Teaching with Video Assistance in Embedded Real-Time Operating System

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***Abstract*—This Full Paper for the Innovative Practice Category presents our method of successfully using micro videos as teaching assistance in the course of real-time operating system (RTOS). With the wide deployment of embedded systems, RTOS has become a very important topic in undergraduate computer engineering curriculum at many universities. Inspired by previous work of using videos in instructions, we implemented a series of micro videos for RTOS to facilitate students' understanding and practice. Different from the flipped-classroom method, our video assistants (VA) serve as a learning support rather than as a repetition or substitute to the course lectures. Students need to have normal lecture meetings to make full use of VAs. Each video is short, typically a few minutes. Each covers a topic such as summary of lectures, concept explanations, and software operation instructions. To assess the VAs, we analyze a number of factors and student attainment of the course learning outcomes. Student attainment of the course learning outcomes, as measured by the students' academic performance on exams, has demonstrated a positive effect of the VAs and that the impact is statistically significant. Additionally, students gave quite positive comments on the VAs in their evaluation of teaching.**

I. Introduction

The embedded system is an important part of a typical computer engineering curriculum. As the capability of embedded systems becomes more powerful, the need of running a real-time operating system (RTOS) on an embedded system in sophisticated contexts also becomes necessary. With the development of embedded systems, the RTOS has become a very important topic in undergraduate computer engineering curriculum at many universities. The current trend of designing software for embedded systems is clearly moving toward developing multi-task operating systems, many times under real-time constraints. For example, a major application in embedded systems is mobile computing [1]. Devices in the mobile computing environment require the system handle multiple tasks at the same time. This can only be done well with an RTOS in place. Hence, designing and implementing an RTOS is necessary for such embedded systems and the ability to design and implement an RTOS is a skill set that computer engineering undergraduates should have. In fact, an RTOS course attracts not only the students from computer engineering, but also other majors such as electrical engineering and computer science who need to design embedded systems. In addition, entry level graduate students in electrical and computer engineering also learn RTOS for implementing their projects that require complicated embedded systems.

Teaching an advanced embedded system RTOS course is challenging. The purpose of an RTOS course is to show how to apply the theory and practice of operating systems (OS) to develop OS for embedded systems that manage multiple tasks in a real time sense. The course requires solid knowledge of both the hardware and the software. The course builds upon knowledge from previous courses in circuits, computer architectures, data structures and programming. Students will learn to apply them all together in a hardware-software co-design manner. In addition to the theory part, there should be heavy hands-on experience in the learning process to give students a deeper understanding of how a complete complicated OS in embedded systems works.

RTOS is not the only challenging course in the STEM education. To help students attain maximum learning outcomes, modern technologies and pedagogical methods play a key role in teaching and learning STEM courses. A very successful technique is to use videos. The video could be a recording of a lecture or a lab tutorial. The videos can be used in both face-to-face and online teaching [2]. The method of using video lectures as a companion to classical classroom teaching is effective for a wide range of majors [3]. Systematic studies have shown that the value that students place on lecture videos as a learning resource exceeds expectations [4]. Video lectures are also a method of presenting course materials in the flipped-classroom setting [5].

Inspired by previous work using videos as a learning resource and a teaching tool, and given their great success in many STEM courses, we found that an application of video-supported teaching in RTOS is missing. This motivated us to apply videos in the RTOS course in an innovative way. With the challenges in teaching both the design theory and the hands-on implementation for RTOS, we feel that videos available out of class time may be a good aid to students. We have made a series of micro videos. Each video is short, typically a few minutes, and each covers a topic such as summary of lectures, concept explanations, sample code implementation, quiz and homework sample solution, and

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detailed software operation instructions. These videos serve as a learning support rather than as a substitute to the scheduled course lectures. There are several objectives that spurred the faculty to develop these video assistance (VA). First, the VAs help to tailor the learning process for each individual student. The VAs give students the flexibility of choosing to view, and review, whichever topics that the students feel that they understand the least. Second, the explanation of the concepts in the micro VAs are more accurate than the explanations provided by the teaching assistants or the student tutors. Third, VAs allow students to watch the micro videos at their own pace after face-to face classroom meetings. Thus, students can access the VAs when the students are involved in homework assignments or reviewing for exams, which should help reinforce the learning of difficult concepts and correct misconceptions before they have been solidified by incorrect application during the assignments.

The major novelty and contributions of our work are the following. First, the application of micro video assistance (VA) to teaching and learning RTOS is novel. VAs are best utilized when the students have attended normal classroom lectures. The VAs are not repetitions of lectures, neither are they for the purpose of flipping the classroom. Second, we propose the methodology of designing VAs. We have carefully designed VAs in terms of topics and functions. Third, we introduce the technology of making VAs. The way to construct VAs is relatively simple yet effective. It should not take too much time and efforts from the instructor and it should be easy to apply the same idea and method to other courses. The student learning outcomes and their evaluation of the teaching both validate the hypothesis that VAs help students' learning in RTOS.

The remainder of the paper is structured as follows. Section II reviews the literature of related work and motivates developing our micro video assistants (VA). Section III describes our proposed method of constructing micro VAs and the technology to make them. Section IV evaluates the effectiveness of using VAs as well as the positive recognition from students about the VAs. We conclude the paper in Section V and point out the direction for future work.

II. Related Work and Motivation

In this section, we briefly review existing work using videos in various aspects of teaching to give a motivation of developing our own micro videos in an innovative way.

Teaching with technology is recognized and recommended by many institutions. Compared with traditional power point slides, videos are richer in helping present information. They can be used in both the traditional classroom settings and the online education settings [2]. There are quite a few recent work using videos in teaching and learning. A majority of them are in lower level courses. For example, instructors have used video lectures in their flipped-classroom course of Principles of Electrical Engineering and the majority of the students felt that the experience of watching video lectures at their own pace while having experiments in the classroom was effective [6]. A circuit class has been redesigned with course materials posted online, mainly in the form of videos, for students to easily review previous course contents [7]. A three-year study on the video-based flipped-classroom style computer architecture course shows that the students had significant gains in higher order outcomes, namely, the outcomes that relate to analyzing, evaluating, and creation [5]. A case study on the impact of using the video recordings of lecture showed an increase of 9% in students' grades [3]. There are quite a few successful work using videos in the flipped-classroom setting for courses on electrical instrumentation [8] and microprocessors [9]. Sometimes, competent peer students were recruited to participate in making lab tutorial videos for other students [10]. In conjunction with online power point slides and handouts, the online videos continue to provide students with self-regulation in learning [11]. Studies on the effectiveness of using videos in teaching give evidence that the video lectures are welcome by the students and help them learn better. From students' perspective, video lectures actually increase the availability of course contents [12]. Students highly valued the lecture videos [4]. Not surprisingly, video lectures have found their place in online distance learning. For example, using online videos in the course of control systems helped the instructor to avoid repetition of course review material that was necessary, such as basic concepts in signals and systems [13].

Due to the great success of using videos in teaching, the technique of capturing lecture videos is an active research area. A list of open-source software tools that help capture videos of lectures has been summarized [14]. Different modes of content delivery have been studied to get a better understanding of the best mode [15]. Most recently, digital video processing techniques have been applied to segment out instructors from the lecture videos so the students can view clearly the whiteboard writing [16]. Cloud platforms have been utilized to host videos as well as other multimedia learning resources [17]. Techniques that facilitate segmenting topics [18], indexing and searching the videos are also proposed [4].

In addition to the flipped-classroom use of videos, the approach called "hybrid" teaching has been applied to redesign some courses. The hybrid approach has some of the lectures delivered in the traditional lecture setting while others in a flipped-classroom setting. For example, in an application of hybrid teaching in the course on circuit analysis, the student learning outcomes were evaluated in five knowledge modules. Students rated the hybrid approach the best compared to "lecture only" and "flipped-classroom" in four knowledge modules [19]. Instead of turning the entire course in to a flipped-classroom setting, a specific challenging topic has been redesigned as a flipped-classroom lecture [20].

In summary, most previous work has done a great job of making lectures into videos. The videos were either supposed to replace the traditional classroom lectures entirely or partly. In addition, recent techniques have been focused on making the indexing and search of the videos easy for students.

The success of previous work along with a few other reasons, listed as following, motivated us to make good use of videos into teaching the real-time operating system (RTOS) course. First, to master the RTOS, students need to have a good understanding on knowledge of computer architectures and data structures. If the instructor spends a lot of time reviewing the knowledge from previous courses, it would limit time available for the design theory of RTOS. Hence, it is desirable to make review materials not part of the core RTOS course. Second, the instructor, the student teaching assistants, and student tutors have limited office time. Besides the above, students themselves may not be able to make the office hours because of their own schedules. As a consequence, students may miss the precious opportunities to solve questions with the instructor or the tutors in a timely manner. Third, with different teaching assistants and tutors, students may not be able to get answers as accurate as those from the course instructor. Students prefer to get "standardized" answers from an authoritative source. Hence, it is desirable to have a mechanism to solve all the above mentioned concerns. The easy accessibility of online stored videos becomes a possible solution. If the instructor makes the videos, the instructor can choose to cover review materials in the videos. Thus, students who are strong in previous classes may omit the videos and students who need reviews may watch the videos. The first concern could be solved. The videos should be easily available to students whenever they want to watch them. Thus, the second concern should not be a problem. Finally, because it is the instructor who made those videos, the explanations in the videos should be more accurate than answers from teaching assistants and tutors under many situations.

III. Proposed Method

In this section, we describe the methodology of making micro videos for the real-time operating system (RTOS) course and the technology behind it.

A. Methodology of Making VAs

Our goal is to make micro videos an assistance to learning, like a teaching assistant or a tutor. The vidoes are not supposed to replace or repeat the classroom lectures. Hence, we call our micro videos "Video Assistance (VA)".

Specifically, we have the following design considerations for our VAs. First, all VAs are short, typically a few minutes. Second, each VA has a very clear topic. The topics include the following.

1) A summary of the entire lecture;
2) A quick review of necessary knowledge from lower level courses;
3) An explanation of a key design concept;
4) An anatomy of a piece of code;
5) A sample solution to a homework or quiz problem;
6) Detailed steps of an implementation;
7) Reference results from running the RTOS at a specific design stage.

The topics of VAs are selected according to the following thoughts. The VA should explain difficult and abstract concepts. The VA should answer commonly asked questions from the students. The VA shhould remind students of information that requires a lot of memorizing, such as software operations.

Third, most of the technical language recorded in VAs should be a careful rephrase of the language used in lectures. This consideration applies to items 1) to 5) in the above topic list. We have to clarify that the lectures never hide what should be taught and defer it to the VAs. VAs and the lectures are different in terms of how contents are presented. For example, VAs are shortened, rephrased version of key concepts. In addition, what the students see in the lectures are different from the visualization in VAs. Typically, the instructor writes on the whiteboard without using power point slides during lectures. In contrast, VAs are recordings of the computer screen in which electronic notes, including schematic diagrams and word documents are shown. For example, a typical VA recording is shown in Figure 1. Hence, students will be able to see a very different visualization in VAs than what they see in the lectures.

The third consideration is to comply with the design idea of making VA an assistant but not a replacement to the lectures. The third consideration would also encourage students to attend the lectures as usual. Students are incentivized to first attend the lectures and then watch the VAs as needed. As such, students are able to get a deeper impression of what was heard in the lectures. In fact, to help students make the best use of the VAs, attendances to the classroom lectures are mandated.

With many micro VAs, students should be able to quickly review course contents on various topics. They should be able to utilize the VAs for "standardized" advice in doing their homework. Students also have the flexibility and freedom to decide when to watch the VAs, what topics to watch, and the frequency to watch.

There are similarities between our VA method and the hybrid method [19]. However, there are obvious differences. The videos in the hybrid method and the flipped-classroom method are usually recordings of the entire lectures. Our VAs are only short summaries or rephrases of key concepts and examples. When students view our VAs, they should feel they are receiving information from a virtual instructor. The VAs are short, giving the students a feeling that they are listening to the instructor who is trying to help them recall and contemplate the digest of a lecture.

With the aforementioned design methodology for making VAs, the VAs for the real-time operating system (RTOS) course are heavily prepared for the modules on memory management unit (MMU), user mode processes and system calls. These modules are challenging to students, so VAs were made to help. There are a total of 36 VAs posted on Black Board Learn for the target modules. The recording lengths of the VAs range from 1 minute to 12 minutes.

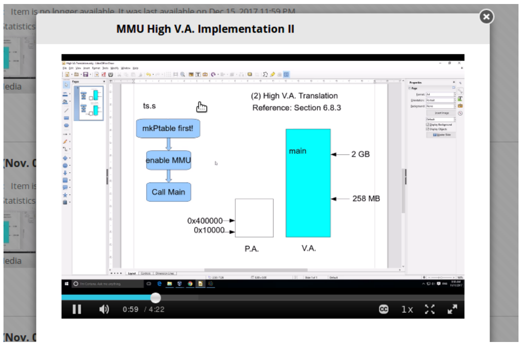

Fig. 1: A Piece of VA in KALTURA Platform

B. *Technology of Constructing VAs*

The process of creating VAs are as follows. First, the instructor prepared suitable hardware and software tools for making the VAs. Since the VAs are not a recording of the lectures, for the RTOS course the instructor only recorded the computer screen where the code and the diagrams were shown. To capture the screen, there are quite a few available techniques and software tools, commercial or open-source. The instructor had used KALTURA [21] and the OBS Studio [22]. The hardware is simply a microphone connected to the PC. In making the VA, the computer screen as well as the instructor's voice were both recorded into a video. Then the video was uploaded to the learning management system (LMS). The LMS under use was Black Board Learn. A screenshot showing the effect of displaying a VA is shown in Figure 1.

The proposed method as well as its technology were used to implement VAs as follows. For each knowledge module in the RTOS course, the instructor made VAs both before the lecture and after the lecture. First, while the instructor is preparing the lectures, the instructor would make the VAs covering important concepts and design ideas. The choices of topics for the VAs were based on the instructor's own understanding on the difficult level of the topics. As mentioned before, VAs are supposed to be short. A typical VA is about three to five minutes. For each VA, the instructor took time that was about twice the video length to make the VA. For example, for a five minute VA, the instructor would take about ten minutes to make it. Second, the instructor usually made a VA right after a lecture meeting. The reason of doing the after lecture VA is to summarize the lecture and answer important questions from the students. During the lectures, the instructor carefully recorded the questions asked by the students.

IV. Evaluation and Data Analysis

In this section, we describe our major discovery when evaluating VAs in improving student learning outcomes, measured by their scores in a module test and the final exam. We also cited comments from students in their evaluation of teaching.

A. *Data Analysis and Results*

We have obtained the IRB approval from our institute's Institutional Review Boards. Data from a total of 31 students

Fig. 2: Distribution of Total Views of the Posted VAs for the Module Test

attending the real-time operating system (RTOS) class were analyzed. We analyze the data from Blackboard Learn on the students' total number of views on the recorded VAs over two months and students' grades on a module test and the final exam. All the statistical analyses were done using the SAS University Edition [23].

We first conducted a pilot test on the effectiveness of VAs on a module test for the students. In this pilot test, a total of 6 VAs were made relating to the module test. Data from 31 students attending the RTOS course were analyzed. The average of students' module test scores is 3.65 and the standard deviation is 2.86. The students' module test scores range from 0 to 7 with median 4. The range of number of total views on the 6 VAs is from 0 to 181 with median 54. Given that the number of total views on the 6 VAs is right skewed, we performed a square root transformation.

A simple linear regression was used to study the linear relationship between the square root of the number of views on the VAs and students' module scores. Figure 2 shows the positive linear relationship between the square root of the number of views on the VAs and the students' module scores. It was found that the linear relationship between the square root of the number of views and the module test score was significant ($R^2 = 0.19, \beta = 0.35, p = 0.01$).

Next, we analyze the results for the final exam. Given the success of VAs on the module test, 35 VAs were made for the second part of the semester relating to the final exam. We analyze the data from Blackboard on the students total number of views on the 35 recorded videos and the students grade on the final exam. The mean of students' final exam scores is 52 with standard deviation 20. The range of students' final exam scores is 7.5 to 92.5 with median 55.

The range of the number of views of watching VAs related to the final exam on Blackboard Learn is from 0 to 730 with a median of 183. Figure 3 shows the distribution of total number of views. Two (2) of the students never watched any videos posted on Blackboard Learn.

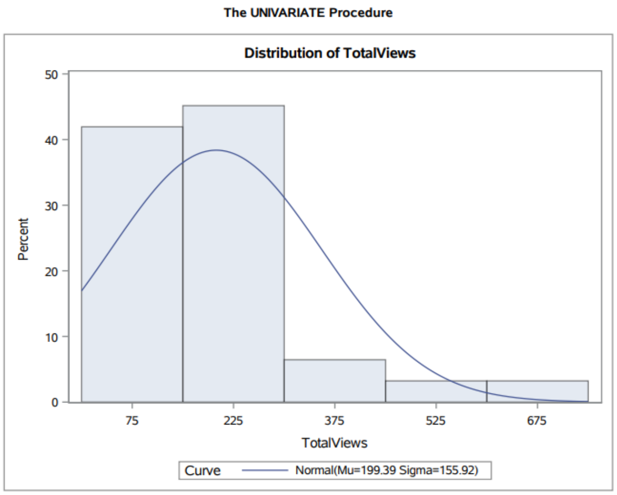

Fig. 3: Distribution of Total Views of the Posted VAs for the Final Exam

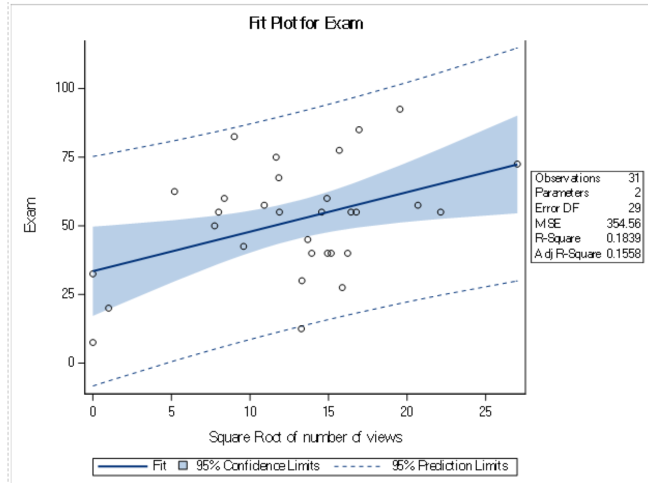

Fig. 4: Fit Plot for Exam

Students can watch the VAs as many times as they would like to. From Figure 3 we see that about 5% students watched as many as 700 times. It would be hardly imaginable that the instructor or any tutors explain a topic to a student hundreds of times. However, with the VAs, students can easily access contents that they feel they understand the least.

Since the number of times of watching videos is right skewed, as shown in Figure 3, a square root function was taken to transform the data to normalize the distribution of number of times of watching videos.

Linear regression was used to analyze the relationship between square root of number of views on the videos and the students' scores on the final exam. Figure 4 shows that the results of the regression including the scatter plot, the fitted linear model, and 95% confidence limits of the fitted model. We found that the linear relationship between square root of number of views and the exam score was significant ($R^2 = 0.18, \beta = 1.44, p = 0.016$).

We have the following major discovery. There was a positive linear association between the square root of number of views and the exam scores. As the number of views on the video increases, the estimated exam score increases. For example, the estimated exam score will increase by 14.4 if the students watched 100 times of the VAs compared with those who never watched the VAs.

B. Student Evaluation of Teaching

Students who took the RTOS course gave positive comments on the usefulness of VAs. In the following, we list the comments regarding VAs.

- "Examples of code implementation were useful, they helped with homework by explaining code as we wrote it. Having supplemental video instructions posted online was also very useful."
- "Posts videos that help further explain the content."
- "...Also the videos uploaded onto Black Board that recap a topic is a nice addition if you missed class or didn't fully understand the concept."
- "The videos that get posted on BBL really help understand the material and have answers to HW and Tests if you really listen to the videos."

In summary, based on the evaluation of students' learning outcomes, we observed that students thought they have benefited from VAs. VA had been an effective assistant in students' learning.

V. Conclusion and Future Work

This paper presents our method of successfully using micro videos as teaching assistance in the real-time operating system (RTOS) course. As embedded systems are widely used in electronic systems nowadays, RTOS has become a very important topic in undergraduate computer engineering (CE) curriculum at many universities.

Inspired by previous work of using videos in instructions, we implemented a series of micro videos for the RTOS course to facilitate students' understanding and practice. The VAs are not a repetition of the in-classroom lectures, but are selected topics on the course with careful rephrasing of the lectures. Thus, students would benefit the most from VAs if they have attended the lectures. The topics of VAs include explanations of difficult concepts, homework sample solutions, answers to in-class questions, etc. The VAs were made with easily obtained open source or proprietary software tools. The VAs are stored on a learning management system for convenient accesses.

To assess the VAs, we analyze the number of videos each student has watched and student attainment of the course learning outcomes. The evaluation of student learning include the scores for a pilot module test and the final exam. Student attainment of the course learning outcomes, as measured by the students academic performance on assignments and exams has demonstrated that there is a positive effect of the VAs and that the impact is statistically significant. There was a positive linear association between the square root of number of views and the exam scores. As the number of views on the video increases, the estimated exam score increases. Additionally, in the student evaluation of teaching, they gave quite positive comments on the VAs.

Future directions of our work could be the following. First, we are to study the effect of VAs in student learning over several offerings of the RTOS course. We could also continuously fine tune the VAs in terms of the topics they cover. Students will then be able to have a much wider selection on what to watch. With the positive and encouraging preliminary results of our VA method in the RTOS course, we will implement the same method in a Digital Signal Processing (DSP) course in addition to the RTOS course in the coming academic year. Hence, we will be able to further evaluate our method across classes and students. Second, we plan to analyze a number of factors and student attainment of the course learning outcomes. Right now, the factor we are using is the number of videos each student has watched. The new factors will include the frequency that students watched each video and the total number of views of videos on specific topics.

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