IMAGE ENHANCEMENT FOR IMPROVING VISIBILITY

AND FEATURE RECOGNITION

A Thesis

by

JUWAIRIA ZUBAIR

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2008

Major Subject: Computer Science

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Approved by:

Chair of Committee,	Richard Furuta
Committee Members,	Christopher M. Quick
	Frank M. Shipman
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ABSTRACT

Image Enhancement for Improving Visibility and Feature Recognition. (August 2008)
Juwairia Zubair, B.S., GIK Institute of Engineering Sciences and Technology, Pakistan
Chair of Advisory Committee: Dr. Richard Furuta

Researchers analyze images in areas such as geology, bat cardiovascular systems and art studies to verify their observations. Some images are hard to study as their details are not vivid; hence there is a need to enhance these images to facilitate their study while preserving their contents. This study is aimed at assisting the researchers in the Cardiovascular Systems Dynamic Laboratory at Texas A&M University by evaluating the importance of Image Enhancement (IE) for improving visibility of features.

For this study the images were collected and manipulated using various IE techniques and were shown to the novice researchers who were asked to perform three different tasks. These tasks were representative of the research work conducted in the lab. The techniques that were selected aimed at reducing the problems that are usually associated with data obtained from microscopic feeds. A customized application was developed to expedite and automate the study. The results indicated that the researchers did not immmensely benefit from the improved visualization for easy tasks. However, their performance improved for tasks that required more practice and skill. Our approach contributes towards designing an effective training program for novice researchers in the lab. Moreover, it is promising for similar research in different fields of study.

ACKNOWLEDGEMENTS

I would first like to thank my advisor, Dr. Richard Furuta, and my committee members, Dr. Christopher Quick and Dr. Frank Shipman, for their guidance and support throughout my research work. I would also like to express my gratitude to Marlo Nordt and Unmil Karadkar for their round-the-clock help and advice. Moreover, I would like to acknowledge the help extended by Rachel Boyle in collating the images.

Also my heartiest appreciation goes to my parents, siblings and my wonderful husband for the unconditional love and patience.

NOMENCLATURE

IE	Image Enhancement
E	Edge Enhancement
C	Clarification
O	Original
WPF	Windows Presentation Foundation
XAML	Extensible Application Markup Language
API	Application Program Interface
ID	Identification
SAR	Synthetic Aperture Radar

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CHAPTER I

INTRODUCTION

Images provide visual representation of the content that is to be examined and allow the users to reflect on them later. They are a powerful data collection medium [1], [2] that is stored easily and used indefinitely. With the advent of digital imaging, a whole new set of possibilities have opened up for professional and amateur users. The amateur users can now easily snap, store, edit and share images [3], while researchers and professional users rely on them to identify areas of interest, scrutinize details and present their findings effectively.

Image Enhancement (IE) transforms images to provide better representation of the subtle details. It is an indispensable tool for researchers in a wide variety of fields including (but not limited to) medical imaging, art studies, forensics and atmospheric sciences. It is application specific: an IE technique suitable for one problem might be inadequate for another. For example forensic images/videos employ techniques that resolve the problem of low resolution and motion blur while medical imaging benefits more from increased contrast and sharpness. To cater for such an ever increasing demand of digital imaging, software companies have released commercial softwares [4], [5] for users who want to edit and visually enhance the images.

This thesis follows the style of *IEEE Transactions on Multimedia.*

This work explores the possibility of using IE techniques to facilitate the researchers in the Cardiovascular Systems Dynamic Laboratory [6] at Texas A&M University. The researchers in this lab, also known as the “bat lab”, conduct cardiovascular research on Pallid bats by non-invasive methods. They study the bat wings under a microscope to gain insight into the mechanics of blood flow and vessels and rely on the images and videos saved from the microscope feed for their observations and analysis. At times these images are blurred, out of focus or not adequately bright which makes their examination difficult, although such problems may be fixed by using IE techniques. The purpose of this research is to evaluate if IE techniques improve the visualization of these images and to study the effect of such an approach. Additionally, this work aims at contributing towards shortening the training period of the novice researchers in the lab.

Towards this purpose, images were collected and enhanced using suitable IE techniques that minimized the problems associated with microscope data. A total of 16 students participated in the study (who will be referred to as the “subjects” in the following chapters). They were categorized into two groups based on their research expertise and were asked to perform various tasks with the images. These tasks were based on the concepts that were acquired and honed over a passage of time. They included (a) Classifying Vessel as artery or vein, (b) Identifying Capillaries and (c) Identifying Magnification factor. A customized application, similar to a Microsoft Power Point slideshow was developed to display images. It included some additional functionality to cater for the different requirements of this study. In the Classifying

Vessels and Identifying Magnification task the subjects chose between the two options provided while in the Identifying Capillaries task they drew the capillary walls on the image. The responses were saved on the computer and later compared to study the effect of different techniques on the tasks.

The data obtained was analyzed to identify interesting trends and evaluate performance of the two groups of subjects. For the Classifying Vessels and Identifying Magnification tasks the effects of IE were not very noticeable but a marked difference was observed for the Identifying Capillaries task. Hence, it was seen that IE techniques were more effective for difficult and time consuming tasks while their importance was diminished for tasks in which the researchers were proficient.

The remainder of this thesis is organized as follows: the following chapter provides an overview of the various applications of IE and the related work that has been conducted at the Cardiovascular Systems Dynamics Lab. This is followed by the description of the experimental setup of our approach for evaluating the effect of IE. The results are explained next along with the methodology adopted for analyzing the data. We conclude by highlighting the significant findings of our experiment and discussing the areas of possible future research.

CHAPTER II

BACKGROUND

Image Enhancement

IE has contributed to research advancement in a variety of fields. Some of the areas in which IE has wide application are noted below.

1. In forensics [7], [8], [9], IE is used for identification, evidence gathering and surveillance. Images obtained from fingerprint detection, security videos analysis and crime scene investigations are enhanced to help in identification of culprits and protection of victims.
2. In atmospheric sciences [10], [11], [12], IE is used to reduce the effects of haze, fog, mist and turbulent weather for meteorological observations. It helps in detecting shape and structure of remote objects in environment sensing [13]. Satellite images undergo image restoration and enhancement to remove noise.
3. Astrophotography faces challenges due to light and noise pollution that can be minimized by IE [14]. For real time sharpening and contrast enhancement several cameras have in-built IE functions. Moreover, numerous softwares [15], [16], allow editing such images to provide better and vivid results.
4. In oceanography the study of images reveals interesting features of water flow, sediment concentration, geomorphology and bathymetric patterns to name a few. These features are more clearly observable in images that are digitally enhanced

to overcome the problem of moving targets, deficiency of light and obscure surroundings.

5. IE techniques when applied to pictures and videos help the visually impaired in reading small print, using computers, television and face recognition [17]. Several studies have been conducted [18], [19], [20], that highlight the need and value of using IE for the visually impaired.
6. Virtual restoration of historic paintings and artifacts [21] often employs the techniques of IE in order to reduce stains and crevices. Color contrast enhancement, sharpening and brightening are just some of the techniques used to make the images vivid. IE is a powerful tool for restorers who can make informed decisions by viewing the results of restoring a painting beforehand. It is equally useful in discerning text from worn-out historic documents [22].
7. In the field of e-learning, IE is used to clarify the contents of chalkboard as viewed on streamed video; it improves the content readability and helps students in focusing on the text [23]. Similarly, collaboration [24] through the whiteboard is facilitated by enhancing the shared data and diminishing artifacts like shadows and blemishes.
8. Medical imaging [25], [26], [27], uses IE techniques for reducing noise and sharpening details to improve the visual representation of the image. Since minute details play a critical role in diagnosis and treatment of disease, it is essential to highlight important features while displaying medical images. This

makes IE a necessary aiding tool for viewing anatomic areas in MRI, ultrasound and x-rays to name a few.

9. Numerous other fields including law enforcement, microbiology, biomedicine, bacteriology, climatology, meteorology, etc., benefit from various IE techniques. These benefits are not limited to professional studies and businesses but extend to the common users who employ IE to cosmetically enhance and correct their images.

Inspired by the use of IE in a multitude of fields, this research aims at using these techniques in the bat lab at Texas A&M University, where researchers analyze images and videos to detect and observe different phenomenon in cardiovascular science.

Cardiovascular Research at Texas A&M University

The bat lab is home to a number of Pallid bats which are instrumental in providing insight into the structure and functionality of blood and lymphatic vessels. These Pallid bats are trained to extend their wings while sleeping thus allowing researchers to observe in-vivo the blood flow and various vessels' characteristics. This technique sidesteps the issue of dealing with an anaesthetized mammal and makes it easier to study the same bat again. A forerunner in such kind of non-invasive research, the bat lab also provides research opportunities in cardiovascular science to undergraduate and graduate students by holding a summer research program. The aim of this 10 week summer program funded by both National Science Foundation and National Institute of Health is to provide a framework where the students can deal with potential cardiovascular research problems.

Earlier Studies at Bat Lab

In order to improve the experience of researchers in the bat lab and to reduce their training time period, different technological solutions have been employed. One of these solutions is eBat [28], a web-based application, that allows distant users to conduct live experiments, communicate, coordinate with lab members and review manuscripts. This application is currently being widely used in the lab and is a main source of dissemination of data and sharing of ideas amongst researchers. It caters for both distant and local researchers and helps in increasing productivity and promoting collaboration. The available features of message boards, chat rooms and web cam to observe live experiments contribute to building trusting relationships in the groups while providing the option of anonymity if preferred. Moreover, a manuscript preparation system allows interactive input from distant users who participate more actively in the latest research.

Another experiment [29] conducted in the bat lab in the year 2006 aimed at investigating the effect of different image layouts on user performance. The subjects worked with images in three different layouts to (a) identify arteries and veins (b) estimate the size of vessels and (c) draw the lymphatic vessel walls. The layouts selected for the experiment provided different spatial and temporal organization to the images and included thumbnail, scrolling filmstrip and montage layouts. The data obtained compared the performance of novices and experts which were categorized as such based on their seniority in the lab. The results showed that the performance of the subjects varied according to the image layout and their research expertise for each task.

Hence, it was shown that the subjects benefited from the additional contextual information in the form of different layouts and that research for exploring mechanism to facilitate them further was warranted.

CHAPTER III

EXPERIMENTAL SETUP

Making use of the analysis and results of [29], our user study aimed at improving the image visualizations used within the bat lab and contributing towards the ultimate goal of designing an effective training program for the researchers.

Techniques

Two IE techniques were applied to the images. The original images were included in the image set to determine performance for enhanced and un-enhanced images. The techniques were:

Edge Enhancement

Edge enhancement reveals the subtle details in the image that might otherwise go undetected. It provides insight into the shape and outline of object and offers vital information to the human visual system. It helps in differentiating features by improving the visual quality perception and is used in many fields. SAR images [30] are edge enhanced to help in surveillance, navigation, moving target indication and environment monitoring. While in medical imaging ultrasound images [31] are enhanced to help in detecting organ boundaries and in subsequent diagnosis and treatment of the disease.

Clarification

At times the images obtained from microscope are out of focus and dull in color. The clarification technique helps in reducing such problems by adding a crisp focused look to the image and brightening it. In oceanography, astronomy, atmospheric sciences, etc., images suffer from light pollution and hence are brightened to identify and capture objects of interest.

Image Enhancement Software

The images were manipulated using Corel Paint Shop Pro Photo XI [5], which is a user friendly image editing software application. Paint Shop allows users to adjust, retouch and restore images and is used widely for image editing purposes.

Tasks

Three independent tasks, which were familiar to the users, were chosen for the study. The subjects performed these tasks using a customized application. These tasks were:

Classifying Vessels

This is one of basic tasks that has to be learned at the start of the research program. In this task the subjects identified whether a marked vessel was an artery or a vein. The vessels are visually differentiable from each other by their appearance: the veins are wider and have relatively clear blood cells as compared to the arteries. The vessel images were enhanced in an attempt to make the differentiating factors pronounced. Each subject was shown 90 vessel images in which 43 were of arteries and 47 were of veins. These 90 images were divided into three groups, one for each technique. Hence, each subject saw 30 edge enhanced images, 30 clarified images and 30 original images in a randomized order.

Identifying Capillaries

The researchers study vascular mechanics and behavior by monitoring various vessels, including capillaries. These small blood vessels have one flowing blood cell, which makes them hard to detect. To make this task easier, IE was applied to capillary images. The subjects had to identify all the capillaries by drawing their walls with the help of the customized application. A total of 30 images containing 33 capillaries were shown to each subject. Each image contained at least one capillary. Similar to before, these 30 images were divided into three groups, such that each subject saw 10 edge enhanced images, 10 clarified images and 10 original images.

Identifying magnification

In [29] images of different magnification were shown to the subjects in all the tasks. Even though the subjects were informed about this fact, they still failed to take it into consideration while estimating the vessel size. For our experiment, magnification was chosen as a main task to gauge the expertise level of the users and also to study the effects of IE in determining the magnification factor. The image collection shown to each subject contained 30 images of 10X magnification and 45 images of 40X magnification. Also these 75 images were categorized into three groups based on the IE techniques; 25 images for each technique.

Location of Experiment

The experiment was conducted at the Veterinary Medical Administration Building at Texas A&M University, College Station, TX. The duration of the experiment was approximately two hours for each individual and subjects were allowed to take breaks when they desired.

Subject Recruitment and Characteristics

The experiment was designed while keeping in mind the convenience of the subjects and the available resources. Towards this purpose, an experienced researcher was consulted to collate an image corpus that was representative of the tasks usually performed by the novices in the lab and which was in keeping with their skill level. The researcher also pitched in to provide us with definitive answers about the compiled image set. Later, we conducted a pilot study to estimate the time taken to complete the entire experiment and to foresee any potential problems. This pilot study revealed that our experimental design and methodology was adequate and our application was easy to use. Equipped with the information gathered, we focused on the recruitment of subjects for our experiment.

Subjects were mainly recruited from the Michael E. Debakey Institute of Texas A&M University with the help and advice of Dr. Christopher Quick (cquick@tamu.edu), who is the director of the Cardiovascular Systems Dynamics Lab. Information fliers were posted on the eBat website [32] to invite volunteers for the study. The flier contained a description of the study along with the risks and benefits involved, as approved by the Office of Research Compliance.

A diverse group of 16 subjects participated in the study. All of them had been in the lab for at least one semester and had adequate experience of working with bat images. Subjects who had been in the lab for one semester were classified as novices while the ones who had spent two or more semesters were categorized as experts. Accordingly, 12 out of a total of 20 available novices participated in the study while 4 out of a total of 8 experts volunteered. Out of these 16 subjects 7 were engineering majors while 9 were pure sciences majors.

Research Procedure

At the start of the experiment, subjects were given anonymous subject IDs, read the informed consent form and filled in a questionnaire that collected demographics and their skill information. Then they used a customized application to perform the tasks outlined before.

All the subjects performed the tasks in the same order by first completing the Classifying Vessel task then the Identifying Capillaries task and finally the Identifying Magnification task. To balance the experiments, the three techniques were randomized for each subject giving a total of 6 combinations (1) C E O, (2) C O E, (3) E O C, (4) E C O, (5) O C E and (6) O E C. Here a combination reflects the order in which the images sets were shown to a subject, C E O means that first the clarified image set was shown then the edge enhanced images and finally the original images. The same combination of techniques was repeated in all the tasks performed by an individual subject. Hence, the first subject saw the techniques in all the tasks in the order C E O, the second saw them in the order C O E, the third in the order E O C and so on. The order of the tasks remained the same for all the subjects and no image was repeated for any individual. The subjects knew the techniques as Technique 1, Technique 2 and Technique 3 so as not to bias them towards any particular technique. Each of them viewed 90 Vessel images, 30 Capillary images and 75 Magnification images. Since Identifying Capillaries was the lengthier task, the numbers of images shown in this task were intentionally kept small to keep the time limit under two hours.

At the end of the experiment the subjects filled in another questionnaire regarding their experience with the tasks and the techniques.

Customized Application

In [29], the subjects responded verbally for the artery/vein recognition and the vessel size estimation tasks while they drew the lymphatic vessel walls using the Microsoft Power Point marker. The answers had to be manually recorded, which was tedious. Hence, in our study a customized application was implemented to avoid the previous procedure.

Our application is implemented in Visual C# 2005 Express Edition and is coded using the WPF feature of .NET Framework 3.0. WPF provides a base for creating visually innovative applications and introduces a new language called XAML that creates graphically rich user interfaces. It also offers APIs for creating drawing applications, which assisted us in the Identifying Capillaries task. This application expedited gathering of responses and enabled us to finish the study in a couple of days.

On starting, the application records the subject IDs to save their responses and keep track of their interactions. Fig. 1 shows the initially displayed screen which states the overview of the study. The same information is placed on handouts that are distributed amongst the subjects. The names of the techniques are intentionally not revealed to the subjects to keep their observations impartial.

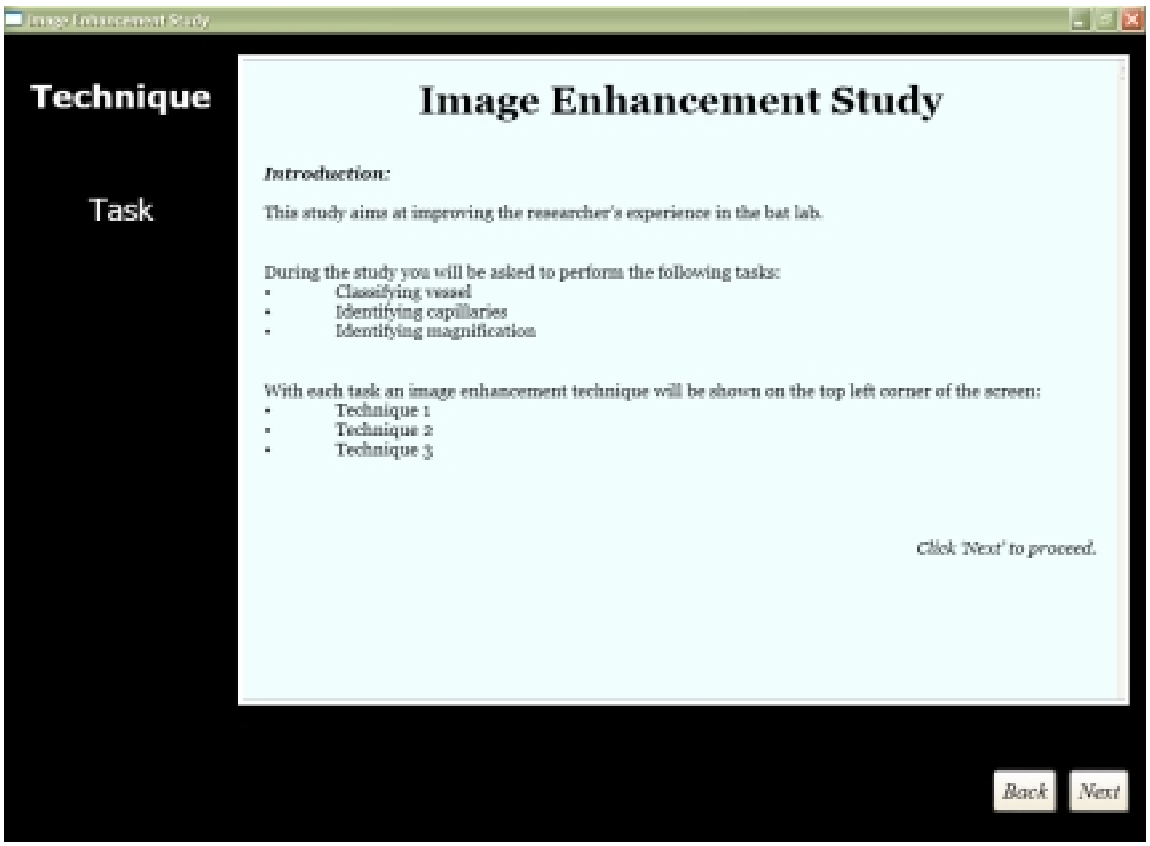

Fig. 1. Introduction screen

On advancing to the next screen shown in Fig. 2, a description of the first task "Classifying Vessel" is shown. This screen explains the various controls that can be used by the subject. On the top left corner of the screen the current technique and task are displayed. The time spent on each image is recorded by the application but the subjects can take breaks when they desire by pressing the 'Pause' button which suspends the application. The 'Back' and 'Next' buttons on the bottom right are used to navigate through the images and to return to any previous image to change their answer.

Fig. 2. Introduction screen for Classifying Vessel

The correct answer is chosen by clicking either the ‘Artery’ or ‘Vein’ text at the bottom, the text is highlighted on selection. For practice, the subjects are shown two un-timed sample images before each task so that they can get familiar with the layout and features of the application. These samples are not timed and are aimed at preparing them for the actual task. After viewing the sample images the subjects can now move on the task by clicking the ‘Next’ button and confirming their choice. Fig. 3 shows a sample screenshot.

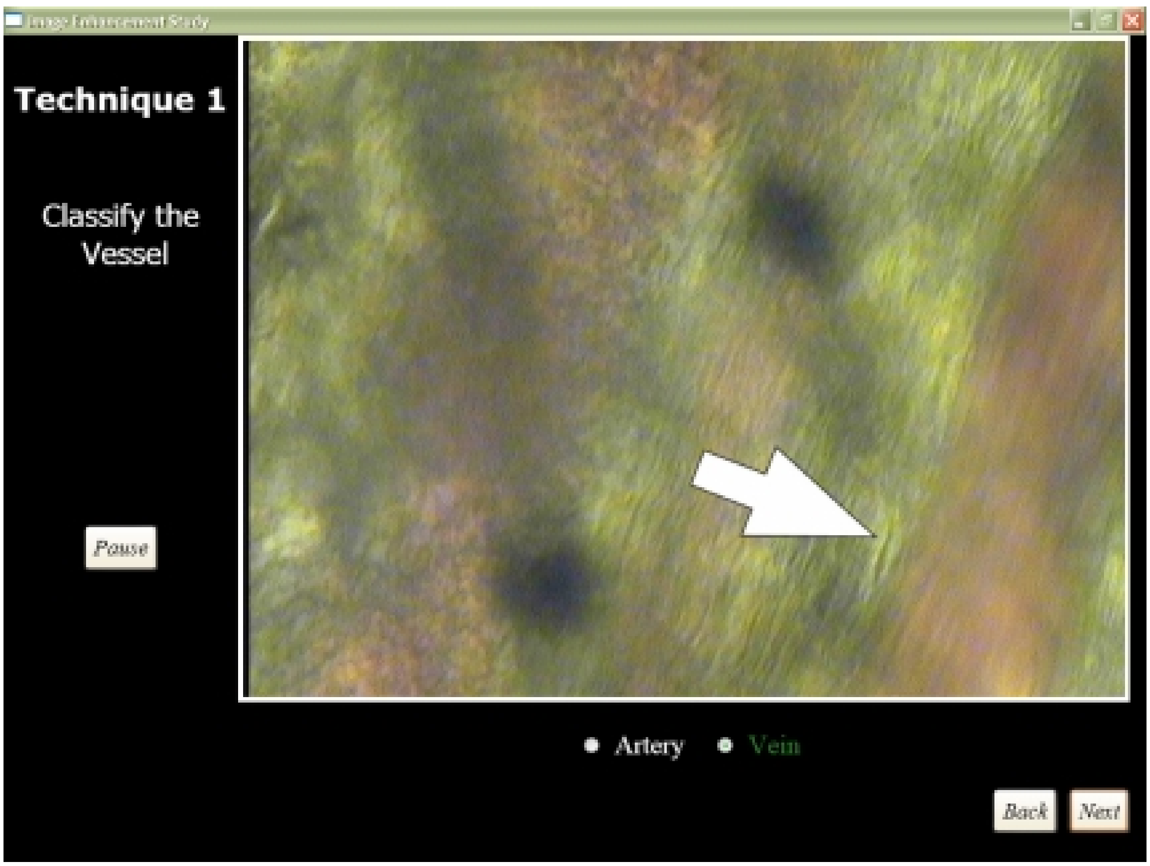

Fig. 3. Making a selection in Classifying Vessel task

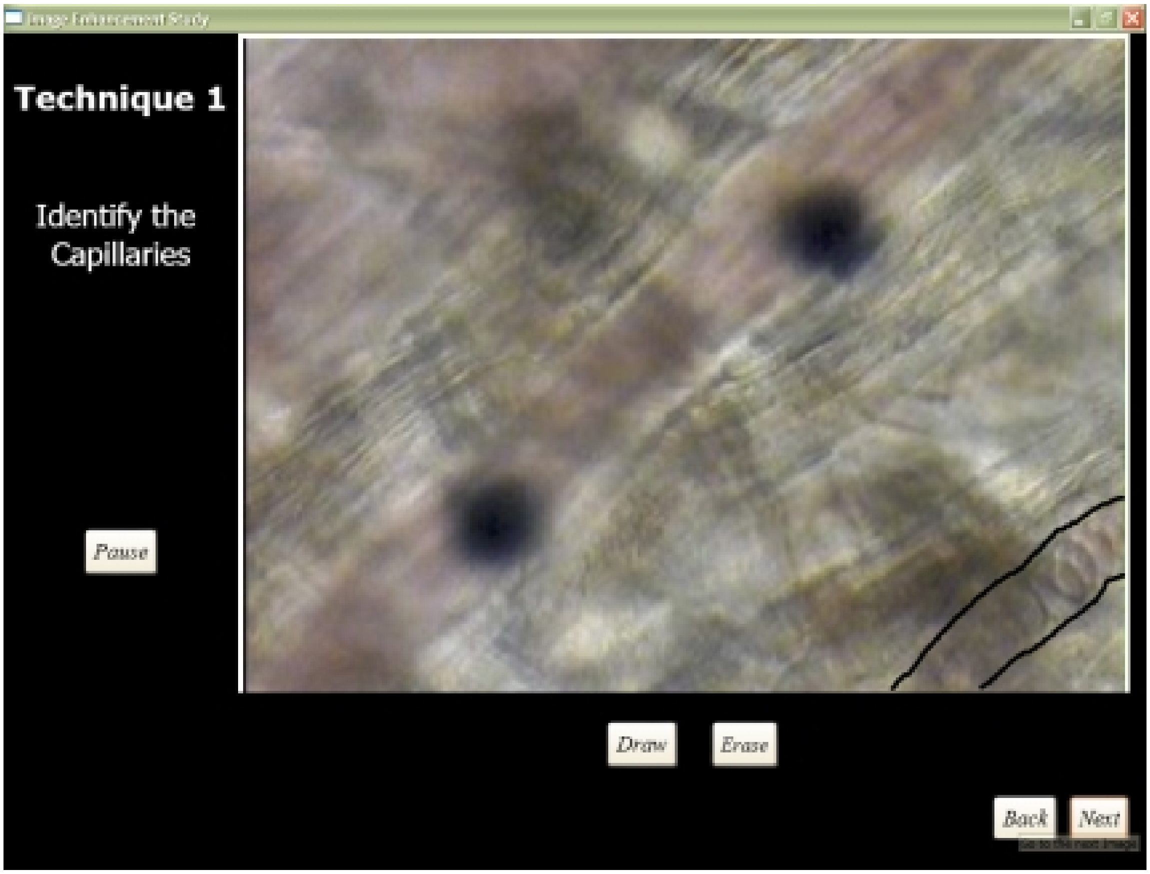

Fig. 4. Drawing a capillary in the Identifying Capillaries task

The subject navigates through all the three techniques in the Classifying Vessel task in the same way. After completing the first task the introduction screen for the Identifying Capillaries task is displayed followed by the sample images. Two new controls are added for this task which are the ‘Draw’ and the ‘Erase’ buttons. By clicking on the ‘Draw’ button the subject can outline the capillary walls using the mouse and can undo the drawing by pressing the ‘Erase’ button and selecting the stroke to delete. The ‘Draw’ feature is similar to the marker option in Microsoft PowerPoint and provides ease of use due to its familiarity. Fig. 4 shows the outline of the capillary drawn with the application.

After completing this task, the subject moves to the ‘’Identifying Magnification’ task, which is similar to the first task. In this task a selection has to be made between ‘10X’ and ’40X’ Magnification. The application saves all the responses, keeps track of the interactions and exits at the end of the last task.

CHAPTER IV

RESULTS

The effectiveness of the IE techniques was evaluated by comparing the performance of the subjects for the enhanced and un-enhanced images. For this purpose, trends in performance were observed through statistical tests and graphs. The results of the novices and the experts were evaluated separately to cater for the difference in their skill levels. However, occasionally their performances were compared to gain insight into these differences. Since the novices were the main focus of the experiments so the description of their results is more comprehensive.

Statistical Tests

To compare the two groups of subjects, parametric tests were performed, which are robust hypothesis tests. They are suitable for data that is sampled from a population that follow a Gaussian distribution. This requirement can be satisfied by the Central Limit Theorem that states that if the samples are large enough, distribution of their means will be Gaussian. Since the number of images shown to a subject in each task were more than 30, our data follows a Gaussian distribution according to the Central Limit Theorem. We chose the paired t-test to compare the performance of the subjects for the two enhancement techniques against the un-enhanced original images. The P value was computed for each task to check if the null hypothesis was true. Data was stored in Microsoft Excel spreadsheets and its Analysis ToolPak was used to conduct the hypothesis test.

Classifying Vessel Results

In [29], the results showed that Classifying Vessels was one of the basic tasks acquired by the researchers. The same is supported by our results. The novices scored the highest in this task spending an average of 7.04 seconds per image. Each of them was shown 90 images, 30 for each technique and was given a score of 1 on classifying the vessel correctly and 0 otherwise. In Table I the novice IDs along with their score and time taken for each technique are listed in a row. For example the first novice 'XN42' correctly classified 27 vessels out of 30 for E technique and spent a total of 03:25.3 minutes for this technique. Similarly XN42 correctly classified 24 vessels each for C and O techniques taking 03:21.8 and 04:22.9 minutes, respectively.

The novices scored the highest in this task by correctly identifying 79% of the vessels as compared to 61.45% for the montage view in the previously reported experiment [29]. This difference may be a consequence of the time constraint; previously the time for each vessel image was fixed at three seconds while now it was not. In comparison the novices took more then twice the time (7.04 seconds per image) in our experiment but their performance improved. Hence the novices benefited from the time leverage and performed consistently better then their counterparts of the previous experiment.

TABLE I

NOVICES' DATA FOR CLASSIFYING VESSEL

Subject ID	E	C	O	Total correct answers	E Time	C Time	O Time	Total time taken
XN42	27	24	24	75	03:25.3	03:21.8	04:22.9	11:10.0
AE52	27	26	28	81	02:24.1	03:10.9	02:41.9	08:16.9
AS84	10	9	8	27	02:32.3	05:22.3	02:21.2	10:15.9
OE32	26	26	25	77	02:15.5	03:29.8	02:15.8	08:01.1
RQ94	27	27	29	83	05:41.8	02:59.4	02:44.2	11:25.3
IU65	25	27	27	79	03:29.6	03:53.2	03:17.2	10:40.1
MK50	25	27	25	77	03:03.5	02:09.9	02:18.6	07:32.1
PK96	27	22	18	67	07:45.6	04:41.0	08:05.9	20:32.4
GE59	23	19	23	65	03:31.8	03:44.0	03:32.5	10:48.3
RX41	25	29	26	80	02:09.7	02:00.5	02:09.2	06:19.4
QW98	20	23	22	65	02:26.0	02:42.2	03:00.7	08:08.9
VX37	26	27	26	79	03:37.2	03:58.6	05:58.1	13:33.9
Total	288	286	281	855	42:22.5	41:33.5	42:48.1	2:06:44
% correct	80%	79%	78%	79%				
Average	24	23.83	23.42	71.25				

While a difference was observed in the performance of the novices in the two experiments, no noticeable variation were seen across the various techniques. They performed equally well in all the three techniques as shown in Fig. 5. They scored the highest 80% for the E technique followed by 79% and 78% for the C and O techniques. One of the possible explanations for this can be their ease and expertise in this task, which diminishes the benefits of any visual enhancement.

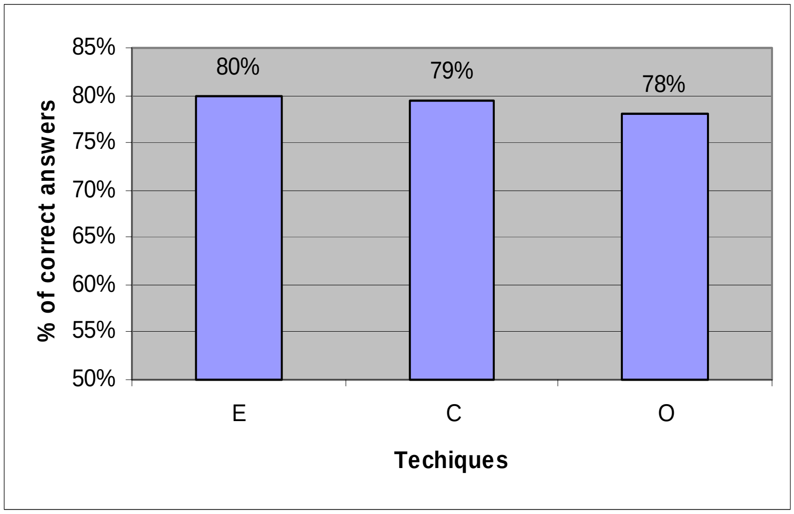

Fig. 5. Performance of novices on Classifying Vessel task

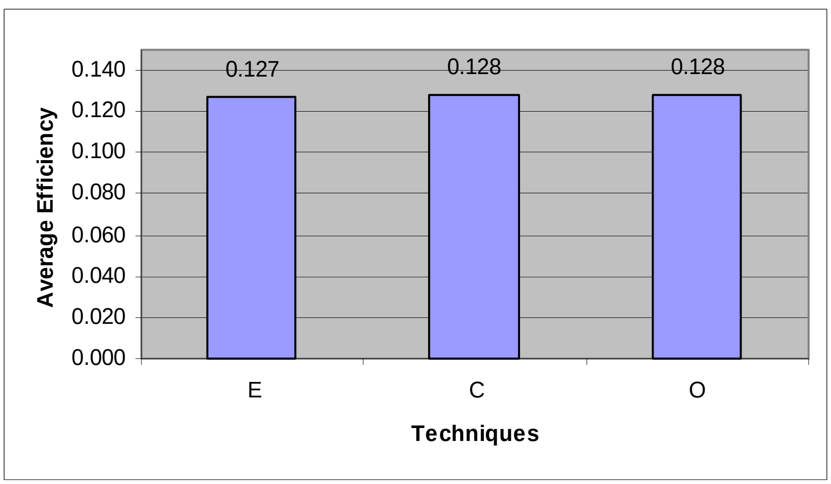

Fig. 6. Efficiency of novices on Classifying Vessel task

The efficiency was calculated to determine the number of correct answers per second and was consistent for all the three techniques as seen in Fig. 6. Furthermore, no technique emerged to be most effective as deemed by the novices in the questionnaire. 4

novices thought the E technique was the most effective, 3 chose C technique while 4 opted for the O technique (1 subject did not reply).

This reinforced our findings that the novices learn this task fast and any visual enhancements do not benefit them. As expected the paired t-test did not show any significant difference between the techniques.

An interesting trend was also noticed while comparing the performance of the 5 novices with Engineering major to the 7 novices with Pure Sciences major as shown in Fig. 7. The Engineering major subjects performed consistently better in all the techniques, hinting that the engineering students were able to better identify the nuances of differences in vessels.

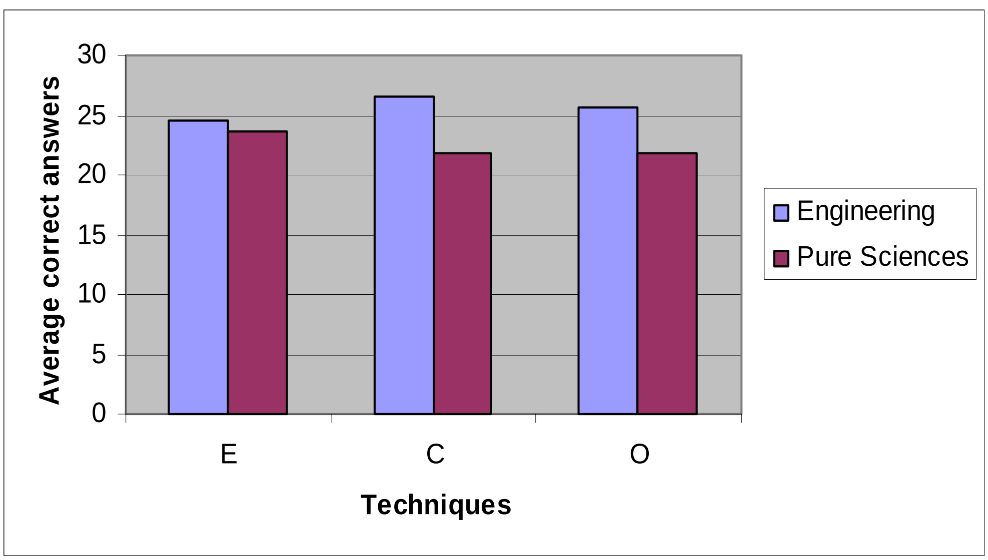

Fig. 7. Engineering vs. pure sciences major for Classifying Vessel task

While the study mainly focused on the novices some data was also collected from the expert researchers to compare the performances of the two groups of subjects. Table II lists the score and the time taken by the experts in a manner similar to the novices table. The experts correctly identified only 74% of the vessels correctly compared to 81.95 % for montage view in the last experiment [29]. Their performance also lagged behind the novices in this experiment although the times taken by both were comparable.

TABLE II

EXPERTS' DATA FOR CLASSIFYING VESSEL

Subject ID	**E**	**C**	**O**	**Total correct answers**	**E Time**	**C Time**	**O Time**	**Total Time taken**
ZH49	22	24	20	66	03:34.9	04:44.4	04:32.1	12:51.4
CX02	19	24	23	66	04:01.8	05:13.5	04:03.9	13:19.1
QR29	22	21	25	68	03:25.0	03:45.3	04:46.5	11:56.8
LT29	23	21	21	65	02:23.2	02:29.9	02:21.6	07:14.7
Total	86	90	89	265	13:24.8	16:13.1	15:44.1	45:22.0
% correct	72%	75%	74%	74%	13:24.8	16:13.1	15:44.1	45:22.0
Average	21.5	22.5	22.25	66.25				

Admittedly we did not have many experts to make any conclusive statements but an interesting trend was noticed: the novices performed consistently better than the experts in all the techniques as is evident in Fig. 8. A possible explanation for this is that the students who are associated with the lab for a longer duration of time move on to higher level tasks and do not observe images daily, as pointed out by them in the questionnaire.

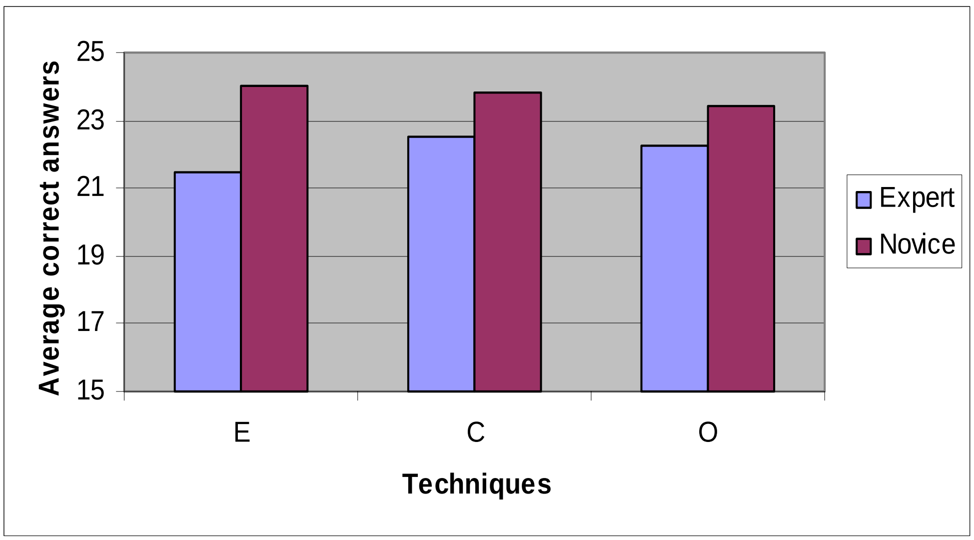

Fig. 8. Novices vs. experts for Classifying Vessel task

Identifying Capillaries Results

This was a new task in which researcher skill level had not been tested before. We hoped to get insight into this task, which we believed to be difficult based on the information gathered by talking to researchers in the bat lab. We tested the effect of applying IE techniques on capillary images by showing each subject a total of 33 capillaries; 11 for each technique. Some images contained more then one capillary, a fact that was conveyed to the subjects. Before starting the actual task the subjects worked with sample images to get familiar with the task and the drawing feature of the application.

TABLE III

NOVICES' DATA FOR IDENTIFYING CAPILLARIES

Subject ID	**E**	**C**	**O**	**Total correct answers**	**E Time**	**C Time**	**O Time**	**Total time taken**
XN42	7	13	7	27	09:03.1	06:39.8	07:15.0	22:58.0
AE52	0	1	1	2	01:27.1	01:12.6	01:21.0	04:00.7
AS84	12	8	9	29	03:23.6	06:21.3	04:28.0	14:12.9
OE32	14	18	16	48	05:39.0	04:18.1	05:04.5	15:01.6
RQ94	11	11	7	29	03:28.4	02:55.8	02:04.1	08:28.3
IU65	12	13	10	35	05:12.7	02:09.5	03:23.8	10:46.0
MK50	13	12	15	40	02:59.4	02:44.1	02:41.0	08:24.5
PK96	5	6	7	18	02:44.6	05:48.3	01:21.9	09:54.8
GE59	13	16	10	39	01:56.8	01:40.6	02:26.4	06:03.7
RX41	14	11	9	34	02:10.7	03:55.2	02:38.3	08:44.2
QW98	3	5	3	11	01:23.2	01:56.8	02:11.0	05:31.0
VX37	11	10	8	29	05:40.7	05:02.8	04:29.3	15:12.7
Total	115	124	102	341	45:09.3	44:44.8	39:24.3	09:18.4
% correct	44%	47%	39%	43%	45:09.3	44:44.8	39:24.3	2:09:18
Average	9.58	10.33	8.50	28.42				

Our results showed that the novices found this to be a difficult and time consuming task. The images were scored on a 2, 1, 0 numbering scheme; a score of 2 was given on identifying both the walls of the capillary correctly, 1 on identifying it partially and 0 otherwise. The results of this task are displayed in Table III with each novice's score and time spent shown in a row. For example the novice 'XN42' scored 7 out of 22 in the first technique and took 09:03.1 minutes.

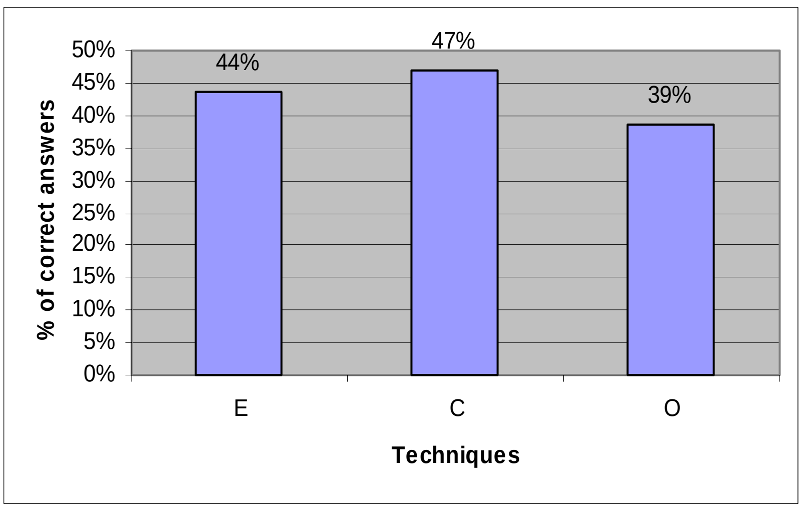

Fig. 9. Performance of novices on Identifying Capillaries task

The novices correctly identified 43% of the capillary walls while spending an average of 19.59 seconds on each capillary. Fig. 9 shows the results of performance of novices for this task. It is evident that they performed better with the C technique by correctly identifying 47% of the capillary walls as compared to only 39% for the O images. Their performance was in keeping with their preference as depicted by their responses in the questionnaire in which half of the novices thought that they were most effective with the C technique. Of the remaining half, 2 selected the E technique as the most effective, 3 opted for O and 1 novice did not reply.

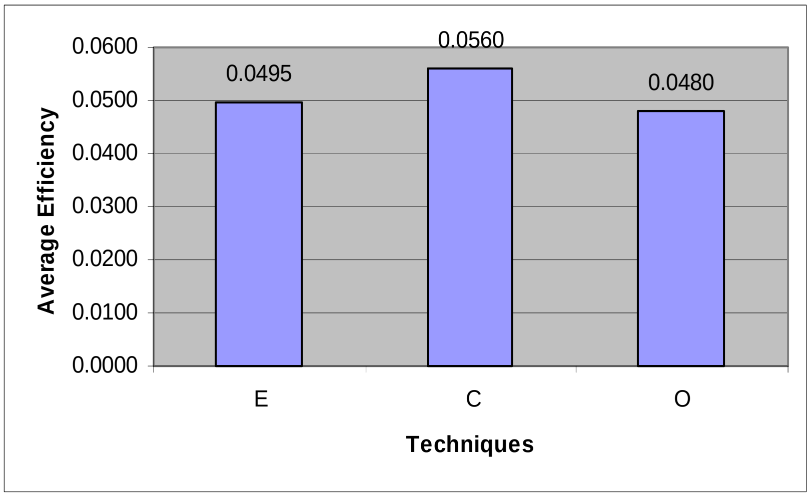

Fig. 10. Efficiency of novices on Identifying Capillaries task

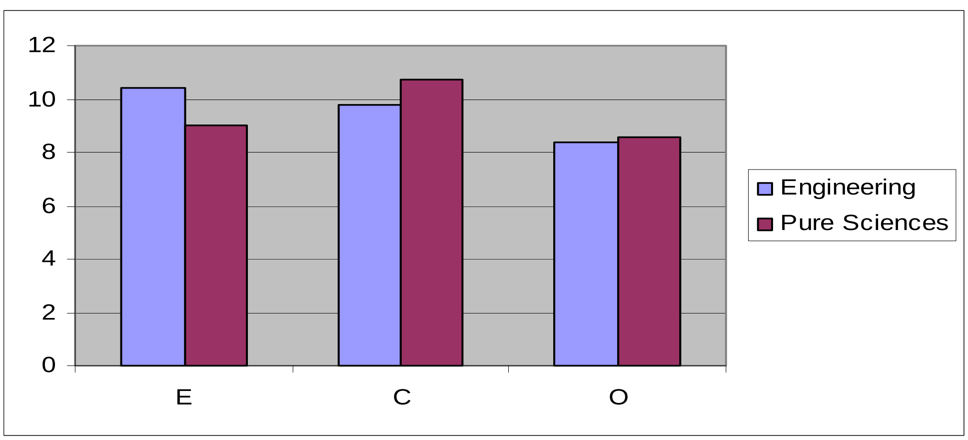

Fig. 11. Engineering vs. pure sciences major for Identifying Capillaries task

The novices were also more efficient with the C technique, as seen in Fig. 10, hinting that this technique made the identification quicker and easier. The P value for the paired t test between the clarified images and the original images was 0.063, which is not significant but hints that the positive effects of the C technique cannot be ruled out. Also noticeable here is the fact that there is no difference in the performance of the novices for the engineering and the pure sciences majors as seen in Fig 11.

On the other hand the experts scored the highest with the E technique by identifying 61% of the capillary walls correctly spending an average of 24.5 seconds on each capillary. Their results are presented in Table IV.

TABLE IV

EXPERTS' DATA FOR IDENTIFYING CAPILLARIES

Subject ID	**E**	**C**	**O**	**Total correct answers**	**E Time**	**C Time**	**O Time**	**Total time taken**
ZH49	13	12	11	37	04:37.4	06:22.2	03:07.2	14:06.8
CX02	12	6	11	30	02:25.0	02:25.6	02:27.5	07:18.0
QR29	19	17	15	55	06:53.2	08:55.5	09:26.1	25:14.8
LT29	9	14	15	38	02:23.2	02:29.9	02:21.6	07:14.7
Total	53	49	52	160	16:18.7	20:13.2	17:22.5	53:54.3
% correct	60%	56%	59%	61%	16:18.7	20:13.2	17:22.5	53:54.3
Average	13.25	12.25	13	40				

The experts performed better then the novices in all the techniques, as shown in Fig. 12, indicating that this is a task that takes time to master and needs to be focused on more while designing a training program for the new researchers.

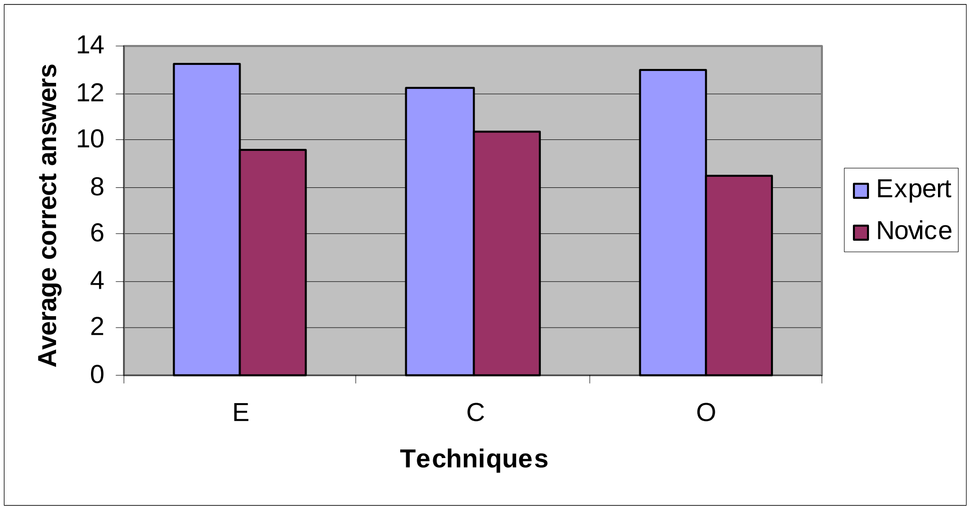

Fig. 12. Novices vs. experts for Identifying Capillaries task

Identifying Magnification Results

This last task was similar to the Classifying Vessel task; the subjects had to mark an image as 10X or 40X magnified. A score of 1 was given for correct classification and 0 otherwise. Each subject viewed a total of 75 images; 25 for each technique. The novices correctly identified 74% of the images spending an average of 4.92 seconds per image. Similar to before, Table V shows the score and time spend by the novices for each technique. For example ‘XN42’ scored 17 out of 25 spending 01:34.7 minutes on the E technique.

TABLE V

NOVICES' DATA FOR IDENTIFYING MAGNIFICATION

Subject ID	**E**	**C**	**O**	**Total correct answers**	**E Time**	**C Time**	**O Time**	**Total time taken**
XN42	17	18	20	55	01:34.7	01:58.3	01:43.6	05:16.7
AE52	19	15	18	52	01:51.3	01:35.7	01:52.5	05:19.6
AS84	16	13	17	46	01:49.9	01:43.7	01:52.1	05:25.7
OE32	23	20	24	67	01:47.2	01:47.1	01:20.8	04:55.1
RQ94	17	23	21	61	02:11.2	02:01.7	01:54.7	06:07.5
IU65	20	21	22	63	01:45.3	01:36.2	01:07.4	04:28.9
MK50	18	22	20	60	01:49.9	01:36.9	01:43.8	05:10.6
PK96	17	19	19	55	06:31.3	03:42.3	01:51.1	12:04.6
GE59	13	14	12	39	02:16.2	01:54.1	02:22.6	06:33.0
RX41	19	18	16	53	01:18.7	01:03.2	01:15.9	03:37.8
QW98	18	17	16	51	02:09.6	01:47.6	01:28.4	05:25.6
VX37	20	19	21	60	02:47.7	03:32.7	03:05.6	09:26.0
Total	217	219	226	662	27:52.9	24:19.5	21:38.7	13:51.1
% correct	72%	73%	75%	74%	27:52.9	24:19.5	21:38.7	1:13:51
Average	18.08	18.25	18.83	55.17				

In this task no noticeable difference was seen between the techniques in Fig.13. The novices scored the highest with the un-enhanced images suggesting that the IE technique did not influence their performance. The questionnaire data also reveals that no technique emerged as the clear favorite though C was preferred by 5 of the novices, 4 chose O while 3 opted for E technique.

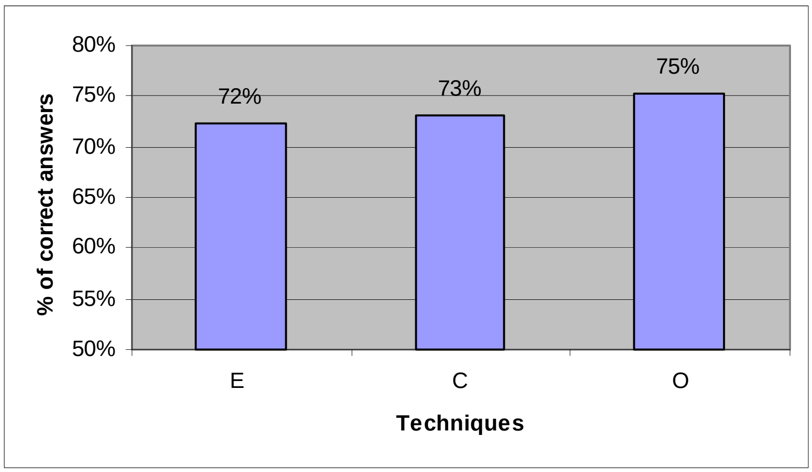

Fig. 13. Performance of novices on Identifying Magnification task

Fig. 14 presents the efficiency of novices for this task and shows that they were more efficient with the un-enhanced images as compared to enhanced ones.

No difference was observed in the performance of the novices belonging to different majors as seen in Fig 15, possibly making the difference in the first task a coincidence. This is encouraging as it suggests that, regardless of their background knowledge, the novices benefit equally from the research program.

On the other hand, the effect of IE techniques was more evident in the experts' data as shown in Table VI. They scored the highest 80% using the E technique taking an average of 5.96 seconds for each image. They were also more efficient while using the E technique.

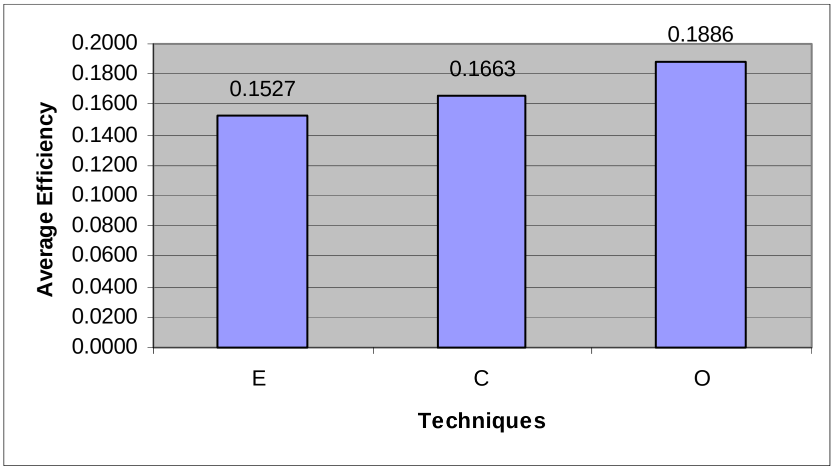

Fig. 14. Efficiency of novices on Identifying Magnification task

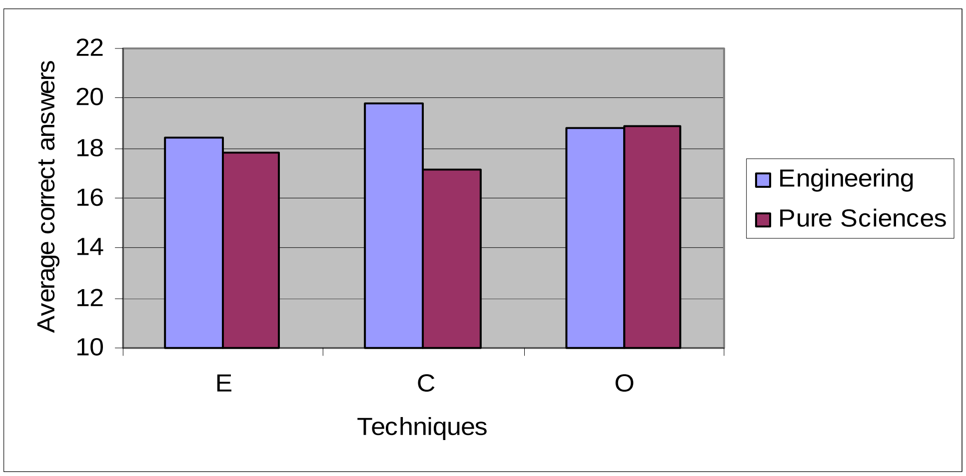

Fig. 15. Engineering vs. pure sciences major for Identifying Magnification task

A comparison of the performance between the two groups in Fig. 16 shows that the experts outperformed the novices using the E technique while in the other two techniques their performances were comparable. This suggests that the experts found something that they liked in this technique that influenced their answers to a great extent.

TABLE VI

EXPERTS' DATA FOR IDENTIFYING MAGNIFICATION

Subject ID	**E**	**C**	**O**	**Total correct answers**	**E Time**	**C Time**	**O Time**	**Total time taken**
ZH49	17	16	16	49	02:41.7	02:44.0	02:43.1	08:08.9
CX02	21	17	23	61	01:24.4	02:07.4	01:43.6	05:15.5
QR29	20	22	15	57	02:20.5	02:19.6	02:18.5	06:58.7
LT29	22	19	20	61	02:30.4	03:24.9	03:28.9	09:24.2
Total	80	74	74	228	08:57.1	10:36.0	10:14.2	29:47.2
% correct	80%	74%	74%	76%	08:57.1	10:36.0	10:14.2	29:47.2
Average	20	18.5	18.5	57				

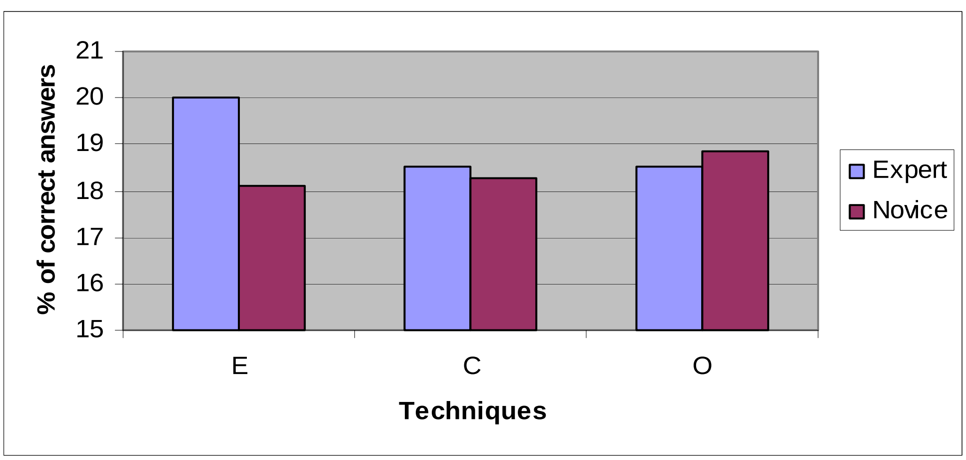

Fig. 16. Novices vs. experts for Identifying Magnification task

CHAPTER VI

CONCLUSIONS

Our research work contributed towards shedding light on using technological solutions to assist the cardiovascular study of bats. Most of the research in the bat lab is based on studying information that is collected from images and videos of microscopic feeds so it is important to obtain maximum benefit from them. Images are of great use in scenarios where researchers want a snapshot of a region of the bat wing for future reference. They are also a valuable resource for comparing various blood and lymphatic vessels side by side. For improving the clarity and visibility of such images, this study aimed at applying IE techniques and studying the effect of such an approach.

Our results led us to conclude that the researcher's performance did not vary much amongst the techniques for Classifying Vessel and Identifying Magnification tasks but a large, though not significant, difference was observed for the Identifying Capillaries task. The fact that in the first and the last task the probability of getting an answer correct by guessing was 50% provides some explanation of the difference in performance but still is insufficient to diminish the positive effects of IE. In the Identifying Capillaries task the novices scored the highest using the C technique, they were also more efficient and deemed it to be the most effective, hinting that for this task the C technique had a definite edge over the others.

Future Work at Bat Lab

In the foreseeable future, to minimize the handling of live bats, direct access to them will be restricted for the undergraduate students to allow the graduate experienced students to carry out the maximum number of experiments. In such a situation the undergrads will rely more on the images and videos for their practice and observations. Hence the research procedure for our experiment may be modified to test the effect of image enhancement for novices in such a scenario. It might be interesting to see the difference in performance of students who have access to live bats compared to those that don't. If the effect of IE is significant then images and videos may be enhanced and kept in a digital library for training the new researchers. Also to expedite the training program, future research may be needed to improve the correctness and efficiency of novices for difficult tasks.

Some work done by a doctoral Computer Science student utilizes the results of our study to build an application to facilitate the researchers in the bat lab. This application among various other features, offers IE capability to manipulate the images and videos. Since our study did not result in significant differences for the tasks so the application offers a vast range of IE techniques in an effort to provide more choices. Instead of restricting specific techniques to specific tasks the researchers will be free to use any technique they desire. It will be interesting to note the preferred techniques of the researchers for the images and videos.

Learning System

Our application can be extended to formulate a learning system that can be used in the bat lab and various other labs which deal with images. With few modifications it can be made into an interactive learning system that guides the novice researchers through the various tasks and asks for their input for each image. On providing wrong answers the application can pinpoint the fault and provide suggestions on how to avoid the same mistake. For example on incorrect identification of a capillary the application can give an overview of how to differentiate a capillary and recommend some guidelines to follow, these would include looking for a single blood cell. Similarly for identifying magnification, if the researcher incorrectly selects 40X instead of 10X the application can highlight the difference between the two magnifications by informing that the 10X images have brighter and denser colors and do not have visible capillaries.

Application in Different Fields

In addition to contributing to the research in the bat lab, our study can be equally effective for conducting similar research in other fields. In the field of geology, our study can provide insight for using IE to identify vegetation, mineral deposits, landslides, etc. In atmospheric sciences it can be conducive for easy identification of bow echoes, fronts and stratifications. In art studies it can help in identifying form and composition of paintings.

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