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# A Study on Virtual Reality-based EDM Learning Framework and Effectiveness Analysis

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## ABSTRACT

A Virtual Reality-based learning framework of electrical discharge machining (EDM) is presented in this research. The architecture supports "hands-on" exercise in precision manufacturing field for distance education and allows learners to practice and access an EDM-based virtual environment by means of the Internet. Meanwhile, a learning website has been planned and constructed in order to facilitate interactivity and support EDM. In this research, open-source software tools and virtual interactive technology available are integrated to develop an emulated, effective, learning environment for distance education. The learning architecture is built independently on specific hardware and software of EDM configuration. Conclude with an example and implementation phase for learning the prototype environment.

**Keywords:** virtual reality-based learning framework, EDM, distance education.
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## 1. INTRODUCTION

Electrical discharge machining, abbreviated EDM, is a tooling method that uses electrical energy to shape and form metal parts. EDM is a method of working exceptionally hard metals and other materials that are difficult to machine cleanly with more conventional methods; EDM also removes metal from a basic workpiece until the desired part is attained. There is no actual contact between the electrode and the workpiece, but rather a conductive path that is established between the electrode and the material. This process takes place in a bath of dielectric fluid, which prevents premature sparking, conducts electricity between the electrode and the workpiece and then flushes out the melted material.

Using this process is extremely accurate and reliable, so it is becoming an increasingly popular choice for many manufacturing companies. Another advantage of EDM is its ability to machine parts on an extremely small scale. Industries that benefit from the use of the electrical discharge machining process include automobile, stamping, electronics, aerospace and medical.

Meanwhile, distance learning can be defined as a delivery mode or method of choice for meeting the needs of students [4]. It also allows the organizations to limit the costs for continuing education both by providing in-house educational facilities that can be used with a flexible and adaptive schedule and by reducing the time spent in an educational laboratory outside of the work place [2]. From the standpoint of manufacturing engineering as a distance learning program, it should provide students with the capability of making changes on the manufacturing system control parameters and further experience the outcomes. Although it is difficult to complement the lectures with hands-on laboratory applications over the Internet, many engineering courses have begun to use the WWW for demonstrations, virtual and remote laboratories, in addition to basic course management, several tools and technologies are being extensively used to supplement traditional online educational contents, e.g. Java applet, working model, etc.[3]

One of the integration of education with the Internet is a “Virtual laboratory (or workshop)” [9]. An instance of a remote animation/simulation virtual laboratory to replace physical experiments is John Hopkins University Virtual Engineering/Science Laboratory, which utilizes Java programming language and the Web to simulate engineering and science laboratory projects [8]. Furthermore, teaching simulation has several advantages when used as a part of a virtual laboratory. It offers an effective learning space for learners (e.g. students, novice in manufacturing industry) to become acquainted with a concept that a specific application related to a physical device and its control parameters at planning and operational stages without interacting with the physical equipment. Learners can experiment and learn at their own progress. The risk of harm to life and damaging the equipment will be avoided. [13]

Currently, the study of EDM focuses mostly on electrode materials and processing control with little attention to the learning system establishment of related topics. Therefore, this study applies two of the most popular technologies nowadays, Internet and virtual interaction, to develop an EDM learning platform. It is a remote simulation/operation virtual workshop to replace physical equipment, not only overcoming the time and space limitations of traditional education but also complementing the lack of interaction in general distance learning. There are several goals achieved in this research: (i) generating a prototype EDM learning architecture to implement the concept; (ii) constructing a VR-based EDM practical environment that allows end users to do exercises over the Internet; (iii) applying this system in a distance course and evaluating the learning effects.

## 2. DESIGN AND DEVELOPMENT OF THE VR-BASED EDM PLATFORM

Among researchers using VR technology in manufacturing engineering, Korves and Loftus [10] introduced VR in factory layout planning and design, allowing for more intuitive and efficient use of computer-based virtual prototypes. Examples of those who incorporated VR technology into the research of product assembly include: (i) Boud *et al.* [3] applied the technology to facilitate assembly trainings, and (ii) Banerjeee *et al.* [1] used VR together with CAD/CAM to digitalize or formalize the preservation of vital concepts, steps and experiences of the assembly process. In particularly, Jayaram *et al.* [7] developed the visual assembly design environment (VADE), which was integrated with the CAD system to facilitate the exchange of design data (including assembly, interference and component fitting allowance), extending the applications of VR technology. As for CAD/CAM technology is concerned, numerous systems have been developed in industrial fields [5-6]. Although many systems incorporate the motion of machine tools into the CAD/CAM platform have been developed and are commercially available, they are executed off-line in a stand-alone condition, not on the Internet [14].

This research discusses the methodologies associated with the generation of self-practice mode in VR-based EDM workshop. The virtual dynamic machining process has to be considered on the web except static objects in this scene. Hence the data structure of VRML model contains information of electrode and workpiece as specified by learner (by means of VRML-mode scene graph algorithm and axis-aligned ellipsoid method). Meanwhile, an agent-based operation processing planning method and simulated machining algorithm are also involved.

### 2.1 Construction of VR models

The nature of the EDM process is time-dependent, so VR enables time-dependent description of geometry and complex digital data, which is needed during all phases of model design and development. It also offers the possibility of interactive immersive or semi-immersive visualization that can be an efficient tool for the visual simulation of the EDM process. Meanwhile, it is a technology often regarded as a natural extension to 3D computer graphics with advanced input and output devices, e.g. dynamic simplified geometry description (VRML format). Currently, most CAD systems can export files in VRML format. As for more complicated geometric shapes, the exporting interface of the CAD system is used to convert them into IndexFaceSet nodes in VRML format. Focusing on the material removal in EDM, this study used the conceptual design system developed by Liang and Pan [11] to construct the prototype workpiece in VRML mode and the generic EDM manufacturing features, including hole, slot, recess and taper pocket. In addition, IndexFaceSet nodes were created and added into the feature parameters to facilitate the control of features’ geometry and topology. Finally, the parameters were fed into the EDM database established in this study.

For static objects in this scene, the completed models are then imported into 3ds MAX to implement the visualization editing of textures, lights, materials and other physical attributes by using MAXScript, a built-in scripting language in 3ds MAX. When the all geometries and textures are ready, it is worthwhile to add more realism to the world (e.g. sounds, illuminations, etc.) and to prepare some extra navigation tools (e.g. fixed cameras viewpoints that move with some objects and enable specific observations). Fig. 1 shows the overall perspective in the EDM workshop.

To achieve the EDM operating goals in this virtual environment, the VR models should behave like real objects, being controlled by events or commands (set in a specified time). To do that, it is essential to set some interactions between objects that will generate some events (sensors, routing and scripting), and to describe many possible types of behaviors and functions. A sensor is wired to a Script node (a node which contains program code) that runs a little program, usually in Java or JavaScript, when the sensor sends it a message. The wiring that connects the ***eventOut*** of one node to the ***eventIn*** of another node is called a route. The last stage is encapsulating the created model as a prototype with a suitable input/output interface.


Fig. 1: The main virtual objects in EDM workshop.

**2.2 Scene Graph and Collision Detection**

The VRML-mode scene graph represents a tree structure, with nodes connected by branches. The uppermost node in the hierarchy is the root, it connects downward to multiple internal nodes, which in turn are parents to other internal nodes or to external nodes (which are also call leaves and have no child). Internal nodes typically represent transformations, which position their children objects in space in relation to the root node or in relation to other objects. VRML-mode scene graph are not static, but change (may be due to the user's input or to object intelligent behavior) to reflect the current state of the virtual world. In the scene graph, the workpiece node (contains its Geometry, shape, etc.) is a child of an international node. After the standard gap is reached between electrode and workpiece, a collision event is created, as shown in Fig. 2. Hence, the scene graph plays an important role in speeding up collision detection for they can reflect the time and location of the collision in real time.

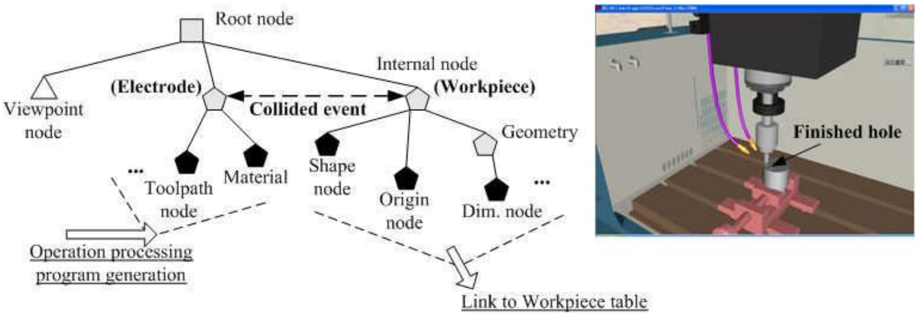



Fig. 2: A scene graph – before/after the virtual workpiece is collided by electrode.

Meanwhile, collision information is required for a variety of primitives in this study. The use of ellipsoid collision detection (in which the electrode is regarded as an axis-aligned ellipsoid) [12] in this system can reduce the problem of point classification caused by moving each of the faces bounding the solid convex regions outward. In detecting collisions between the electrode and workpiece, the system uses the following process: (i) the system detects a possible collision by finding contacts spots between the ellipsoid boundary of the electrode and any plane of the rectangular boundary of workpiece; (ii) if the contact spot is within the acceptance scope, the system will check the relative velocity of the contact points to predict if a collision will occur; (iii) if a collision is confirmed, the system will store related data for the collision response, including array index collided objects and model, normal vector, tangent vector and coordinates of collided point, and the relative velocity between model and object. The collision diction mechanism is deployed in the electrode and workpiece. In producing the collision node, the process in the system is as follows: (i) placing the CollisionObject node under the model frame intended to detonate; (ii) adding the reproduced links of CollisionManager node in the file folder under the CollisionObject node (however, the two collided objects must use the same CollisionObject node); (iii) setting the geometric shapes (GeometryType) of the collided objects. The logical connections between the collision output signals and other nodes are illustrated in format of class diagram as in Fig. 3.

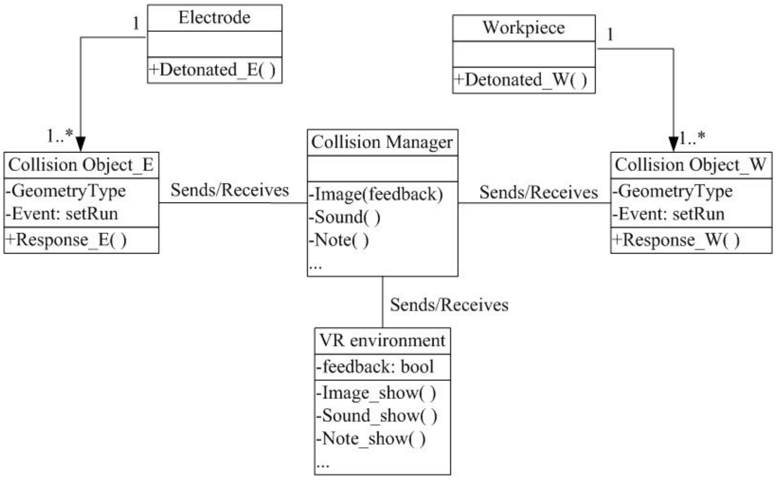



Fig. 3: UML Diagram for simplified class of collision mode.

**2.3 Structure of Virtual Reality-based System**

On the tier of client, the essential components are listed: (i) user interface - a html document interpreted by a web browser; (ii) virtual world – a VR file placed in VRML plug-in, then embedded in a html frame, interpreted by Java applet in the web server). As for the tier of server, there are three important parts: (i) dynamic webpage creation built in PHP and supported by Apache server; (ii) relational database – MySQL data management system; (iii) repository of files for storing the data of objects in art design. The relational database includes information about the following: (i) files stored in the repository; (ii) models of objects in virtual world; (iii) layouts and scenarios for EDM operating process; (iv) data of self-practice mode (e.g. table of EPI and ECODE, etc.).

Clients are passive entities directing input to the server and displaying the current state of this system. The server itself actually performs all of the system computations and acts as the communications hub for the drivers. Furthermore, two different networking protocols are used for communication in this system – TCP/IP and UDP. The problem with the former is that it has a high latency and cannot be used for messages such as positions of car model that need to be sent up to 60 times per second. By contrast, the latter does not guarantee delivery or order of packets, but does provide very low latency. Therefore, it is used for message that need to get the destination quickly but do not affect overall procedure if some are dropped.

On the other hand, the operation processing used in the EDM can be divided into the following major portions:

(1) initial portion – The initial portion defines machine origin, initial value of $z$ and $c$ two axes, start points and lengths of workpiece in $x$ and $y$ directions. Except for the machine origin which is a default value, the others are input by learners through a virtual control panel.
(2) hardware driving portion – This portion includes the closing of dielectric fluid gate, the detonation of liquid level sensor and the starting of dielectric liquid injection. In the processing, the main program will activate electrical fluid injection to remove residual metallic particles from workpiece and control processing temperature. When the processing is over, the injection will be closed and the gate will be opened.
(3) machining program portion—This portion can be further divided into main program and sub program. Usually,

some repetitive tasks and operational procedures are written as sub program and stored in the EDM database, ready to be called by main program. This division can help significantly simplify program contents. The function codes of both programs are composed of addresses and values. The addresses can be roughly divided into EPI, ECODE, GPACK and APACK.

Hence, the proposed VR-based EDM system performs the graphic simulation of a dynamic operating process through the following procedure (as shown Fig. 4): (i) when learner accesses the data (includes the size and start points in three axes of workpiece) through interface on client end, the system takes workpiece dimensions as inputs, automatically generates the workpiece VR model; (ii) the interface agent interprets and creates the operation processing program (includes main machining codes and auxiliary sections) after accepting learner inputs such as EPI and ECODE; (iii) using main machining program, the simulator finds the machining region and sends the instructions to VRML browser to visualize the electrical discharging shape. Besides, the simulator follows the auxiliary sections and performs the pre/post EDM processing, e.g. return of machine origin, coordinates' compensation, release of dielectric fluid, and so on.

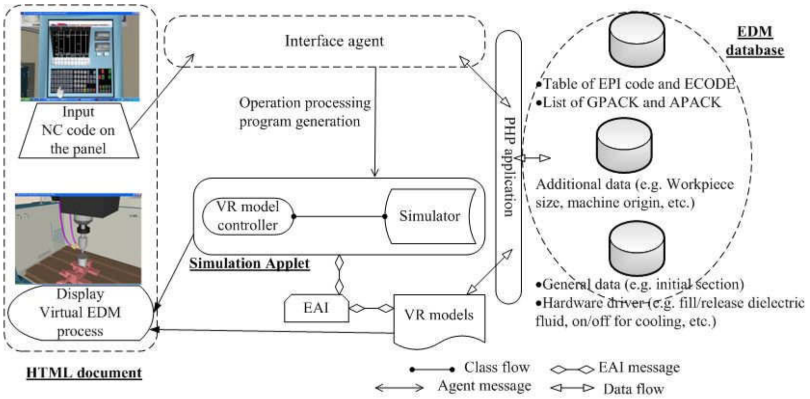



Fig. 4: Diagram of VR-based EDM learning system in self-practice mode.

In the virtual EDM learning platform, the simulate machining algorithm developed in this study has the following functions: (i) when the electrode and workpiece are within collision domain, it will respond to the system and start the processing; (ii) it will adjust the attributes of manufacturing features corresponding to processing commands and parameters to reflect the EDM results on the workpiece (including depth and diameter). Details of the algorithm are described as a flowchart in Fig. 5. VRML does not support difference operation between objects, the above collision detection between workpiece and electrode are computed and, if it exists, then difference operator subtracts the EDM manufacturing object from the workpiece.

The following is a brief description of the computing procedure:

step 1: Confirm the shape, dimension attributes, position, constraints, and non-geometric attributes according to the EPI and ECODE in the machining program section.

step 2: Use the difference operation of the kernel interpreter module [13] to conduct computing and store the generated data such as the EDM features on workpiece and the electrode height in the database.

step 3: Display processing results in the VR environment through the simulation applet.

step 4: Repeat step 1 to step 3 until all the machining program sections are implemented.

## 2.4 Modular Architecture of Interface Agent

The interface agent offers a modular design. It is designed to fit easily into new and existing agent architectures by providing the application developer an inference unit that can be contained within an agent. There are four main components: Knowledge engine, Rule, Fact, and Criteria. With these four components, it is possible to load and evaluate simple rules and assert facts. The agent also has externally defined functions that "plug-in" dynamically. Rules can be written to use these externally defined functions. These functions can take a variety of arguments, which include literal values, variables and other functions. Their functionality is limited by the Java language and the user-defined function interface. Interface agent was designed to be embedded into Java application and applet.

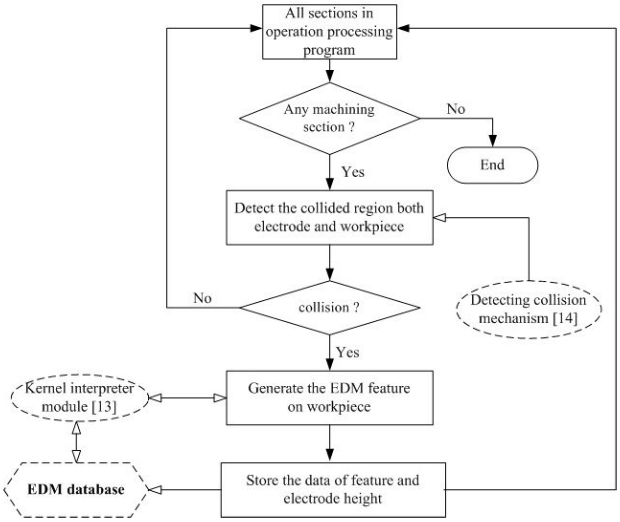



Fig. 5: Simulated machining algorithm for EDM.

The knowledge engine provides functionality to load rules, assert facts, evaluate rules and control evaluation. Fig. 6 depicts the knowledge engine functional flow. The knowledge engine may load rules from an existing file, memory, or dynamically as they are created. When a rule is loaded, the syntax of the rule is checked. If the rule is syntactically correct, the rule is placed into the rule list of knowledge engine. Since the knowledge engine implements a priority scheme, each rule has a priority associated with it. This means that when the rule is loaded, it is placed into the rule storage location of knowledge engine in an order based upon this priority. When the rules are evaluated, they are evaluated in an order that is also based on this priority. Facts can also be asserted from an existing file, memory or dynamically as they are created. The same syntax parser used for loading rules is also used for facts. Acts are also asserted after rule evaluation during execution of the knowledge engine.

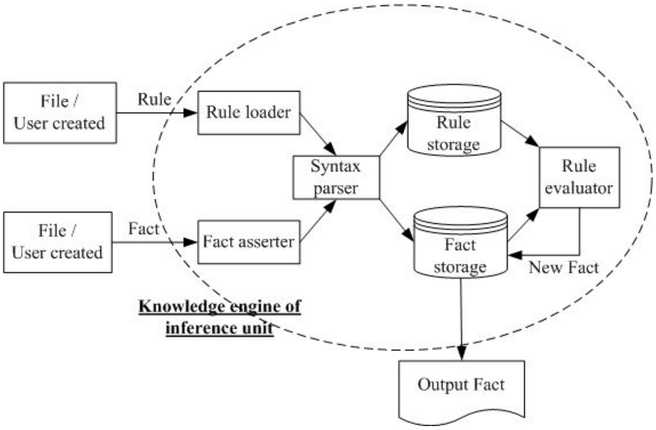



Fig. 6: The knowledge engine functional description.

The knowledge engine has two methods of rule evaluation. The first method evaluates all rules with a consistent set of facts. This means that all rules are evaluated before any new facts are added to, or retracted from, the list of active facts. Since the knowledge engine continues to evaluate until no new facts are created or until it has performed the maximum number of iterations defined by the user, all rules will eventually be evaluated with all facts. The second method of evaluation applies changes to the fact base immediately. As each rule is evaluated, all of the assertions and retractions created due to a rule firing are immediately added to, or retracted from, the list of active facts.

The Rules consist of a list of criteria and a list of assertions and retractions. It provides functionality to add and delete criteria, assertions and retractions; assess criteria; and perform the individual rule evaluation. Once a rule has been evaluated, if all of the criteria have been met, i.e. all of the conditions are true, the rule returns a list of assertions and retractions to the knowledge engine. During rule evaluation, a tree is constructed which contains all permutations of the facts in the system as they relate to the rule that is currently being evaluated. The rule then "fires" for each permutation using the facts that make up that permutation. A variety of features are supported that are activated during rule evaluation. The rule syntax allows users to define variables and user-defined functions as well as the standard pattern matching inherent to most inference unit. When a criteria is defined, a symbol preceded by a "$" signals the rule to assign the value within the fact being assessed to that symbol. This defines the symbol as a variable. As the rule continues to be evaluated, a table is created with all of the variables and their assigned values.

The Fact consists of an action, a user defined tag, and a variable length list of modifiers. A fact has two purposes: it is used as the storage type for facts in the knowledge engine and is used by the Rule to store the assertions and retractions. The action field is used by the rule to tell the knowledge engine what to do with this fact should this rule "fire". This field has three values: assert, retract and print. Assert tells the knowledge engine to add this fact to the list of active facts. Retract tells the knowledge engine to find a fact that matches this fact and remove it from the list of active facts. The print action writes output to the standard output device and is useful in evaluating and testing rule sets (satisfied or error).

The modifiers are used to discriminate between facts with the same tags. In their simplest context, a pattern-matching algorithm is used to compare modifiers as a group to determine if they are equivalent. Modifier can be captured in variables within a rule. If a modifier in a rule criterion is described as a variable, then the corresponding modifier of the fact that is being compared is put into that variable name for future use.

## 3. IMPLEMENTATION

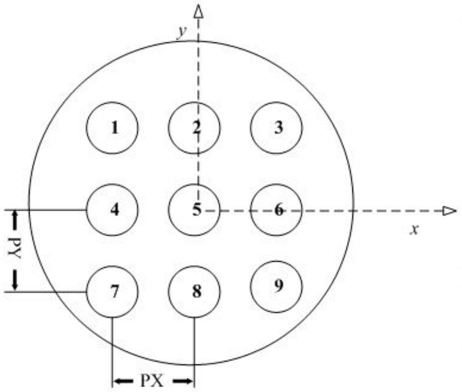
### 3.1 Example Explanation

The learning module developed in this study generally consists of three parts: (i) contents of brief edition with voice-over, (ii) on-line achievement tests, and (iii) emulated demonstration / interactive practice. By incorporating the convenience of Internet, it enables on-line learning through browsers such as IE and Firefox. Figure 7 illustrates the demonstration mode of linear hole pattern EDM on a cylinder workpiece. Fig.7(*a*) is the design draft with related processing information. Fig. 7(*b*) is the EDM procedure flowchart. In setting the initial condition, the following steps are implemented: (i) return to the machine origin; (ii) return the initial values in *z* and *c* axes; (iii) detect the start point and lengths of the workpiece to decide the workpiece origin in *x* and *y* axes. In editing EPI codes and EDM parameters, learners input the values through a virtual panel (as indicated in Fig.7(*c*)) and then the values are translated by the system into the machining program to start the dielectric liquid level setting, closing of the discharge gate, and dielectric liquid injection. Finally, the discharge gate is opened and the workpiece retrieved to complete the processing. Fig. 7(*d*) is a fragment of the whole operation program.

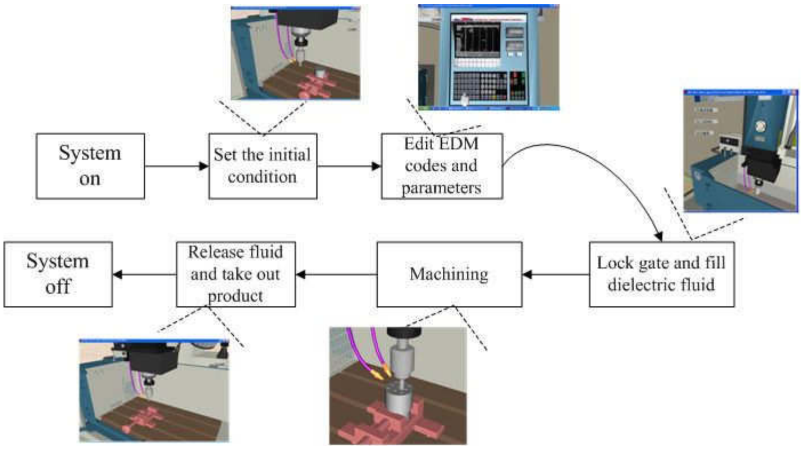
In the demonstration mode, the system automatically sets everything (including EPI, ECODE, workpiece dimensions, etc.); through this mode, learners can become more familiar with the whole processing procedure and related information.

### 3.2 Learning Effectiveness Analysis

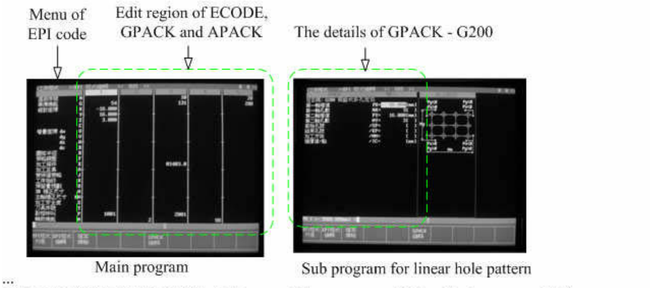
For the purpose of prototype testing, the system architecture has been implemented in the course Numerical Manufacturing System and Practice during spring semester 2006 with thirty on-site students, who acted as off-campus students. In addition to quizzes, achievement tests and practical exercises, a questionnaire survey of the students was also conducted. The questionnaire used in this study contains the following eight statements and students could express their opinions about each statement by choosing among the five options of "very disagree," "disagree," "fair," "agree," and "very agree" (Likert – summated rating scale, 1932):




(a)




(b)




```
...
G54 X-16.0 Y16.0 Z3.0 P1001  //Main machining program, P10: call sub-program N10
M02  //Program termination
//N10 - subprogram
N10 G131 [L-1.0 LR0.5 E1403.0 P2001]  //L: depth, LR: extra machining radius for  original hole,
                                       //P20: call sub-program N20
M99  //break subprogram
//N20 - subprogram
N20 G200 [PX16.0 NX3 PY16.0 NY3] //G200: linear location of hole pattern,
                                 //PX, PY: moving distance in X and Y,
                                 // NX, NY: total holes in X and Y
M99
...
```

(c)

```
//VOPP.idl
Module VOPP
{
  class sequence StringSeq<writing> { };
  //class for storing the result of inference unit
   class IROutput
   {
      short numSection; //section no. of EDM codes
     float startPos[3]; //starting point
     float length[3]; //compensation in coordinates
     float center[3]; //central position of workpiece
     bool s_gate; //switch of dielectric fluid
     bool s_level; //sensor of fluid level
   };

   class ElectrodeInfo
   {
      float toolRadius;
      short n_EL-WK;  //the material of electrode and workpiece
    }
    class sequence ElectrodeInfoSeq<ElectrodeInfo> { };

    class MMPOutput
    {
      short numSection; //section no.
      char EDMCode; //type of EDM code
      short e_value; //value of ECODE, GPACK, APACK
      short g_value; //value of GPACK
      short a_value; //value of APACK
     };
      class sequence MMPOutputSeq<MMPOutput> { };

    interface inference unit //interface for inference class
    {
      //method return the results of inference of the given codes
      IROutSeq inference(inout StringSeq inoutCodes,  in ElectrodeInfoSeq inElectrodeInfo,
          out MMPoutputSeq outMMOOutputSeq, out StringSeq outMessages);
    };
```

(d)

Fig. 7: The EDM process in demonstration mode.

- The course topics are clear and the contents are easy to understand.
- The voice-over instructions are helpful in understanding each course unit.
- The test questions are clearly stated and the question difficulty is suitable.
- The demonstration mode provides detailed descriptions and suitable references for hand-on practices.
- The practice mode effectively and vividly simulates the actual EDM processing and, therefore, can enhance learners' confidence in actual operations.
- The learning interface and VR interaction mode in the system are easy to use.
- The system is helpful in boosting learning motivation and broadening learning methods.
- The use of an Internet-based VR environment in this system can meet the goals expected by learners.

In designing the learning satisfaction questionnaire, according to the factor analysis, the components of each factor are not very different from one another in this study. Therefore, the originally decided component titles in the questionnaire are used and the component titles are in the sequence of "material" and "environment". The questionnaire uses a five-point scale to the each question. Five points are given when a learner checks "very agree", three points for "fair", and one point for "very disagree." The results indicate that the reliability of this questionnaire is acceptable with a total reliability of the scale reaching 0.91, and the reliability of each field is listed in Tab. 1 and Tab. 2. This study demonstrated that a substantial proportion of those students in the EDM course benefited from using the web-based learning system. In addition, it also demonstrated a consistent performance advantage for those students who used the web-based learning system. The paired-samples T test revealed significant differences between their pre-test and post-test (as shown in Tab. 3).

| | Scale Mean if Item Deleted | Scale Variance if Item Deleted | Corrected Item-Total Correlation | Cronbach's Alpha if Item Deleted |
|---|---|---|---|---|
| Var01 | 17.0909 | 7.3247 | .8294 | .9141 |
| Var02 | 16.9091 | 8.0866 | .7926 | .9165 |
| Var03 | 16.9091 | 9.4199 | .8005 | .9216 |
| Var04 | 16.6364 | 82424 | .8213 | .9104 |
| | | | | |
| No of Cases = 30.0 | | | | |
| Cronbach's Alpha .9285 | | | N of Items 4 | |

Tab. 1: Reliability for learning material field.

| | Scale Mean if Item Deleted | Scale Variance if Item Deleted | Corrected Item-Total Correlation | Cronbach's Alpha if Item Deleted |
|---|---|---|---|---|
| Var05 | 16.4545 | 6.5455 | .8633 | .9065 |
| Var06 | 16.9091 | 5.8009 | .7798 | .9274 |
| Var07 | 16.2727 | 6.3030 | .8840 | .9011 |
| Var08 | 16.5455 | 6.1645 | .8329 | .9101 |
| | | | | |
| N of Cases = 30.0 | | | | |
| Cronbach's Alpha .9297 | | | N of Items 4 | |

Tab. 2: Reliability for learning environment field.

| | Students | Mean | Std. Deviation | t |
|---|---|---|---|---|
| Pre-test($X_1$) | 30 | 45.2273 | 23.01538 | -4.612*** |
| Post-test($X_2$) | 30 | 65.272 | 13.25997 | |

Note: *** means $p < .001$

Tab. 3: Result for pre- and post-test.

Generally speaking, the participating students in this study indicate positive opinions about this learning system. Their responses in the questionnaire indicate that, through the learning framework and the virtual interaction functions of the system, they have acquired substantial knowledge about issues related to EDM process. Therefore, it can be said the system is significantly helpful for enhancing learners' operational knowledge and abilities. Feedback received during the course is being explored to improve the overall user-experience and the system functionality.

## 4. CONCLUSION

This study successfully developed an EDM learning system by using VR technology in the PC platform. The system is characterized by (1) allowing learners to know more about EDM technology through Internet along with Web-based textual and audio instructions that learners can repetitively read or listen to until they fully understand and absorb the course contents; (2) enabling learning anytime and anywhere via the Internet and overcoming the time and space limitations in traditional teaching; (3) incorporation of Web-based VR interaction mode that can intrigue learning interests and hence improve learning efficiency, and finally (4) the emulated model supports multi-user access to the virtual environment since it replicates the actual system. Thus there is no difference between the "real" and the "simulated" worlds from the standpoint of EDM learning.

This study also shows that there are software tools available in the market that can be integrated to develop a fairly complex learning environment for distance education. Because the architecture presented in this study is not dependent on specific EDM hardware or software, it represents a generic infrastructure.

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