to establish for workshops, tutors and students. This further negatively affects the teaching quality of workshop training.
3. Challenges in training workshops: Without efficient evaluation mechanisms, the teaching methods for workshop training are hard to improve. Tutors in the workshops are reluctant to update frequently to communicate with the real-world industry parties because they have to do a great deal of extra work, due to the paper-based teaching environment. It is observed that some teaching examples have been used for over 10 years without being updated or modified. These examples are unsuitable for some training items such as lathe operation because the performance of equipment, such as accuracy degree, speed, etc. has greatly improved over time. In addition, workshop training involves a large number of resources, such as training plans, equipment, materials, students, toolings, etc., which are a challenge to manage due to the limited number of tutors and the paper-based operating mechanism.
4. Challenges in training executions: Training executions are paper-based, which leads to a great deal of inflexibility. First, workshops are cluttered with paper, which are easily damaged and mislaid. This makes the teaching processes awkward. Secondly, the level of visibility is

poor, since the paper-based data is difficult to query, calculate and classify. Therefore, the bottom-up feedback system is inadequate. Thirdly, the tutors keep students' marks on a score sheet that is often filled in late because the tutors have to recall the training processes of each student and give them a mark. Finally, the management of teaching objects is expensive in both labor and time.

The main root causes of the above challenges are the lack of: Auto-ID identification for labeling various teaching objects, an information system to manage the training processes for different parties and a suitable and scientific pedagogical principle to guide the engineering education workshop training. In order to tackle these challenges, GDUT has initiated a project that aims to adopt the TELD principle in the engineering workshop training and build up a RFID-enabled EWTC in terms of hardware facilities and software components to put it into practice. This paper takes the training of a lathe-hand as an example to demonstrate how RFID technology can be used to enable the TELD principle in engineering education through three typical user's representative operations within the RFID-enabled ubiquitous workshop training environments.

3.3 Representative user operations

After the deployment of RFID devices in the workshop for lathe training and the development of associated software, the RFID-enabled EWTC was established. It has rationalized and reengineered different users' operations and behavior. Typical users are: teaching supervisors from the EWTC, tutors from various workshops and students who participate in the workshop training.

3.3.1 Teaching supervisors

Teaching supervisors mainly use the computers to open RT-EWTP to facilitate their daily operations. There are eight typical steps, which are demonstrated in Fig. 4. They are described in detail as follows:

1. Add teaching programs
According to the engineering training objectives, teaching supervisors first add teaching programs through "Teaching Programs Adding Explorer". Each program includes some critical training information such as items, credits, hours, name and the number of students, etc.

2. Select classes
Teaching supervisors open "Classes Selection Explorer" to choose a class to take part in the pre-established training program. They can determine which specific tutor is responsible for a program, given some particular requirements such as the task's accuracy, tutors' familiarity, etc. In this

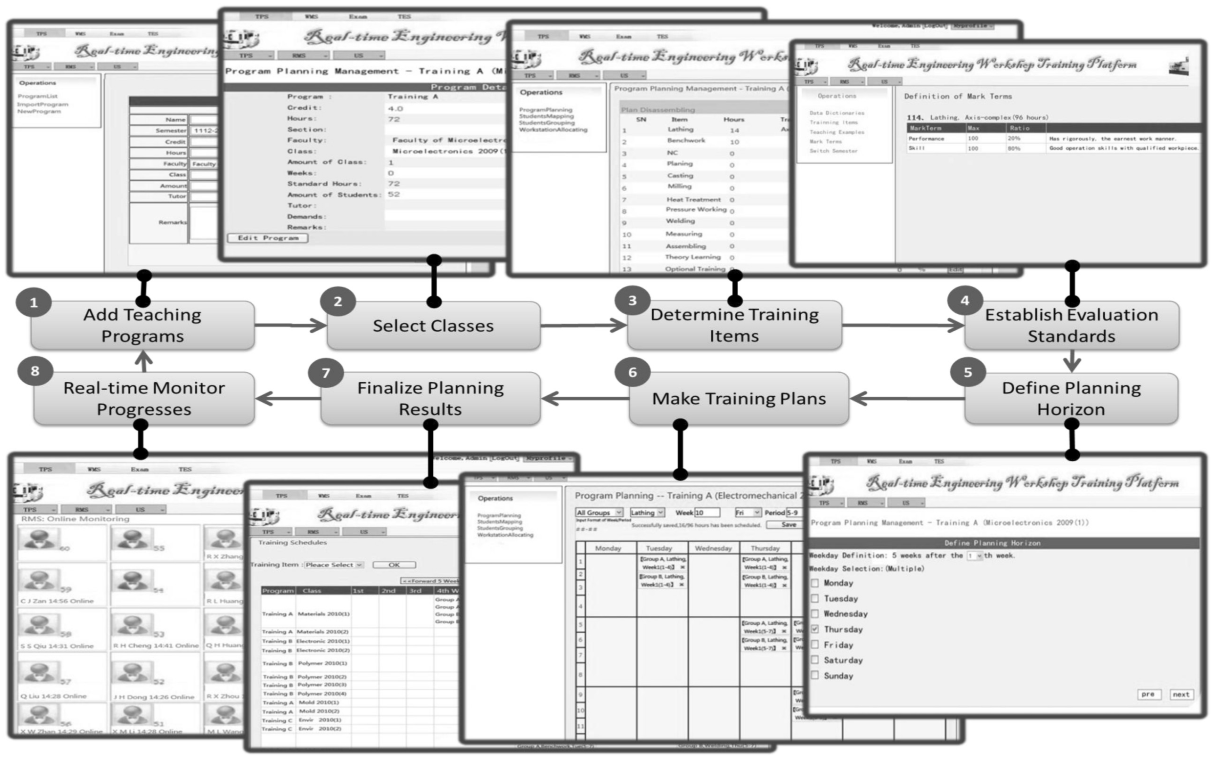

Fig. 4. Representative operations for teaching supervisors.

situation, they will describe these requirements or remarks specifically so that they can be referenced by the workshop tutors.

3. Determine training items
After selecting a class, teaching supervisors use "Training Items Determination Explorer" to determine which training items will be carried out. There are thirteen items, such as lathe, drilling, welding, etc., which are listed for supervisors to choose from because different classes will focus on different items with different training credits and hours.

4. Establish evaluation standards
Sequentially, teaching supervisors use "Evaluation Standards Setting Explorer" to establish the evaluation standards for different training items. With the evaluation standards, workshop tutors and students are able to give marks and to fulfill the training tasks, respectively, in the execution phase.

5. Define the planning horizon
Teaching supervisors define the planning horizon using "Planning Horizon Definition Explorer" after settling the training evaluations. Two elements are involved in the horizon: one is the start of teaching week; the other is the choice of teaching days of the week.

6. Make training plans
Teaching supervisors adopt "Training Plans Making Explorers" to make training plans according to the predefined horizon. The plans decide which class will execute which training item at what time. Different objective functions are developed as web services so as to meet different situations when making the plans. This is because different semester and training items have specific considerations such as optimization of equipment utilization, minimization of materials, etc. Teaching supervisors can easily make a suitable choice for a situation by picking different web services.

7. Finalize planning results
After making the training plans, the planning results are listed in "Planning Results Explorer", where the teaching supervisors have to finalize them. The finalized results will be released to the tutors in different workshops for further processing.

8. Real-time monitor progresses
After the release of the training plans, the teaching supervisors open "Real-time Progresses Monitoring Explorer" to control the training processes by putting the RFID data into a graphical fashion. Therefore, the real-time monitoring such as equipment status, student progress, material consumption, etc. could be captured and used for assisting in the decision-making.

From the above steps, the operations of the teaching supervisors are greatly improved in several ways. In the first place, RT-EWTP provides a set of explorers that are standardized and logical to facilitate their operations. Secondly, the paper-based operations are replaced by the web-based system, so that the working efficiency is significantly improved. Thirdly, feedback from the engineering training workshops can be visualized in real-time. Therefore, if any disturbances are observed, they can make corresponding solutions that will be noticed by the frontline tutors and students immediately. Finally, the reengineered operations end the "blind-eye" situation that occurs in different training entities and the management level is improved in real-time.

3.3.2 Tutors

Tutors in workshop for lathe-hand training use computers and RFID devices to facilitate their daily operations. Fig. 5 shows the six critical steps, which are described in detail as follows:

1. Select a teaching program
Tutors first pick a teaching program through "Teaching Program Selection Explorer", which lists a set of programs that have been created by teaching supervisors. They can check the information that concerns them, such as training items, evaluation standards and so on.

2. Establish teaching examples
Tutors open "Teaching Examples Establishment Explorer" to create the teaching examples for various training items. They can update and modify these examples easily so as to keep them fresh. These examples are typically divided into three levels: simple, medium and complex and can be selected by students, given their own engineering skills.

3. Design technical pictures
"Technical Pictures Design Explorer" is used by the tutors to build up the associated technical pictures by uploading various file formats such as .BMP, .DWG, .DXF, .PDF, etc. These pictures can be downloaded by the students and can also be zoomed in on online as. Tutors can regularly update them according to different training items.

4. Assign equipment to students
Tutors choose one class and use "Equipment Arrangement Explorer" to set up the equipment for students in two ways. First is the automatic arrangement using a random mechanism. Second is manual operation, which is necessary for taking

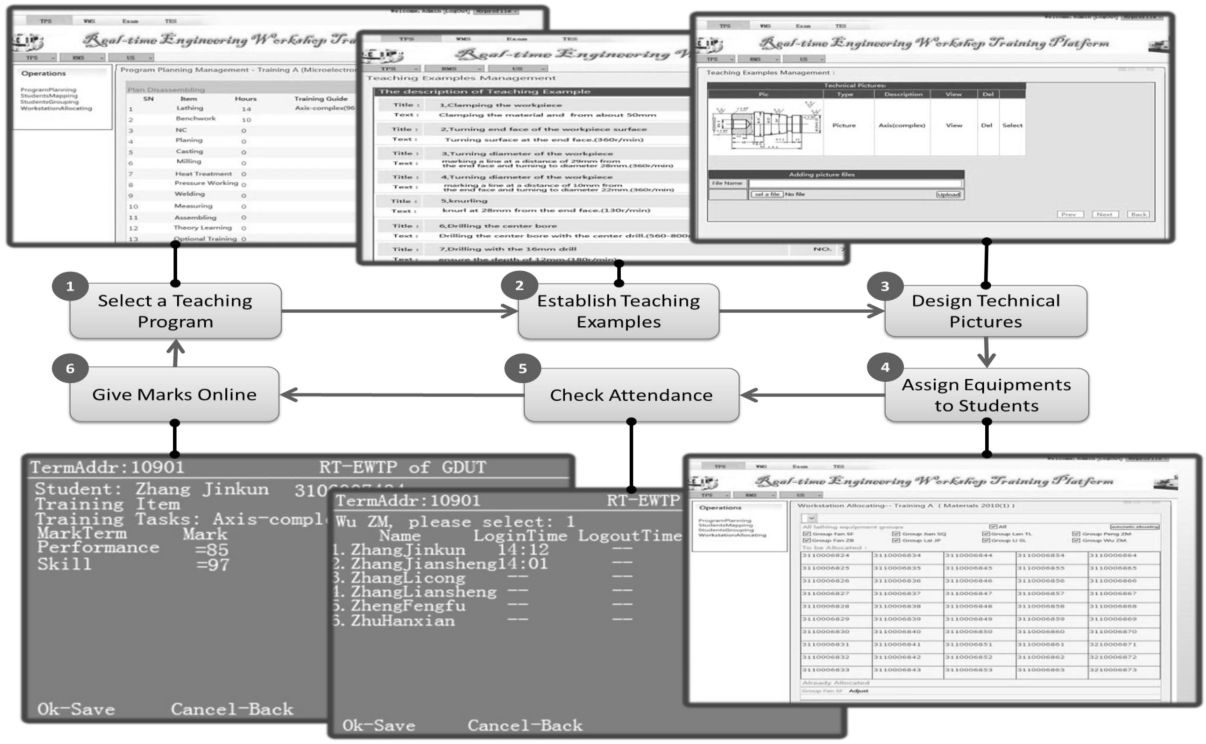

Fig. 5. Representative operations for tutors.

into account the students' skills and equipment properties. The explorer provides some functions to adjust the arrangement to deal with disturbances and emergencies, such as equipment breakdown or tutors' leave.

5. Check attendance
During the execution of workshop training, tutors are responsible for guiding some students in the workstations because students may encounter some difficulties or problems when they are learning by doing. Therefore, tutors are needed in the workshops and they can use their staff cards and pat them on an RFID reader to check on students' attendance within their equipment groups.

6. Give marks online
After a student has completed a program in the workshop training, tutors can give marks through the readers deployed on the equipment. They can check the evaluation standards and immediately make comments on students' practical operations via readers. By this online approach, marks are not delayed and are more precise and correct.

Using the six steps, the operational difficulties of tutors in different training workshops are ameliorated. First, their teaching methods become more diversified according to the different training items. This can attract students' attention and stimulate their interest in learning. Moreover, the paper-based mechanism is changed to an e-form, which is based on the Internet and RFID devices. This accelerates the speed of information transmission, resulting in more effective workshop training. Furthermore, they can use the services provided by RT-EWTP and RFID technology to control the training statuses in real-time, such as the students' arrivals, the equipment situation, etc. This strengthens their ability to overcome any disturbances or emergencies. Finally, through the working mechanism, the distance between the workshop tutors and students is reduced. This improves their interactions, which may lead to better and more harmonious teaching and learning.

3.3.3 Students

Students are able to use both RT-EWTP and RFID devices for their engineering workshop training; this is divided into two phases. One is "learning from examples", which is provided by the RT-EWTP via computers and Internet/Intranet. In this phase, four steps are involved. The other is "learning by doing" which is achieved by RFID technologies in the near-life workshop. In this phase, four steps are included. Both phases aim ultimately to realize the TELD principle in engineering workshop training. Fig. 6 shows these eight steps; their details are as follows:

1. Select teaching programs
Students open "Teaching Programs Selection

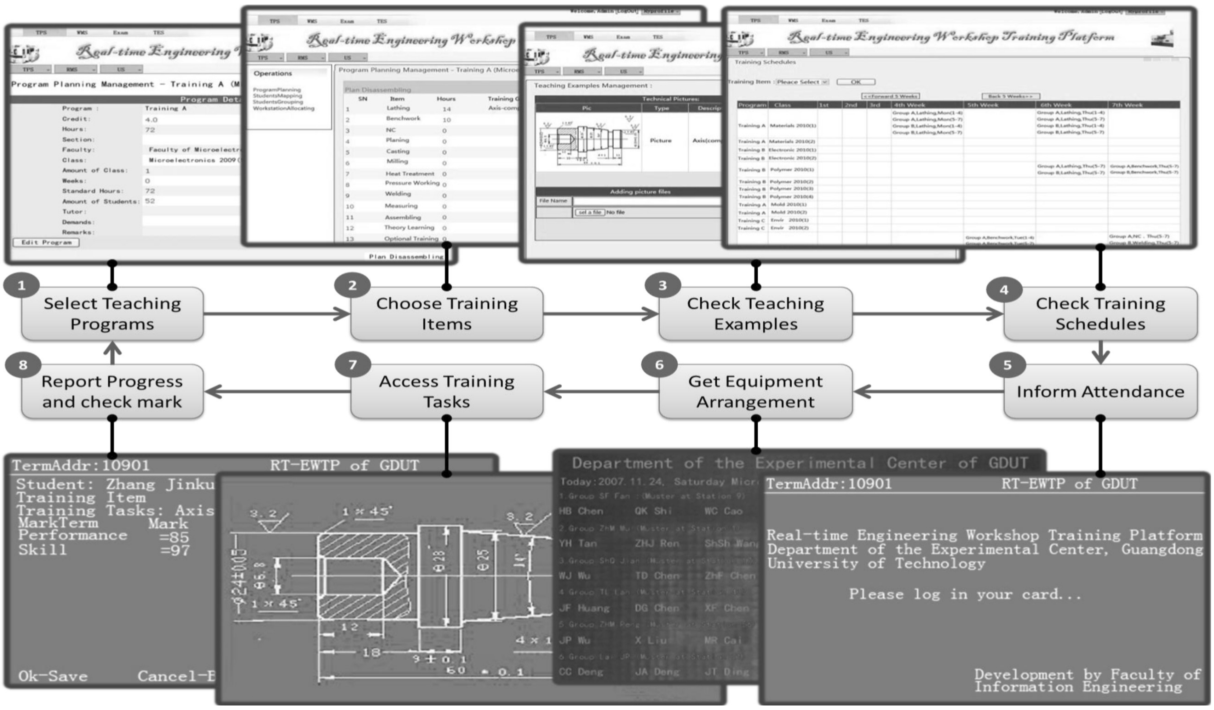

Fig. 6. Representative operations for students.

Explorer" to choose a teaching program that has teaching examples and engineering workshop training plans. They can check the corresponding information about the teaching program such as training credits, hours, etc.

2. Choose training items
Next, they open "Training Items Selection Explorer" to choose a training item from the list of workshop training. They can check the training objectives of different levels, evaluation standards, etc. Therefore, they can select suitable levels, from simple to complex, and then learn step by step.

3. Check teaching examples
After choosing a reasonable level of workshop training, students use "Teaching Examples Depository Explorer" to check the teaching examples. They are able to pick one and check the corresponding tasks, instructions and technical pictures. They can review the tutorials before classes and revise after classes as well as obtaining a comprehensive understanding before experiencing practical workshop training.

4. Check training schedules
After the learning from the examples, students check the workshop training schedules to take part in practical workshop training. The schedules determine who carries out which training item at what time and in which workshop. Therefore, the students are authorized to enter the workshop at a specific time.

5. Inform attendance
When entering the workshop, students have to pat their student cards to register their attendance. This information is immediately sent back to the system and these activities can be visualized in the "Student Attendance Explorer", which gives real-time visibility of frontline behavior to teaching supervisors or workshop tutors.

6. Get equipment arrangement
Students obtain the information about the arrangement of equipment from an LED screen, which is fixed in the lathe workshop. The information includes training items and hours, program name, tutors, etc. They can easily observe which tutor is responsible for guiding their workshop training at which workstation.

7. Access training tasks
Students pat their student cards to access training tasks through the RFID reader deployed on individual equipment. A task is downloaded from the database and displayed on the reader screen according to the student's learning records. The contents of a task involve training items, schedules, tasks instructions, technical pictures, evaluation standards, etc. Students are able to check different information through choosing various function

buttons. They can get online help as well when they press 'F1' (a specific function key in RFID readers).

8. Report progress and check mark
When the students carry out their operations to fulfill the workshop training tasks, they can input some data, such as processing steps that have been finished, etc. through the keyboard in the readers. The data are converted into the progress of each task so that tutors and teaching supervisors can monitor their developments in real-time. In addition, students are able to check their marks and comments from tutors after they complete their workshop training.

Students operations in engineering training are improved to a level that is adaptive and timely. Prior to the project, the students had no idea about what training items would be carried out in which strategy and how to fulfill the training tasks. All they obtained came from the tutors' onsite arrangement. However now, they can adaptively choose the training contents that are closest to their engineering skill level. In addition, their operations are captured by RFID technology so that their performance will be more fairly and objectively evaluated by the tutors.

3.4 Improvements

3.4.1 Qualitative improvements

RFID-enabled EWTC brings several improvements in various aspects, which are summarized as follows.

- For students, their studies become more autonomous. First, they log-in on the RT-EWTP to choose suitable tutorials, given their engineering skills, from a set of teaching examples established by the tutors. Secondly, they enter the training workshops using student cards and there fulfill various training items through the "learning by doing" principle. They are able to adaptively select training tasks according to their level of learning from the teaching examples. Finally, the students can adjust their engineering training steps after receiving comments from their tutors. For example, they can completely skip the medium level of teaching examples and execute complex level examples after fulfilling the simple ones.
- For workshop tutors, their operations are facilitated in two ways. First, RT-EWTP provides abundant services for them to build up a set of teaching examples, aimed at suiting individual students to different engineering skills. The teaching by examples mode becomes more flexible and interesting so that the students' desire to learn is greatly stimulated. Secondly, the RFID reader with predefined teaching operations eases their work as they carry out engineering training in the workshop. They can operate the device to carry out some online processes, such as checking attendance, giving marks and evaluating students' operations. These two ways are much more efficient and effective than the paper-based working mechanism.
- For teaching supervisors, their operations are more practical and precise, since training data from the frontline workshops are captured in real-time, and sent and displayed to support their decision-making. Their corresponding decisions can be retrieved by the frontline operators, such as tutors and students, on time. Therefore, they can work with the truth, go with the time and predict with the data. Ultimately the evaluation system can be established for students, tutors and workshops, aiming at achieving continuous improvement.
- For the workshop training center, the paper-based working mechanism was illuminated by using RFID technology. RFID devices are systematically deployed in workshops to collect the training data that are used for tracing and tracking various teaching objects, as well as supporting the decision makers' operations. In this way, the information sharing within the center has been improved to a level that is real-time, accurate, complete and scientific. This positively affects the efficiency of engineering teaching as well as the effectiveness of the workshop training.
- For GDUT, TELD and RFID technology has been naturally integrated and this project has enhanced its capacity for providing more chances for students to participate in workshop training. The chances are not only for GDUT students, but also for students from other universities. The improved engineering capacity increases its influence in the Great Pearl River Delta (GPRD) and thus GDUT is able to contribute to training more people for the Guangdong province and even for the whole nation.

3.4.2 Quantitative improvements

The improvements are not only qualitative, but are also quantitative. Table 1 shows a statistics analysis of the real-life data from the RFID-enabled RT-MWTC in GDUT. The data were extracted from a typical lathe workshop between 2009 and 2011, including four terms. The total service hours (TSH = student number × program hours) are calculated. Comparisons of three training courses are carried out. They are: regular training, advanced training and assistant training. Regular training means that the training items are organized by GDUT to meet their training objectives for various engineering

Table 1. Statistics analysis of TSH

	2009–2010		2010–2011		Improvements (%)	
Category	**Term 1**	**Term 2**	**Term 1**	**Term 2**	**Term 1**	**Term 2**
Regular training	88264	141184	132416	162816	50.02	15.32
Advanced training	4020	4528	4890	4618	21.64	1.99
Assistant training	4224	3936	4544	4800	7.58	21.95

students. Advanced training is some special training programs, such as engineering competitions, new technology training and advanced training courses. Assistant training is the services provided by the center to students from other universities.

From Table 1, after the establishment of the RFID-enabled real-time training workshop, the total service hours provided by the center are greatly improved. In the first term (Term 1), the improvements in these three categories are 50.02%, 21.64% and 7.58% respectively. That means that the RT-MWTC allowed about 460 extra students from GDUT to experience lathe training without adding any facilities. It also implied that the number of students participating in advanced training and assistant training increased by 29 and 11 respectively. In the second term, the services provided to the other universities were greatly improved, while the numbers in regular and advanced training were relatively less. That indicates that the boost in reputation of this center has been noticed by more universities and it can provide more engineering training services for them. The main causes of these improvement may partially be the innovative pedagogical mastery—TELD, the high technology—RFID naturally integrated into the training processes, as well as the positive promotion from all those involved.

3.5 Discussion

From the case study, several innovations are significant. First, the adoption of TELD in workshop training opens up a new perspective in which teaching by examples is carried out at the class learning stage through a web-based platform. At the learning by doing stage, students get different training items according to their engineering skill levels. Secondly, teaching resources are converted into smart teaching objects (STOs) by equipping them with RFID devices. STOs possess specific operational logics, data memory and teaching functions, and are therefore able to sense, reason, act/react/interact with each other to create an intelligent ambience in the training workshops. Thirdly, a simple-to-deploy, easy-to-use and flexible-to-access system architecture for implementing the RFID-enabled RT-MWTC is proposed through the innovative use of cutting-edge technologies such as SOA, web service, etc. The system architecture fills the information gaps between the frontline sites and control entities. Therefore, the information flow is highly synchronized, which positively affects the effectiveness and efficiency of mechanical workshop training.

The proposed RT-MWTC is also significant for students, workshop tutors, teaching supervisors and pedagogical activities.

- For the student, RT-MWTC provides an autonomous learning platform for all at different levels. Through this approach, the characteristics of individual students could be strongly explored and enhanced as RT-MWTC not only allows them to learning according to interests, but it also rouses their engineering thinking whilst they are carrying out the procedures.
- For workshop tutors, RT-MWTC encourages them to keep up with practical industry so as to feel the pulse of new engineering technologies. As a result, workshop tutors have to keep investigating and studying, which, on the one hand, improves the subject by adding new materials and tutorials into the training and, on the other hand, enhances the engineering technologies/theories by enriching their frameworks or practical cases.
- For teaching supervisors, RT-MWTC allows a real-time visibility and traceability mechanism so that they can work out strategic decisions based on the real-time information from training sites. This creates a novel method of supervision in engineering education.
- For pedagogical activities, RT-MWTC provides a real opportunity for the participants to experience an advanced teaching, learning and supervising environment. Within the environment, they can experience the natural integration of training processes and information flows, as well as the facilitation brought by the high technology.

4. Conclusions

This paper introduces an RFID-enabled real-time mechanical workshop training center (RT-MWTC). Some lessons are learned from this work. With respect to hardware, the deployment of RFID devices should cover all the teaching objects. Therefore, a deep and wide investigation before deployment is necessary. With respect to software, parallel and module design methodology greatly reduce the development cycle. With respect to operations, suitable training and effective guidance are important for allowing the end-users to catch up with the system easily and immediately.

The work has two limitations. First, all the STOs are controlled by the central system so that the reliability and robustness is relatively weak compared with a system based on agent technology. The agent integrated with RFID technology would be carried out in the ubiquitous mechanical workshop training environment to improve the entire dependability. Secondly, XML models are used in this work. It is not enough to implement the integration of control systems, such as other teaching management systems, office automation (OA) systems, etc. A standard widely used in industry could be adopted for this purpose. This is ISA-95, which compromises a set of models and terminology to determine which information could be exchanged among heterogeneous systems.

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