Teaching Multimedia Data Protection Through an International Online Competition

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***Abstract*—Low-cost personal computers, wireless access technologies, the Internet, and computer-equipped classrooms allow the design of novel and complementary methodologies for teaching digital information security in electrical engineering curricula. The challenges of the current digital information era require experts who are effectively able to counteract piracy, forgery, copyright infringement, and so on. Digital watermarking is one possible technique for fighting piracy, which consists of the insertion of invisible but robust information to protect the data. In this paper, a new teaching approach, designed for testing student skills and progressing in multimedia data protection, is presented. This consists of a distributed security game where students compete by first using the developed watermarking techniques and then attacking each other's methods, thus verifying their robustness. Groups of students from different universities and countries play against each other, trying to compromise other teams' hiding systems while protecting their own data from attacks. The proposed methodology can be considered as an appealing approach for stimulating learning, cooperation, and team competition. The effectiveness of the teaching method is verified by a student survey and their academic results.**

***Index Terms*—Competitive learning, computer utilization, data hiding, digital watermarking, engineering education.**

I. Introduction

DIGITAL watermarking is a state-of-the-art technique, generally adopted for preventing users (whether malicious or not) from removing copyright information, which embeds an imperceptible mark into a multimedia document without damaging it, and which allows its recovery even after the processing of the multimedia data. Basically, a signature, known as the *mark*, is invisibly embedded inside a host data source, the *cover data*, by the owner before distribution. The basic watermarking scheme is shown in Fig. 1.

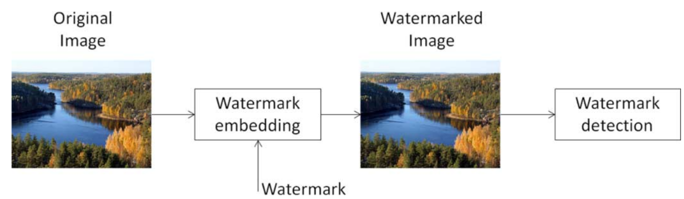

Fig. 1. Basic watermarking scheme.

Since copyright protection and content authentication potentially have a high impact on the growth of multimedia business, the importance of digital watermarking in engineering education is increasing. As a result, many universities are now including a data hiding course in their undergraduate and/or graduate curricula. These courses are usually based on lectures and laboratory projects for testing basic watermarking schemes.

Three different aspects were taken into account in the development of the proposed teaching approach. First, as demonstrated by several studies [1]–[12], collaborative learning is an effective system for spreading knowledge. It is based on the active involvement of students organized in small groups and gives more effective results than other learning formats with respect to both the amount of content learned and its retention. Moreover, it produces positive side effects, such as an increase in students' social skills, self-esteem, and tolerance of diversity. The use of this learning scheme has also been addressed by the European Union under various initiatives such as ECOLE [13] or *Leonardo* projects. Second, it is now accepted that the use of multimedia tools for teaching improves students' satisfaction and learning [14]. Finally, the use of learning by gaming has been a topic of growing interest in recent years, and computer-based games attract and motivate students. Relevant studies to support this idea were proposed by Prensky [15], [16], Gee [17], and Johnson [18]. They tried to establish and design a theoretical framework to identify how cognitive and effective such an approach can be. An exhaustive and detailed survey of learning by gaming can be found in [19].

Based on these considerations, at the Università degli Studi Roma TRE, Rome, Italy, the authors have been practicing a novel method since 2005 for teaching digital information security by using an international contest among students called *Catch the Mark* (CTM). The authors believe that in order to better understand the challenges imposed by information security problems, a direct experience of state-of-the-art watermarking schemes can be very effective. In comparison to other student competitions, in CTM each student team plays a double role: As defender, it has to design and implement its own watermarking solution; as opponent, it tries to remove or destroy the watermark inserted by other teams. This helps the students to experience the strengths and vulnerabilities of the designed algorithms in a virtual context—the competition—which mimics

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the real world. Moreover, having the students also acting as attackers forces them to better analyze the drawbacks and weaknesses of the developed technology. To assess the effectiveness of incorporating CTM into a final-year class of a M.Sc. Electrical Engineering curriculum, every year a questionnaire was given to the contest participants. The aim of this paper is to share the experience gained and to promote a debate on the use of competitive, collaborative games in graduate engineering education.

The rest of the paper is organized as follows. In Section II, the CTM game is presented. Section II-A details the methodology used in training the students for the game, and Section II-B describes the rules and the game framework. The evaluation of the student surveys is reported in Section III. Finally, some conclusions are drawn in Section IV.

II. Catch the Mark: The Competition

As was briefly described, CTM is a competition between student teams. From the beginning of the course, the students have to start training for the competition. Each group prepares a code by eventually improving upon state-of-the-art methods. The learning objective of each team is twofold. Each member of the group has to understand the problems related to data hiding and the leading methodologies to autonomously gain knowledge on the most advanced solutions in the literature and to develop his/her own solution by understanding their effectiveness and faults. In addition, he/she has to develop the ability to anticipate future requirements, scenarios, and user needs by designing test patterns (the attacks) to reveal limitations and drawbacks of the state-of-the-art solutions.

The task of each team is to design and implement a data hiding system, trying to improve upon existing methodologies. In the competition, each team has to: 1) mark a given number of multimedia contents with the developed method; and 2) perform attacks against the other teams' hiding systems in order to remove their watermarks. All data are uploaded online, where all other groups can download them, try to destroy the inserted marks, and then upload attacked versions. The effectiveness of each proposed solution is graded with respect to its ability to resist to the attacks during the competition.

Over the years, the number of students and countries involved in the CTM contest has increased. Graduate and Ph.D. student teams from France, Finland, and Romania joined Italian teams composed of students from the Universities of Trento, Trieste, and Roma TRE.

In 2009 the fifth edition of the game was held. Nevertheless, there are still technical issues that have to be addressed, as described in Section IV. The training phase before the competition is described here, as are the rules of the contest.

A. Student Training

At the Engineering Faculty of the Università degli Studi Roma TRE, each course has a duration of either 50 or 100 h, depending on the related credits. During the class, face-to-face teaching is performed with the aid of multimedia content and computer-based interactive examples. The students are asked to deepen their study by reading textbooks and articles and by attending laboratory sessions. Individual learning assessment is performed by means of homework assignments and a final examination. The data hiding topics are addressed in the first half of the semester; the remaining part of the course is devoted to cryptography.

The teaching of data hiding and watermarking is organized in two phases. In the first, the background of state-of-the-art methodologies for designing watermarking schemes is presented. The most common data hiding algorithms and architectures are detailed, detailing the peculiarities of each solution, their applicability in a particular scenario, their computational complexity, implementation issues, and their advantages and disadvantages. In the second phase, the students are asked to implement the algorithms by themselves and to assess their performance through simulation. The students are not provided with code in order to push them to think critically about solutions and not just to acquire ability in assembling already-available solutions.

During the training phase, when algorithms have to be developed, students usually form groups of three or four people. Since students may have different backgrounds and skills, this grouping is supervised by the instructor in order to ensure that each team member can actively contribute to all activities—rather than just giving a specific contribution to some highly specialized aspects—thus promoting collaborative interaction. The criteria used for determining group composition are a prior knowledge of computer simulation tools and eventually knowledge of the topic. The rationale behind this choice is to create balanced groups.

B. Contest

The watermarking contest was inspired by experiences at the University of California, Santa Barbara (UCSB), in the course ECE 178, "Fundamentals of Computer Image Processing," and the UCSB CS *Capture the Flag contest*.

The *Catch the Mark* contest is a one-day competition, usually lasting 4 or 5 h. Before competition day, each team is trained in the rules. The public advertisement of the game, posted one month before the day on the Internet, is summarized here.

- *Competition Goals*: Students have to form groups of no more than four people. Each group has to implement a technique for embedding and detecting the watermark. This technique has to comply with the requirements of invisibility, robustness, and capacity.
- *Gradings*: Each group's activity is evaluated by considering the following:
  - — the quality of their watermarked images (watermark imperceptibility);
  - — the ability of their embedded watermark to resist the other groups' attacks (watermark robustness);
  - — the number of the other groups' images from which it has succeeded in removing the watermark (activity).

The CTM competition schedule is shown in Table I. The first 20 min are devoted to the *warm up* phase, to set up network systems and to cope with possible last-minute problems. The *watermarking* phase lasts for an hour, while the *attack* phase is 2 h long. At the end of each phase, the groups are required to upload their watermarked images to the Web site. To avoid

TABLE I
CTM SCHEDULE

Typical CTM competition schedule	
Warm up	Internet connection check up
	Password distribution
	Watermark distribution
Watermarking	Download images
	Embedding phase
	Quality control
	Upload watermarked images
	Upload detection code
Attack	Download other groups' images
	Attack phase
	Effectiveness control
	Upload attacked images

multiple uploading, it is not possible to modify or to reload a processed image after it has been uploaded to the server.

At the end of the watermarking phase, after each group has uploaded the watermarked images, they become available to all other groups. Such images have to satisfy the fundamental imperceptibility and robustness requirements. As stated above, grading takes into account the quality of the watermarked data and the robustness of the embedding procedure used. At the end of the competition, all groups upload the images from which they have succeeded in removing the watermark (the number of attacked groups is highly dependent upon the single group activity and/or on the robustness of the involved data hiding methods). The tight schedule of the game forces the students to collaborate, thus reducing the possibility of unbalanced work within the groups.

Before and after the competition each group can discuss the algorithm design with the instructor, who can provide help and suggestions. The work of each group has to be shared with the whole class. Therefore, each group is asked to do the following:

- schedule a meeting with the instructor to discuss the project details and goals;
- give a brief presentation of the project during the last week of classes;
- demonstrate the project in the laboratory to the instructor or to the local supervisor;
- write a brief project report.

III. RESULTS EVALUATION

The pedagogic effectiveness of the proposed approach was assessed by means of a questionnaire focused on collecting information about background variables and the opinions and attitudes of the participants. The first part of the questionnaire records background variables such as gender (85% male, 15% female), age (average 24.8 years), year of enrollment (first and second year in Master's of Science), mean scores (28.8/30), time to prepare the final examination (1.9 months), and the final score obtained in the specific course (29.15/30 for people attending the contest).

The second section of the questionnaire, reported in Table II, is devoted to defining the general learning context: information on the availability of learning materials (if sufficient or not), resources used during the course (documents, study units, tutoring, peer-to-peer exchange, university library materials, downloadable presentations, software, past examinations, exercises, and so on), the level of interaction between teacher and student, opportunities to practice what has been learned in theory (if sufficient or not), and the possibility of creating peer groups for study. The third and fourth parts of the questionnaire are dedicated to gathering information about students level of involvement in and satisfaction with the course (see Tables III and IV). In most questions, the students were asked to associate one of five possible evaluation levels with each element of the course: a) strongly disagree (or completely useless); b) partial disagree (or somehow useless); c) neutral; d) agree (partially helpful); and e) strongly agree (very helpful). In other questions, possible answers were *yes/no*, and finally, in some cases, open answers were requested to get suggestions, criticism, and feedback from students.

Some of the results from the students attending the CTM contest are reported here. In particular, from the results shown in Table II, it can be noticed that the students gave a positive evaluation of the training phase based on the collaborative/competitive approach. In fact, the average score for all questions is greater than 4. Moreover, the opportunity to practice and to interact with the lecturer and their peers was taken advantage of and appreciated by most students.

Table III provides statistics for the answers related to evaluation of student involvement in the course. It can be seen that the training for CTM did not significantly increase the amount of time required to prepare for the exam compared to other courses, and the impact on the overall study performances was not significant. Therefore, more than 60% of students were able to prepare for more than one exam. It is worth mentioning that in Italian universities, it is common for a student to prepare for more than one exam simultaneously due to the quarter/semester class scheduling (lessons followed by exams periods). Moreover, the high percentage of students who studied in groups (74%) demonstrates the achievement of one of the goals for this approach.

Finally, the interaction with teacher and assistants was stimulated by the need for getting more details about the competition. In fact, more than 55% of students met the teacher and the assistants during "office hours" in order to improve their preparation. Very often the questions asked during these hours concerned technical details, time schedule, rules, and so on, showing students' willingness to improve both theoretical and practical skills.

From the answers to the question about the material used by the students to prepare the exam and the game, some interesting observations can be made. To prepare for the game and to increase the chance of designing an efficient watermarking algorithm, as well as using the recommended textbooks, students

TABLE II
SECTION 2 OF THE COURSE QUESTIONNAIRE

During the training classes:	Answer range (min - max)	Average score	Variance
Did you use the opportunity to interact with teacher for more details about the topic?	(1-5)	4.31	0.58
Could you test/apply what you learned during lectures?	(1-5)	4.25	0.97
Did you have enough information on the topic?	(1-5)	4.25	0.88
Did you succeed in creating study groups?	(1-5)	4.31	0.86

TABLE III
SECTION 3 OF THE QUESTIONNAIRE TO UNDERSTAND THE STUDENT INVOLVEMENT IN THE COURSE

Question	Answer range	Result statistics
Average grade in previous exams?	(18-30)	28.8 (average)
Time required to prepare for the exam?	n. months	1.9 (average)
Did you prepare other exams in the same period?	yes/no	62% yes 38% no
Did you study alone or in group?	(alone/others)	26% alone 74% group
Did you use the teacher and assistants "office hours"?	yes/no	55% yes 45% no
If *yes* how many times?	number	4 (average)
What materials did you use for studying?	free answer	—

also used lecture slides (available on the Internet for downloading) and in-class notes, books from the library, and IEEE transactions and proceeding papers on the topic. This active behavior among students can be considered as one of the positive side effects of the proposed approach. Moreover, the opportunity to learn a software simulation tool while gaming was considered to be very useful by almost all students (Matlab simulation software with the image processing toolbox was used). In fact, in the free comment and suggestion session, many students requested more time to learn the simulation software in order to have enough time to dedicate to the design phase. A common request has been to insert more lab-based classes.

The Italian participants were asked to answer the questionnaire at the end of the course. Their age was from 23 to 28 years old. Although optional, a high percentage of students completed the survey. A few students enrolled in the class (mainly those in work) were not able to attend class sessions and to thus participate to the game. These students had to take the final exam as an oral interview. After the exam, they were asked about their willingness to attend the new-style class and the interactive game. Even though they could not answer the part concerning the effectiveness of the game, almost all of them regretted not being able to attend the class, and they positively encourage the use of similar teaching methods in other classes. Their answers, together with their final grade, and the analysis of the questionnaire variables allowed different student profiles to be compiled (effective students and less effective students). In Fig. 2, the comparison of the histogram of the scores obtained in the final exam by students participating in the competition with the histogram of the scores of the students not attending the contest is reported. As can be noted, the proposed game approach produces a significant positive difference in competencies and knowledge gained. In particular, the average scores are 29.15 and 23, respectively, for the two groups of students; the scores of the students participating in the game were always higher than those of the other students, revealing a deeper understanding of the course contents. It is important to underline that in Italian universities, the scores are in the range [0, 30] with a value of 18 corresponding to the "passed" $(\mathrm{D}-)$ grade; 30 corresponds to "excellent" $(\mathrm{A}+)$ grade.

The overall evaluation of the effectiveness of the method from the point of view of the students was the subject of specific questions in Section 4 of the questionnaire. As illustrated in Table IV, this evaluation was completely positive, and the general feeling of the students about this education method can be effectively summarized by the following comment: "*thanks to the game, the interest of students is caught*." Considering the effort spent by the students in acquiring the theoretical background and the skills on the specific topic, the following percentages can be observed.

- Of the methods employed in the competition, 12% was an implementation of state-of-the-art methods. All of these were fully explained in the class material both from an algorithmic and an implementation point of view.
- There was 65% that was modifications of existing methods, trying to solve the inefficiencies of those methods (stated during classes), usually obtained by fusing together different approaches.

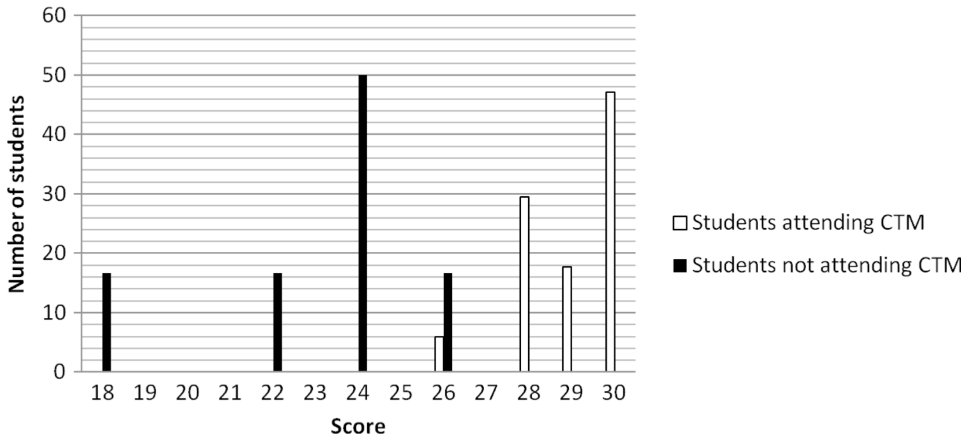

Fig. 2. Scores obtained by CTM students (white bars) with respect to nonparticipating students' scores (black bars).

TABLE IV
SECTION 4 OF THE QUESTIONNAIRE ABOUT THE STUDENT SATISFACTION

Question	Answer range	yes	no
Possibility to achieve cross-curricular skills, useful also in other classes?	(yes/no)	90%	10%
Appropriateness of the approach to the subject	(yes/no)	99%	1%
Recommended the course to others colleagues	(yes/no)	100%	0%
Would you like to have the same teaching system in other classes?	(yes/no)	94%	6%

- There was 23% that was almost completely new. Independent of their effectiveness, this active behavior is one of the main achievements obtained by this teaching scheme.

From these reported percentages, it can be seen that the goal of pushing students to think creatively was fully achieved. The effectiveness of some methods developed by the students resulted in M.S. thesis and international conference publications. Moreover, inspired by the topic as learned in the fashion proposed here, five former students of this class at Università degli Studi Roma TRE are now Ph.D. students.

IV. CONCLUSION

In this paper, the experience gained in using an online contest in education for improving both knowledge and human interaction has been presented. The goal was achieved by a competitive-collaborative learning scheme in an information technology security class. It was verified that the use of technology in education is effective, in particular when combined with creative teamwork. This allows students to exploit collaboration, learning how to work together and how to achieve goals by exploiting the skills of all team members. In particular, the game approach allows the groups to increase positive competition and to get involved in the design of high-performance algorithms.

Ongoing development of this work is based on the use of a social network framework as a precontest information-sharing instrument. The use of social networks for organizing and publicizing events is becoming more and more common. A social network group has been created (Catch The Mark) to allow discussion between students of different universities, to publish competition rules and schedule details, and to gather student feedback.[1] A Web site is also available with all the necessary information about the current year's CTM.[2]

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