Remote-Access Education Based on Image Acquisition and Processing Through the Internet

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***Abstract*—This paper describes a new system for remote education through the internet based on image processing. By means of an image acquisition system installed in the authors' laboratory, the user may interact with the remote environment and obtain visual information of the task being developed. The images acquired may be processed in order to obtain information concerning the training task. At the end of the exercise, students must answer questions related to key issues of the process and send the answers to a server. Finally, the system automatically evaluates the results. The aim of this system is to provide every element necessary for the students to self-train: theoretical background, lab equipment, and self-evaluation methods. The internet constitutes the ideal way to reach these objectives.**

***Index Terms*—Distance learning, education, evaluation, image processing, internet, self-learning.**

I. Introduction

In recent years, the issue of education through advanced technologies, such as the World Wide Web, has experienced an extraordinary growth [1]–[4]. Presently, it is common to find sites that offer training courses by the internet [5], [6]. Tools, such as e-mail, electronic tutorials, images, or video offer exciting opportunities to educators and students.

The development of online courses for remote-access education has many pros and cons [7], [4]. In the system presented in this paper, it has been shown that the more dynamic the system is, the more attractive it becomes to users, and as a consequence, also more efficient pedagogically (see Table I). Visual information is an elemental key in any online education strategy. Images provide us with very rich sources of data to understand many complex processes [8]. The system presented here is built upon these ideas, and it serves as a broad base for teaching and researching.

This paper describes in detail a new system, Laboratory Test Remote Training by means of Real Image Transmission via Internet (TITERE), which makes use of images for remote education through the internet and is available for public use at http://titere.disam.etsii.upm.es. TITERE is a controllable environment located in the authors' laboratory that can be visualized by means of a web camera. The images acquired with TITERE serve as the basis for further processing and understanding.

TABLE I
EVALUATION OF THE FIRST 85 STUDENTS WHO USED THE TITERE SYSTEM

Questions posed	Average grade [0-10] [a]
Has TITERE been a valuable tool for the developing of the subject of study?	8.5
Are the different options of TITERE suitable for the set of topics of the subject?	7.8
Did I get a better understanding of the subject by using TITERE?	8.7
Was the documentation given for learning how to use the system good enough?	6.3
Please, evaluate the degree of interaction and communication reached with the physical remote system	8.2

[a] The average grade has a rank between zero and 10 points

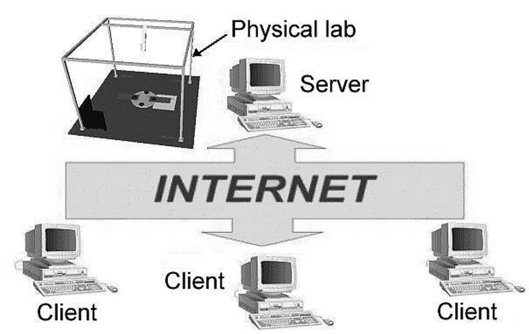

Fig. 1. Architecture of the TITERE system.

Even though this system was designed for self-training in computer vision initially, it has also been successfully employed in many other cases, such as advanced Ph.D. classes. For instance, several Ph.D.s from Latin American and European universities have used TITERE as a valuable tool, accessible from any country in the world. Since all that is needed is a simple PC with an internet connection, the teacher can use TITERE comfortably in the classroom, complementing important concepts with real experiments. With this system, it has been shown that students take an interest in the subject, pay more attention, and participate more during the lesson. Furthermore, the teacher and the students can connect and use the system at the same time. Authors frequently use TITERE in their research activities because it is totally available at any time from anywhere.

The TITERE system could be considered as a remote control laboratory [6], [9], [10]. Even though some work has been done in the field of computer vision [11], no other remote laboratory with these characteristics has been reported.

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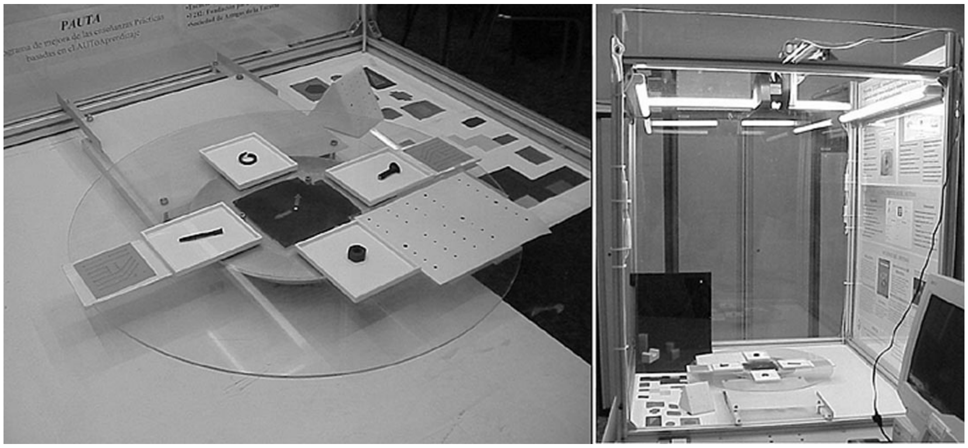

Fig. 2. Panoramic view of the physical laboratory.

The contents of this paper will unfold as follows. First, a description of the system is presented. Second, the different options the system offers will be covered in detail. Third, three examples of training tasks with TITERE will clarify the various features that this system offers. Finally, the authors' conclusions and future work will be presented in Section V.

II. System Description

The description of TITERE is divided into three parts: the modules of the system, student's tasks, and the description of how the system works internally. The first part itemizes the hardware and software of each module. The second explains briefly how students use the system, and finally, the third part explains how the different components of the architecture interact with each other. More details about how the system is used by students and a deeper knowledge of the functioning of TITERE will be given in Sections III and IV.

A. Modules' Description

The architecture of the TITERE system is described graphically in Fig. 1 and consists of three basic modules: the physical laboratory, the server, and the remote clients.

1) Physical Laboratory: This scenario is where images are taken (Fig. 2). It has the following three components: 1) color camera SONY EVI-D31 with a RS-232 link to the server PC for changing any of the three degrees of freedom (pan, tilt, and zoom); 2) rotating platform, where industrial parts and small objects to be analyzed are placed; and 3) back illumination system that can be turned on and off by remote clients.

As can be seen in Fig. 3, some color objects have been placed on the working table, and any kind of object can be added at any moment. This ability makes TITERE a very flexible system because new experiments can be added immediately.

2) Server: This computer interacts with both the physical scenario and with the remote clients through the internet. The server has the following hardware parts: 1) a PC, Pentium 100 MHz with 16 Mb of RAM memory and hard disk of 2 Gb; 2) an internet card of 10 Mb compatible NA-2000; 3) a frame grabber Matrox Meteor for image capturing; 4) a digital input/output card for controlling the rotating table and the illumination system; and 5) a camera controlled by the serial link of the PC.

The software used is: 1) Linux operating system [12]; 2) Apache web hyper test transfer protocol daemon (HTTPd) server [13]; and 3) CGI applications (common gateway interface) [14], which allow the control of the elements in the physical laboratory. CGI applications run in the server CPU and may be called from a web page. In TITERE, this web page allows the users to select the system parameters and recover the image captured.

3) Client: A client is the computer of a remote user with any operating system and with any standard internet browser with Java 1.0.2 support [15]. This support will allow the student to access the image-acquisition and image-processing environments, implemented as Java applets. There can be several clients connected to the server at the same time. The client interface can be seen in Fig. 3. The web address [16] is all that is needed to access the system. These days, without restriction, TITERE is open to anyone who wants to learn computer vision. Further details about client options will be given in Sections III and IV.

A virtual environment of the laboratory (VRML simulation [17]) has been developed to familiarize the user with the remote environment.

Some tutorials are available for the clients. They cover the most common image-processing techniques described in the literature. This tutorial is the basic reference tool to do the training task.

B. Student's Tasks

As stated in the introduction, even though the TITERE system has been used in many kinds of applications, the initial goal was for self-learning in the subject of computer vision.

Students must pass several practicals about different key issues on the subject of computer vision. In Section V, three of these practicals are explained in detail. The student must perform the following tasks.

1) Image Acquisition: The student must direct the camera, adjust the zoom, move the rotating table, and select the illumination condition to capture the best images for his/her algorithm. With this task, students learn the common problems of image acquisition using a remote environment.

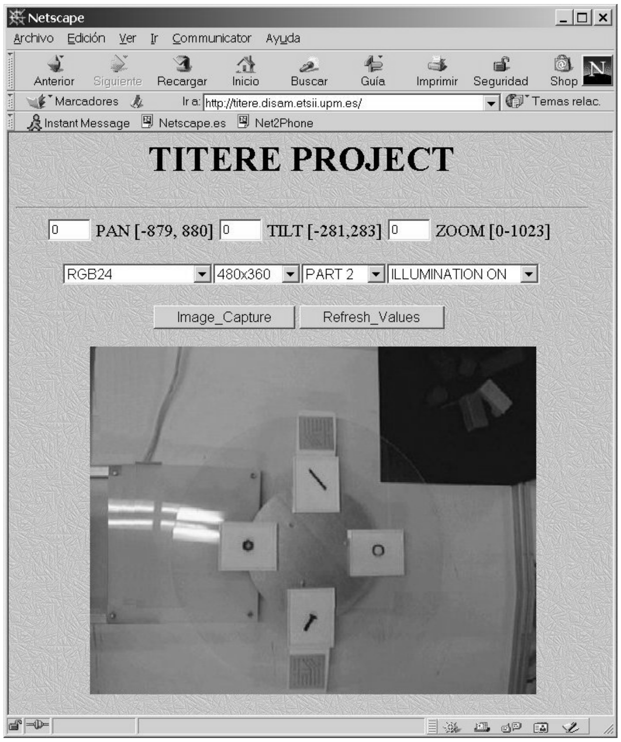

Fig. 3. Image-capturing interface of TITERE.

2) Algorithm Design: Using the image-processing environment implemented as a Java applet (Fig. 4), the student must process the image with a combination of different basic algorithms studied in class. With this task, he/she practices and experiments with the theoretical concepts.

3) Self-Evaluation Tests: Finally, the student must answer several questions in order to show himself/herself and the teacher if the student has understood the important concepts of what he/she has done. This task is very important because it automatically measures whether the teacher has been well understood and whether the knowledge of the student is adequate.

C. Operation Description

The HTTPd server receives the commands from the remote client and executes the corresponding CGI application, which is executed in the computer server. In the authors' case, this application consists of a camera-control process that modifies the environment in the laboratory and captures the image. Once this acquisition is finished, the server redirects this image to the client. Therefore, except for the input–output operation, the problem of controlling remotely a physical device is exactly the same as controlling it locally.

Since there is normally one client at a time capable of moving the camera, CGI applications are suitable, and it has not been necessary to rewrite the existing C code into a Java Servlet. Furthermore, the degree of concurrency is usually not too high (the highest peak has been 65 students connected simultaneously during a class). This approach, as has been demonstrated, is very convenient for a remote lab when not a large number of users are connected.

The frame grabber, the rotating table, and the camera, which form the physical system, are the unique external resources that

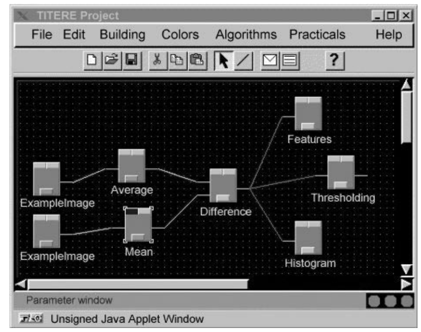

Fig. 4. Image-processing environment of TITERE. Example of algorithm for metallography analysis in Section IV.

can pose conflicts to several users. These conflicts are solved with a semaphore. The rest of the web page is managed concurrently by the Apache server in such a way that several clients can access the web site simultaneously.

The application being executed in the server knows the state of the physical system at all times. Thus, if more than one user is trying to modify the physical system at the same time, a control access manager is used to avoid conflicts. In this way, if a user accesses the system when it is in a free state, the user takes control over it. On the other hand, if the resources are occupied, the user gets a warning message to try again later. This mechanism provides a comfortable operation.

III. What TITERE Offers to the Student

This section describes the different tools available in TITERE for students. All of them are integrated into the web page and can be used and accessed with the aid of a simple internet browser.

A. Simulation

In order to ease the operation of the system, a virtual simulation representing the remote environment has been developed. It was clear after the first trials that students had problems orienting the camera toward a specific target. The addition of an interactive simulation of the scene in the laboratory makes its use easier and reduces the time to capture a specific image. This approach may also be of great help to apply this system in other fields.

B. Image Capture

The image capture interface consists of two areas (Fig. 3). The first area contains menus and text areas that allow the user to select the system parameters. The control options are related to the camera (pan, tilt, and zoom), image settings (format and size), and rotating table or illumination. The second area displays the last image captured by the system. This image has been compressed to JPEG with little loss of quality.

C. Image Processing

An image-processing module (Fig. 4) has been developed using Java and may be loaded into the client memory as applets. The interface is inspired in the well-known Khoros image-processing environment [18], which has been widely used for teaching image processing [19]. It consists of a workspace on which different blocks may be connected to create a network. Each block can perform an image-processing algorithm or a single input–output operation.

In the authors' opinion, this approach has many advantages since very complex processing tasks may be built up from basic ones. Therefore, the student can be challenged to develop newer processing strategies when facing a specific problem. Besides, the content of this working area (blocks, parameters, and connections) can be saved as easily as a text file. This process eases operations such as the recovery of previous work or evaluation as described in the following sections.

Another way of using TITERE is proposed: online or local. In order to work online, the user connects to the server, and then Java applets are loaded in the memory of the client's computer. When the browser is closed, the only way to run these programs again is by downloading the web page via internet. According to the security restrictions that Java language imposes ("Java sandbox"), an applet may not have access to the client hard disk. Only the server from which the applet was downloaded may be accessed. To be able to store the results, the user has some space available in the server hard disk. Operations, such as reading or writing files to the server are transparent to the user. If the user does not want to get connected to the server every time, a second version of the image-processing environment has been developed. This version may be stored in the hard disk and run as a local application by means of a Java interpreter. Therefore, the user only needs to get connected to the server in order to get a new image.

D. Tutorial

The tutorial consists of two different sections. The first one describes the basic image-processing techniques. It is meant to serve as a theoretical basis for the students who want to explore further in this field. The index of issues covered by this tutorial is as follows: introduction to computer vision, digitization, image features, image transformations, noise reduction, image enhancement based on histogram operations, sharpening, edge detection, morphologic transformations, geometric reconstruction, color image processing, image segmentation, feature description, and classic recognition techniques.

The second part of this tutorial is like a user manual, describing the features and functions of TITERE.

E. Tests Proposed and Auto-Evaluation

After the completion of a practical, the student must perform a test that can be accomplished directly with the internet browser. He/she can repeat the tests as many times as wished to measure his/her own evolution. Practicals are enumerated in Section IV, and three of them are explained in detail.

For each test, the objectives to be reached are as follows: a basic theoretical approach and a methodology for its development. Depending on the specific test, the images to be used may need to be captured by the user or may be predefined. In most cases, specific methods to quantify the quality of the results obtained are included.

Concerning evaluation, different strategies have been proposed. The first one consists of providing a form with specific questions about the tests proposed. The user must fill it out and send it to the server via the internet. The answers are automatically evaluated according to certain criteria specific for each test. It is worth mentioning that the criteria used to evaluate the results are not the number of correct results but the relative consistency among them. Special interest has been given in detecting incoherent answers that may indicate a lack of understanding. As a second strategy for evaluating, the user sends the teacher the original images and resulting workspace. These provide the teachers with a deeper understanding of the strategy followed by the student.

Experience in teaching this subject shows the suitability of not basing the mark in static response, since the result of a particular vision algorithm can be very different from time to time. In this way, the answer depends on the processed image and the processing algorithm the student has performed each time. Thus, the self-evaluation test measures the coherence between answers.

IV. Practicals to be Done by the Student

The following practicals have been developed: 1) noise filtering; 2) edge detection; 3) color image processing; 4) segmentation, localization, and recognition of machine parts; 5) metallography analysis; and 6) defect detection in printed circuit board (PCBs). This section describes in detail three of these six practicals.

A. Metallography Analysis

This practical consists of determining the depth of the peripheral zone of a steel rod with a high content of carbon. The surface layer appears after a cementation treatment on a steel rod in order to increase the resistance against corrosion or friction. This method provides the user with a specific tool for analyzing the size of this peripheral ring by means of morphological operations. The images to be analyzed are predefined. One of them is shown in Fig. 5.

In order to solve this specific problem, the following algorithms are proposed:

- morphologic operations (erosion, dilatation, etc.);
- binarization based on a single threshold;
- two image operations (difference, AND);
- feature generation (histogram).

Also, two specific algorithms have been developed to facilitate the solution and improve visualization.

- Distance-to-an-edge. This calculates the distance between a point that belongs to a binary object to the closest edge of the object.
- Color-highlight. It represents in color pixels an image over and under specific thresholds.

The steps to be taken are as follows.

1) Image Filtering: Starting images have a certain amount of noise. Opening and closing algorithms are proposed for noise reduction. Nevertheless, the user is free to use different algorithms.

2) Image Binarization: Images consist of three different fields corresponding to image background, surface layer, and nucleus. Students must obtain binary images that contain only relevant information of the original image; on the one hand,

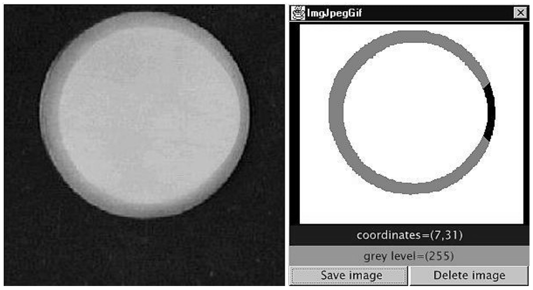

Fig. 5. Image of a steel rod and its output of the color-highlight algorithm

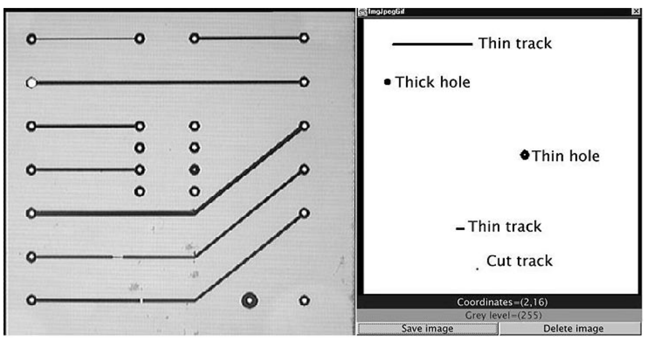

Fig. 6. Image of a PCB.

a binary image of the whole rod, that is, the surface and the nucleus, and on the other hand, a binary image of the nucleus. These two binary images (from now on referred to as ROD and NUCLEUS) need to be compact. If small spots appear in the binary objects, further filtering needs to be performed on the binary image by means of closing operations.

3) Determining the Distance to the Border: On ROD, the distance of each pixel of the binary object to the closest edge is calculated by means of the distance-to-an-edge algorithm previously mentioned. This iterative algorithm analyzes the binary object from the outer surface to the inside part. It makes use of a kernel that controls the degree of advance. The kernel proposed is a 3×3-shaped star [0 1 0;1 1 1;0 1 0]. The resulting image is a gray scale image in which the value of the pixels represents the distance to the border. This value will be referred to as DISTANCE.

4) Determining the Analysis Area: The analysis area is the boundary between the nucleus and the surface layer. The method proposed consists of dilating NUCLEUS and then subtracting NUCLEUS from the dilated image. The result is a ring-shaped binary image (from now on referred to as RING). The depth of the ring is one pixel. In order to obtain the values of the pixels in the area of analysis, one must perform an AND operation between the images RING and DISTANCE. The resulting image is called RING_DISTANCE.

5) Global Distance Evaluation: To evaluate numerically the resulting values for the distance of the pixels to the boundary of the binary image, the histogram of RING_DISTANCE needs to be calculated.

6) Enhancement of the Analysis Area: To allow a better visualization of the results, the "color-highlight" algorithm on RING_DISTANCE may be applied. By means of a single threshold, the user may represent in a different color (green) the values of the pixels whose distance to the border is higher than that threshold (Fig. 5). If the distance is less or equal, the pixels of the image become red, except for the background pixels whose value is zero and become black.

7) Final Auto-Evaluation: To evaluate the test, students must report the values of the binarization thresholds and calculate the histogram of RING_DISTANCE. This test may be performed on a set of five different images.

B. Defect Detection in PCBs

This practical enables students to clarify certain techniques for inspection of PCBs using computer vision. In order to do so, two very similar PCBs have been built for the purpose of image analysis. Although both have the same layout, some defects have been introduced in one of them. The purpose is to be able to detect certain manufacturing errors, such as engrossment, cracking on a track, etc. Both PCBs can be accurately positioned in front of the camera by means of the rotating table. An image of a PCB with a large resolution can be obtained. A back illumination system allows clear visualization of the presence or absence of each element on a PCB. Fig. 6 shows an image of one of those PCBs as seen by the camera, and the result of processing it with the image-processing environment.

Based on this approach, different analyzses can be proposed. One of them consists of detecting the presence or absence of certain types of errors in the PCBs.

In this case, the steps to be taken are as follows.

1) Gray Scale Image: As one is processing a color image, the PCB is set on a yellow board so that the user may try to dispose of irrelevant information. Since the blue color is complementary of the yellow color, the strategy proposed consists in extracting the blue component of the image.

2) Noise Reduction: The gray-level image obtained may have a certain amount of noise. A closing–opening operation is proposed as a correct treatment on the image. One may also select a region of interest in the image.

3) Segmentation: By means of selecting two different threshold levels, the user may segment the holes of the PCB and the tracks (from now on referred to as HOLES and TRACKS).

4) Searching for Cracks: The user may calculate the inverse of TRACKS. Depending on the type of defect one is looking for, he/she may perform a *hit-or-miss* morphological operation on the image using different masks. For example, if the defect to search for is a U-shaped crack, one may use the following 5×3 masks: [1 0 0 0 1;1 0 0 0 1;1 1 1 1 1] and [0 0 1 0 0;0 0 1 0 0;0 0 0 0 0].

5) Dilation of the Image Result: In order to magnify the defect found, one could perform a dilation operation on the image. Then the defect becomes clearly visible.

The student may search for different types of defects on the PCBs. The evaluation information is based on the original and final images.

C. Segmentation, Localization, and Recognition of Machine Parts

The purpose of this practical is to approach the problem of recognition based on images. The student may acquire images of different elements, such as a ring, a screw, or a nut, and calculate the most significant features of each one in order to recognize them. Fig. 7 shows examples of real images acquired with the TITERE system.

The student captures two sets of images. The first set consists of images of the same element acquired using the same resolution but from a point of view slightly modified. The second set consists of images of the same element acquired using different resolutions but from the same point of view.

The steps to be followed for the images of each element are described in the following.

1) Filtering: Images usually need to be filtered in order to avoid noise. The approach proposed consists in filtering the images using closing and opening filters. In order to reduce the amount of information to be processed, a region of interest is defined. The resulting image is referred to as WORKING_IMAGE.

2) Binary Conversion: The WORKING_IMAGE is converted to binary format using a single threshold. The user needs to find the most appropriate value. The resulting image is later inverted.

3) Analysis of Blobs: Analysis is performed on the WORKING_IMAGE. The features obtained are area, perimeter, bounds, center of gravity, compactness, and gray level of the original image. This information appears on a specific panel in the processing application.

4) Examination: Successive analysis on different images of the same element could provide statistical information about each of the features. Based on typical deviation of these results, the user could decide the features that can help recognize each element as opposed to the others.

5) Auto-Evaluation: In order to evaluate the student's work, he/she needs to answer questions related to the validity of certain features in recognition.

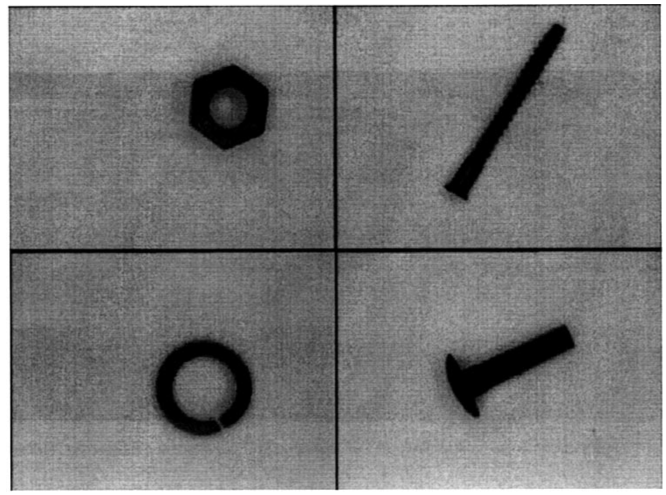

Fig. 7. Examples of real images.

V. Conclusion

The system presented constitutes another step to improve education by means of incorporating new technologies in education [20]–[22]. Some advantages of TITERE are: it allows the performing of training tasks remotely; students and teachers do not need to follow any rigid schedule; and a flexible and fast self-evaluation can be performed in real time. Having a teacher available and a real laboratory open 24 h/day for each student would be the ideal pedagogical condition. However, this situation is not realistic, and the TITERE system is more than an adequate substitute.

In TITERE, visual information is used as a base for learning. Based on a flexible design, the user is free to develop new image-processing strategies to solve practical problems. The potential of this approach has not been fully exploited yet, but new practicals for students are being developed at present.

Up to now, more than 600 students have used the system as a distance-learning tool, and nearly 100 students are using it at present, including a number of Ph.D. students from Latin American and European universities. TITERE has been successfully applied during the 1998–1999, 1999–2000, and 2000–2001 academic years on the authors' computer vision course, and the last year of the university degree in industrial engineering. The acceptance among students has been notably appreciated, as can be seen in Table I, where the evaluation of the first 85 students who used the system is shown. These grades have been similar in the two following academic years, and they have encouraged the authors to extend this experience to other subjects.

The authors are focusing on image analysis where they think many fields exist in which learning based on visual information may be greatly improved. Other fields of engineering, such as material analysis, metallurgy, automatic control, etc., are very suitable for these kinds of applications. Currently, two other projects are being developed.

The first one tries to extend the possibilities of TITERE, which is only capable of acquiring static images. The new system, called SIVANET [23], will allow the students to capture and analyze a sequence of images. The purpose is to develop new tests based on analysis of dynamic processes, such as evolution of a mechanical system, in order to help develop a control strategy.

The second is a specific application of TITERE for analyzing the internal efforts that appear on a probe when it is being tensioned. With this system, called ELASNET [24], the tensions that appear on a plastic element with complex geometry may be analyzed by means of a special color filter. Through the internet, the tension state of the probe can be modified and analyzed by color response.

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