Assessing Multi-disciplinary Teamwork in an EE Capstone Design Project in Video Compression and Error Concealment Over the Internet

Paul Salama, Maher E. Rizkalla, and Charles F. Yokomoto

Electrical and Computer Engineering
Indiana University-Purdue University Indianapolis
723 W. Michigan Street
Indianapolis, IN 46033

I. Abstract

In this paper, we describe the project, the weekly activities of the team, the method for assessing teamwork, the results of the assessment of teamwork, the outcomes of the project, and the website. This paper covers both the technical and educational activities of the senior capstone design project including design approaches and weekly topics given by guest lectures that assist student accomplishment while in progressing with their technical activities.

II. Introduction

EC2000 requires that programs demonstrate the ability to work successfully on interdisciplinary teams. At the IEEE training workshops for EC2000, we have learned that this can be accomplished, at least for electrical engineering programs, using teams of students where each individual on a team is responsible for design that calls for different technical expertise from the others. Thus a project that calls for design expertise in DSP, software engineering, telecommunications, and use of the Internet would qualify as a venue for demonstrating multi-disciplinary teamwork. In this paper, we describe such a design project, where the goal of the project is the improvement of the video quality and frame rate maximization for real time video transmission between two computers over the Internet or a local Area network (LAN). Since real-time video is used, the products of the development can be used for video-conferencing, real-time medical diagnosis, real-time control of industrial processes, or any other use of real-time video.

A website that was developed to for this project covers both educational and technical aspects of the course. The educational aspects include the schedule of weekly activities, and the technical aspects including software design using a software implementation of the H.263 video compression standard and Microsoft Netmeeting, which were used for video conferencing. The site also covers methods used to accomplish error concealment when compressed data transmission is corrupted due to channel errors.

III. Context of the Design Project

All senior students in the Department of Electrical and Computer Engineering are required to take a three-credit hour, senior capstone design course. Although students have always worked in teams in this course, projects were not always structured in such as way that multi-disciplinary teamwork as "defined" at IEEE sponsored EC2000 training workshops could be assessed. In order to facilitate the assessment of multi-disciplinary teamwork, the projects were restructured.

III.1 *Criterion for Projects Sponsored by the Faculty*

In order to satisfy the multi-disciplinary dimension of the assessment of teamwork for EC 2000 and to provide students with authentic learning experiences, the projects proposed by faculty had to meet the following criteria:

1. The solution to the technical problem must be based on knowledge learned in various senior courses such as DSP, telecommunications, software engineering, multimedia applications, and advanced C programming.
2. Students on the team must be responsible for non-overlapping aspects of the project.
3. Students must be required to do library and Internet search to supplement the knowledge that they received in pre-requisite courses.
4. The project must have industrial applications.
5. Faculty expertise must be present within the Department of Electrical and Computer Engineering to ensure that faculty will be available to supervise the projects.

For the particular project discussed here, as an example of this project format, four students met the student pre-requisites. The project topic was attractive to the students because of their interest in pursuing careers in the area of the project or in pursuing an advanced degree in the area.

III.2 *Description of the Sample Project*

In order to demonstrate how a design project can be designed to satisfy the current interpretation of multi-disciplinary teamwork in a design project, we will describe a project that involved the transmission of compressed video over the Internet. This will allow the utilization of the Internet for video-conferencing, diagnostic medical procedures, and industrial process control as well as many other technologies. Students were required to investigate problems associated with the transmission of real-time audio and video, which are not immune to glitches as they are transmitted over the Internet. It is in fact more critical during real-time transmission to deal effectively with common Internet problems such as loss of data and lack of bandwidth. For instance, if excessive data is lost during the transmission of medical images, an improper diagnosis could be made which could deny a patient lifesaving treatment. If an infrared video image of a boiler is sent over the Internet and the data cannot be interpreted correctly by a control system, a boiler that is too hot could explode. The technical requirements of the project include:

1. Full understanding of how the H.263 encoder and decoder are used in the transmission of video over the Internet.
2. Modification of the manner in which a video sequence is encoded by the following:

a. Using quantization tables that would be used ideally in such a way as to directly alter the data rate of the encoded video so as to relate it to the varying load applied to the Internet at any given time,
b. Integrating error detection and concealment into the software decoder.

The educational components of the project included the following:

1. Creativity
2. Team work
3. Critical thinking and brain storming
4. Oral presentation, and
5. Writing professional report

IV. Composition of the Project Team

There were four students in the team that selected the project described in this paper. Each student was responsible for a different aspect of the project. The four areas covered were the following:

Team Member #1: Software—Modifying and adding new C++ programs for compression and decompression

Team Member #2: Hardware Selection: 3Com HomeConnect PC digital camera with detachable Universal Serial Bus (USB) cable to determine video codec to use during transmission and to monitor the bandwidth of the network.

Team Member #3: Network Interfacing

Team Member #4: Testing and integration.

V. Classroom Topics and Schedule of Technical Activities

Table 1 presents the contents of our three-credit capstone senior design course. Students met once a week in a formal class setting for lectures and student presentations. Laboratory work was done in an open-lab format, where students were given access to departmental laboratories throughout the day.

Table 1: Classroom Topics and Team Activities

Week	Classroom Topics	Team Activities Related to the Project
1-3	Faculty presentations the projects they are sponsoring, formation of teams, selection of projects.	
4-5	Library and Internet research, design methods	Reading and searching the Internet for information on the transmission of video and related problems

6-7	Instructions on making oral presentations, 1st oral presentation	Researching existing transmission techniques for solving the problem. Proposing approaches emphasizing encoding and decoding procedures via the quantization tables and the concealment of the errors caused by data loss during transmission. The approach to meet these objectives was to use and expand knowledge learned in DSP courses related to video and audio compression standards, compression/decompression codecs to design an approach to solve such problems with transmission of video over low data rates as are used with the Internet.
8-12	Writing technical professional reports, 2nd oral presentation, electronic manufacturing, human factors in design	Writing, debugging, and testing software
13-14	Third oral presentation and draft report due.	Refining the design to meet the design specifications and draft report due
15	Final presentation and submit written report	

VI. Assessing the Team Performance for ABET EC 2000

Table 2 below demonstrates how the assessment of the team's performance on the project can satisfy many of the competencies stated in EC2000's Criterion 3. The items in the left column describes the competencies that students are graded on, and the cells marked with an X show how they are linked to ABET EC2000's Criterion 3, items a-k.

VII. DESIGN OVERVIEW

The design objectives for this project were to improve the video quality and maximize the frame rate for the transmission of video between two computers over the Internet and/or a Local Area Network (LAN). A description of the students' approach is given in the following.

VII.1 *Description*

Since any communication link has a limited bandwidth, transmitting video will require that the data be compressed prior to transmission. This renders the data vulnerable to transmission losses as and varying bandwidth. The effects are normally experienced in the form of jerky video as well as low quality images. The goal is to then attempt to alter the compression factor and consequently the data rate at the sending to permit a graceful degradation of image quality at the receiving end in the event that the available bandwidth becomes constrained. In order to tackle this problem and better manage the entire project, the students broke down the project it into the following components and investigated them individually:

- Necessary Hardware
- Bandwidth
- Networking,
- Microsoft® NetMeeting® Software Development Kit (SDK), and
- Compression and Decompression.

A description of each component follows:

- Hardware: A video camera was used to capture images of the user. The camera that was utilized was the 3Com HomeConnect PC digital camera with detachable Universal Serial Bus (USB) cable.
- Bandwidth: To determine which video codec to use during transmission it was necessary to monitor the bandwidth of thenetwork. This was accomplished by the use of a bandwidth meter, the DU Meter by Hageltech.
- Networking [1]: Compressed video is sent from one computer system to another computer system by way of a network. Since the networks use protocols, which are sets of formal rules describing how data is to be transmitted, the students had to learn about the Transmission Control Protocol/Internet Protocol (TCP/IP) suite. This suite includes telnet, File Transfers Protocol (FTP), and User Datagram Protocol (UDP).
- Microsoft® NetMeeting® Software Development Kit (SDK) [2]: Microsoft® NetMeeting®'s Software Development Kit was used as a means of implementing the ideas put forth by the students. Microsoft® NetMeeting®'s SDK provides software developers with the software application programming interfaces (API) to incorporate their developed features to the Microsoft® NetMeeting® application platform. Microsoft® NetMeeting®'s SDK allows for the development of these features and the ability to incorporate them into Microsoft® NetMeeting® with the use of the C programming language.
- Compression and Decompression: To achieve real-time transmission of video, it is necessary to transmit between 25 to 30 frames/ second. This would require transmitting 207.36 Mbits/sec to 248.832 Mbits/sec through the network, in the case of ITU-R 601 sized images, or 15.2 Mbits/sec to 18.25 Mbits/sec, for QCIF images, respectively. Most networks cannot carry multiple streams with such bandwidths, hence the need for compression. Compression was accomplished by utilizing a software implementation of the H.263+ standard. With the H.263+ software the students were able to change quantization parameters as well as allow for error concealment.

VII.2 *Design Considerations*

Video compression can be implemented in software, hardware or a hybrid of software and hardware. Although each approach has similarities to the others, each has numerous advantages and disadvantages. Table 3 gives the specific advantages and disadvantages for each implementation.

The unique combinations of advantages and disadvantages make each implementation approach ideal for specific applications. The software application is ideal for the project because of its portability and low cost. Figure 1 illustrates the components utilized in the project. First, the 3Com HomeConnect PC digital camera obtains the video data. The interface between the digital camera and the computer system is accomplished with a detachable USB cable. Video can also be gathered using a parallel port transmitting digital camera. The computer system in turn compresses the video and then transmits the compressed video across the network to the receiving computer system. The network in the illustration can be either the Internet or some local area network. The receiving computer system then decodes and decompresses the information received and displays the video on a monitor.

VII.3 *Design Approaches*

The first objective of the project was to improve video transmission quality over the Internet. Specifically, this design will allow the image quality to decrease gracefully with decreasing available bandwidth while allowing real-time video transmission and reception. Since the varying bandwidth restricts the speed of the transmitted data stream, reducing the data rate of the compressed video will permit graceful degradation in video quality during the periods when the available bandwidth is restricted.

The design must monitor the data stream to guarantee minimum data for acceptable quality of image reproduction. This minimum data stream will be referred to as the Visual Threshold of the Quantized DCT Coefficients. The size of the data stream can be decreased using Quantization-Shift which increases the size of the quantization step, and hence decreases the number of DCT coefficients that have non-zero value (see Figure 2). The second design objective is to perform error concealment for received video over the Internet. This involved two different error concealment approaches, low motion and high motion concealment. The low motion technique repeats the previous block of data if the received present block exceeds predetermined error limits. The high motion approach repeats the entire previous frame if the received present block exceeds predetermined error limits. The error limit value for each design is determined using the motion estimation process within the H.263+ codec. Low motion error concealment implementation will take place during a slow motion video like an evening newscaster talking with little motion in the background. Implementation of high motion error concealment will occur with fast changing frame information as during a football game broadcast. The desired result of the high motion design will allow the frame to repeat, causing the video to appear jerky. The desired result of the low motion design will allow the frame quality to decrease showing some blockiness within the video. The procedures for error concealment are implemented at the decompression side of the process (see Figure 3).

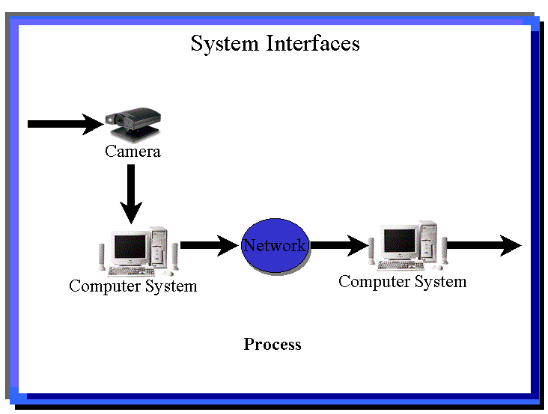


Figure 1: Components used in the project

Table 2: ABET Criteria

ABET EC2000 Criteria → / Project Scoring Criteria ↓	a. Application of knowledge of mathematics, science, and engineering	b. Designing and conducting experiences; analyzing and interpreting data	c. Designing a system, component, or process	d. Functioning on multidisciplinary teams	e. Identifying, formulating, and solving engineering problems	g. Communicating effectively	h. Global and societal impact	i. Lifelong learning	k. Use of techniques, skills, and modern engineering tools
Quality of the design process			X		X				
Internet and library research								X	
Proper use of engineering principles	X								
Proper use of design principles	X		X						
Technical competencies					X				X
Product testing		X							
Analysis and interpretation of data		X							
Success of the design			X						
Quality of the design			X						
Teamwork				X					
Global and societal concerns							X		
Writing skills						X			

Oral presentation skills						X			

Table 3: Comparison of the hardware and software implementations of video compression

Implementation Technique	Advantage	Disadvantage
Software	Portability / Multiple applications/ Easily modified (SDK) / Low cost	CPU usage
Hardware	Speed / Accuracy	Application specific High cost
Hybrid of Software & Hardware	Speed / Accuracy / Easily Modified (SDK)	Limited applications High cost

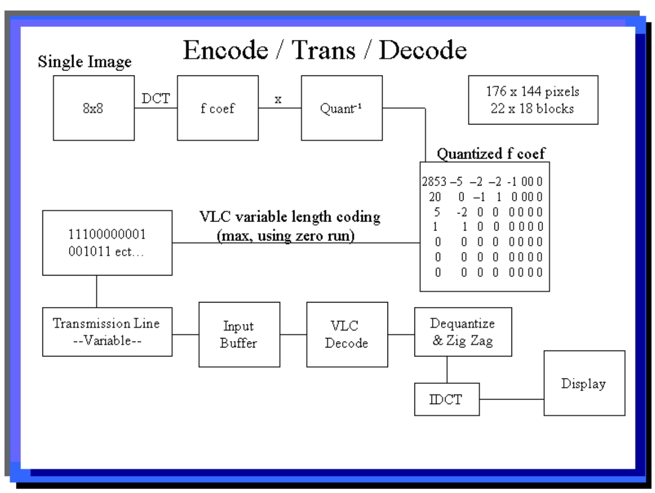


Figure 2: Compression, transmission and decompression

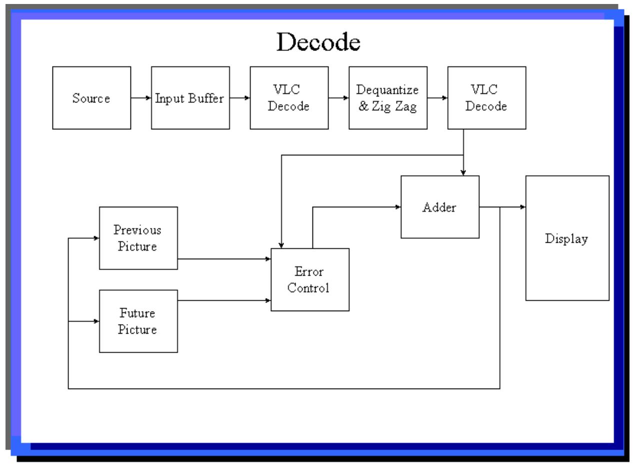


Figure 3: Frame error control diagram

VII.4 *Experiments and Results*

The following describes the experiments and simulations conducted by the students to implement and test their approaches. To test their ideas the students compressed three video sequences *Akiyo, Carphone*, and *Foreman*, each consisting of 300 frames, at varying data rates. The *Carphone* sequence has a substantial amount of changes in the background regions of the sequence. The *Foreman* sequence has less block motion and higher frame data changes than the *Carphone* sequence. The *Akiyo* sequence has very little motion and mostly unchanging frame data.

Quantization-Shift:

The students implemented a quantization-shift on an 8 x 8 block of DCT coefficients. This was done to illustrate the decrease in transmitted data rate with the implementation of the quantization-shift. The data collected includes the quantization table, the quantized DCT coefficients, and the video data stream before and after variable length coding is performed. This collected data is used for calculating the average bit length of the transmitted data stream. When performing the experiment, an 8 x 8 block of DCT coefficients was first quantized and coded using a Variable Length Code (VLC). A quantization-shift was applied to the quantization table and the original 8 x 8 block of frequency coefficients was again quantized and coded using VLC. This process was repeated using values of 1, 2, 3, and 4 for the quantization-shift, for every 8 x 8 block of DCT coefficients. Table 4 below gives the effect of varying the quantization-shift on the size of the data stream when the *Carphone* sequence was encoded at a target data rate of 32kbits/sec.

Table 4: Effect of quantization shift on transmission time and size of compressed sequence.

Quantization-Shift value	Average Size(kbits)	% Decrease in Size	Transmission time of 200 bits at 16Kbps
s=0	1.968	--------------	24.6ms
s=1	1.859	5.56%	23.2ms

s=2	1.843	6.35%	23.0ms
s=3	1.718	12.7%	21.4ms
s=4	1.515	23.0%	18.9ms

Figure 4 and Figure5 depict the effect that a quantization-shift of 10 has on the visual quality of a decoded image.

Error Concealment: Repeat Block/Frame

The students implemented a form of error concealment in which a damaged portion of the current frame was replaced by the corresponding area in the previous frame. This performed well in the case of the *Akiyo* sequence but not as well for the *Carphone* and *Foreman* sequences due to the amount of motion exhibited by these sequences. Figure 6 illustrated the regions in a frame from the Akiyo, Carphone, and Foreman sequences respectively, that can be replaced from the previous frame without greatly affecting the visual quality of the reconstructed sequence.

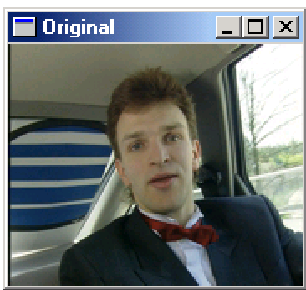


Figure 4: Original frame from *Carphone* sequence

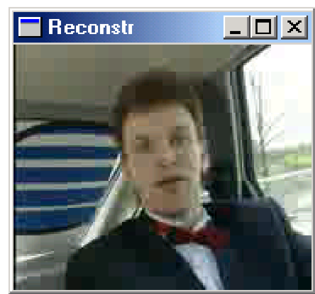
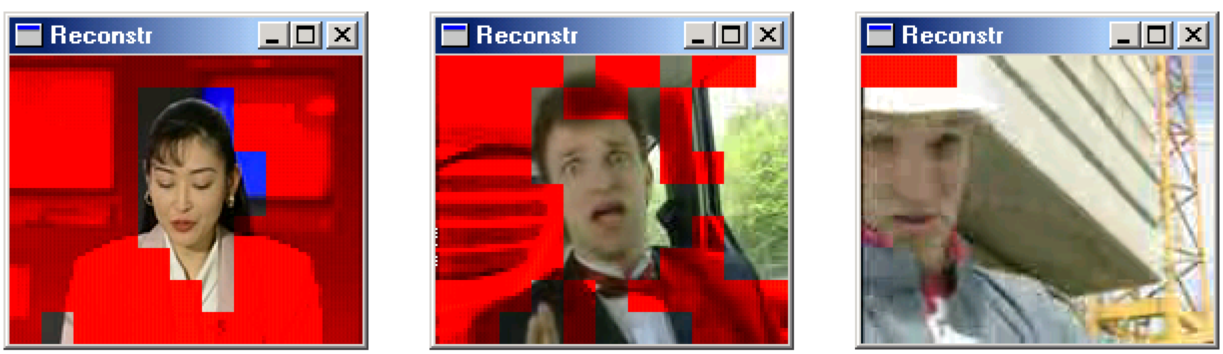


Figure5: Frame compressed at a target data rate of 32kbits/sec and quantization-shift of 10.



Frame from *Akiyo* Sequence
Low block motion
Small data frame changes

Frame from *Carphone* Sequence
High block motion
Medium data frame changes

Frame from *Foreman* equence High block motion
Large data frame changes

Figure 6: Frame regions that can be replaced from the previous frame.

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VIII. Assessing the Project and the Team

Two kinds of assessments were planned for the assessment of student performance. The first is the traditional assessment of the quality of work done, and the second is an assessment of teamwork. Both assessments will be conducted throughout the semester to give students continuous feedback. The assessment of the technical aspects of the project was based on the following:

1. Progress reports presented orally throughout the semester
2. The oral presentation of the final design
3. The written final report
4. Feedback from the project advisor

The assessment of teamwork was assessed through surveys, which ask students the following:

1. What are some of the major teamwork problems facing the team?
2. Would you like your project advisors to help you solve the teamwork problems?
3. On a scale from 1 (worst) to 5 (best), rate the team ability in the following:
   a. Solve technical problems
   b. Seek input from expert sources
   c. Work as a team
   d. Seek feedback from others on your team on personal performance
   e. Encourage and support risk taking by members of the team
4. What do you like most about your team?
5. What problems concerning your executive team would you like solved?

VIII.1 *Results of the Assessment of the Technical Aspects of the Project*

Students were evaluated individually based on their progress in the design throughout the semester. Feedback from the supervisor and the team members (students evaluated each other) was incorporated in the evaluation. Table 5 shows the evaluation of each team member.

Table 5: Evaluation of every student based on the technical aspects of the project.

Item	1st St.	2nd St.	3rd St.	4th St.	Overall
Technical competencies	A	A	B+	A	A
Product testing	A	A	A	A	A
Analysis and interpretation of data	A+	A+	A	A	A
Success of the design	A+	A	A	A	A
Quality of the design	A	A	A	A	A
Instructor evaluation of teamwork	A	A	A	A	A
Creativity	A	B+	A	A	A
Writing skills	B+	B+	B+	B	B
Oral presentation skills	A+	A	A+	A	A

VIII.2 *Results of the Assessment of the Teamwork Aspects of the Project*

This part of assessment is based on the evaluation of the team by a number of faculty members consisting of the instructor, the supervisor, and the faculty members who attended the presentation. The following summarize student activities' throughout the semester in the various items.

Table 6: Student evaluation based on his/her performance within the group.

	1st Stud.	2nd Stud.	3rd Stud.	4th Stud.	Team Grade

Quality of the design process	A	A	A	A	A
Internet and library research	B+	A	A	A	A
Identification of the problem	A	A	B+	A	A
Use of engineering principles	A	A	A	A	A
Use of design principles	A+	A+	A	A	A
Consideration of alternatives	A+	A+	A	A	A

IX. Conclusion

The project described in this paper was selected as an example of how a capstone senior design project can provide a venue for assessment multi-disciplinary teamwork for electrical engineering majors for EC2000, while simultaneously is used to assess EC2000's technically related outcomes. For this project, the project components included hardware and software design in video compression, use of the Internet to transmit audio and video, and telecommunications. The project was completed satisfactorily and students met the design specifications. Students were able to achieve a good level of success in the implementation of the quantization table modifications in order to compensate for varying bandwidth and implemented a from of error concealment.

Outcomes:

The technical and educational activities of the project are detailed in a website developed by the student under the faculty supervision:
http://www.engr.iupui.edu/~salama/courses/ee492/ee492.html

X. References

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XI. Biographies

PAUL SALAMA
Paul Salama received the Ph.D. degree from Purdue University. He is currently an Assistant Professor in the Department of Electrical and Computer Engineering, Purdue School of Engineering and Technology, IUPUI. His research interests include image and video compression, and medical imaging. He is a member of the IEEE, SPIE, Tau Beta Pi, and Eta Kappa Nu.

MAHER E. RIZKALLA
Maher E. Rizkalla is a Professor of Electrical and Computer Engineering at IUPUI. He received the Ph.D. degree in EE from Case Western Reserve University. His research interests include electromagnetics, VLSI design, electronic manufacturing, and applied engineering applications. He has developed two courses under separate FIPSE grants.

CHARLES F. YOKOMOTO
Charles F. Yokomoto is a Professor of Electrical and Computer Engineering at IUPUI. He received the Ph.D. degree in EE from Purdue University in 1970. His current interests are in the areas of assessment of learning outcomes for ABET accreditation, coaching, problem solving, and personal heuristics. He has been using the MBTI in research and classroom applications since 1980.