

Development of a Machine Vision Laboratory¹

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Abstract

We have developed an undergraduate Machine Vision laboratory under the sponsorship from National Science Foundation, Cognex Corporation, and Florida Atlantic University. The laboratory supports mainly a 3-credit senior-level machine vision course called Introduction to Machine Vision. Most of the proposed lab experiments are design-oriented and hence open-ended. The students, after learning the basics, devise their own schemes to accomplish their task objectives using the available lab equipment and software packages, thus greatly enhancing their ability to solve real-world engineering problems.

In addition to the Machine vision course, the laboratory also supports a number of other undergraduate courses, including a freshman course (Fundamentals to Engineering), a sequence of senior Engineering Design Courses, and a summer course (Picture Processing) for gifted high school students.

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A. INTRODUCTION

Innovative solutions to the embedded machine vision applications are critical to the profitability of many manufacturing industries. Responding to this need, the National Science Foundation has actively supported a number of projects involving Machine Vision lab development for undergraduate education. Samples of such projects can be found in [1-4]. Some of the successful endeavors in mentoring undergraduates in computer vision research are reported in [5,6] and resulted in the design of extensive software packages for image processing and machine vision applications [7,8]. Despite this success, most American universities are yet to offer senior-level hands-on lab courses in the machine vision area. Major impediments to the development of such lab courses have been the high cost of specialized equipment and lab space. With the advent of new technology, low-cost machine vision systems can be configured from inexpensive personal computers and optics. This certainly helps in developing affordable undergraduate laboratories that support machine vision related courses.

A characteristic of the Engineering college at FAU is that a high percentage of the students work full- or part-time, and they commute to school every day. Due to busy schedules, many students find it difficult to spend a substantial amount of time to do experiments at the lab-site at specified times. Thus, a new approach is needed to conduct a lab course that is based on flexible timing and portability of the required work. The developed machine vision lab courses are readily conformable to this new approach, as a large portion of the student work involves experimentation with computer algorithms.

Another pressing issue in the college is the problem of student recruitment and retention. Although our university is fast-growing [9] overall, the enrollment in Engineering college does

not reflect this trend. Many local high school students are not fully aware of our engineering programs. Moreover, a large fraction of the low-division Engineering students change their major after the first two years. To rekindle their interest as well as to attract prospective engineering students, lab activities that back up learning through visualization (such as these conducted in our department) can be very effective.

We have developed an undergraduate machine vision laboratory, which was sponsored jointly by the National Science Foundation, the Cognex Corp, and Florida Atlantic University. The laboratory mainly supports an undergraduate senior elective course (Introduction to Machine Vision). The course is fashioned to promote learning through practicing by stressing greatly on the hands-on experimentation using the equipment students are likely to encounter when they enter their workplaces. The course also emphasizes an integrated system approach rather than on the specific algorithm implementation. By doing so, it greatly enhances the students' ability to address and solve complete real-world engineering problems.

The laboratory also supports a number of other undergraduate courses, including a freshman course (Fundamentals to Engineering), a sequence of senior Engineering Design Courses, and a summer course (Picture Processing) for the gifted high school students.

B. LAB DEVELOPMENT PLAN

The undergraduate laboratory development programs at other universities [1-4] were reviewed before coming up with a development plan for the Machine vision course. The machine vision course is structured to have a 2-credit theory part and a 1-credit lab part. The lab

experiments are synchronized and tightly coupled with the theory lectures, so as to reinforce the learning of theoretical aspects better.

B.1 Overview

The description given in this section is mainly targeted to the lab portion of the course. The theory portion is mostly standard material therefore only a summary description is given here.

The laboratory has six workstations. Each workstation (as shown in Figure 1) consists of a personal computer with a frame grabber, a CCD camera, a lighting and optics setup and an optical stage. The workstation is a stand-alone system by itself in the sense that all experiments can be run on it. On the other hand, the six workstations are linked by a local area network so that the scarce lab resources can be shared.



Figure 1 A Machine Vision Workstation

In order to keep the setup friendly for the remote student, low-cost and easy to use image processing packages such as Matlab image processing toolbox were used for certain image processing tasks. Remote students can either run Matlab through remote login-in or in their own computer, as the cost of such software is low.

Students are assumed to have a basic knowledge of computer programming as a pre-requisite to take the machine vision course. Normally, each regular experiment requires one to two lab sessions. Each session has a duration of three hours. A short lecture is given at the start of each experiment to review the basic principles involved in the experiment and to outline the experimental procedure. During the experiment, students work in groups of (maximum) two. Upon the completion of each experiment, they submit laboratory reports detailing their learning and inferences. There is a lab examination conducted at the end of semester, which carries 15% of the grade. The lab reports and the student lab performance account for 30% of the grade. Please refer to Appendix (Machine Vision Syllabus) for more details on the grading policy.

A key objective of developing the set of machine vision experiments is to provide students an opportunity to learn an integrated approach for solving machine vision application problems. The students examine the options in combining different sub-procedures to achieve the overall goal. For example, one group of students may choose bar code interpretation as their core application task, but they may opt for different solution strategies during different experiments. After each of the experiments, the students are asked to devise and implement procedures that can effectively solve the bar code reading problem at each of the stages. Similar planning can be made for students who select other tasks such as integrated circuit inspection, package label interpretation, and character recognition as their core tasks.

B.2 Experiment Descriptions

The proposed set of experiments is a natural outgrowth of the experience gained in teaching the course.

There are 6 experiments and one class project for the lab course. In most of the experiments, we use applications from industrial automation because they expose the students to the variety of engineering problems under the common solution framework. Regular experiments are ordered in the same manner as the theory courses [10-13]. The results of previous experiments are often utilized in the subsequent experiments.

For successful conducting of the lab, and making consistent progress, it is critical to motivate students to prepare in advance of actual lab work. One of the measures we have taken is to supplement a number of the experiments with Matlab simulations. Our experience with similar labs indicate that this phase of the lab is very effective in helping students to focus their reading and extract critical information for the experiment. Hereafter we provide a brief description of each lab experiment.

Experiment 1: Image Acquisition

This experiment is to familiarize students with the machine system setup, the programming environment, and the process of image acquisition. Through the experiment, the student obtains an understanding of the basic issues such as how the image is generated and acquired by the computer, where the image is stored, and the effect of image sampling and quantization on image quality. This experiment needs one lab session to complete.

Experiment 2: Lighting and Illumination

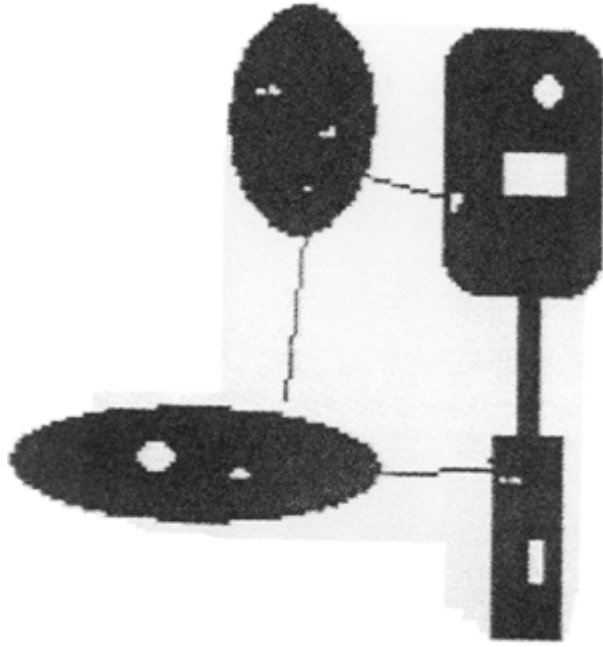
Lighting and illumination are a critical elements for machine vision. After having experienced the process of image acquisition, the student study the effect of back-lighting and direct lighting on the resulting images and observe the factors that affect the selection of lighting

sources, such as material surface, environment, and object motion pattern (e.g. stationary or moving).

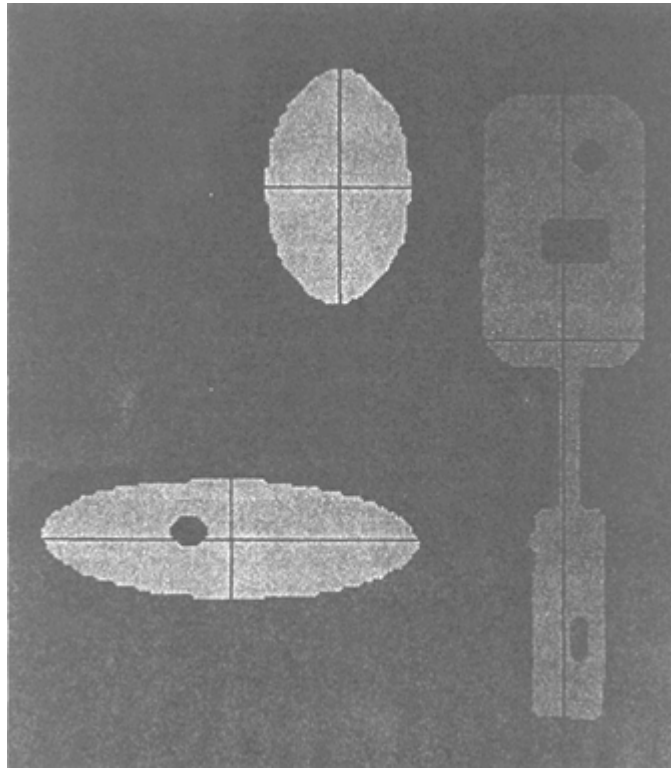
After learning the basics, the students propose and test a lighting scheme for a machine vision task, say for instance, the bar code reading. Results from subsequent processing experiments provide them with valuable feedback on the feasibility of their design and help them to modify or redesign their lighting schemes. This experiment needs one lab session to complete.

Experiment 3: Binary Image Processing

In this experiment, the students familiarize with the techniques used in binary image processing. They plot an image histogram of the provided component parts and perform histogram equalization to compensate for poor lighting. They also select the threshold parameter to convert gray-scale images to binary images. Further, they will perform component labeling, moment computation, and morphological operations to find geometrical features such as areas, perimeters, centroids and orientation of each component on an image. This experiment needs two lab sessions. Matlab Image Processing Toolbox is used for the experiment and some illustrative results are provided in Figure 2.



(a) Image taken with Cognex Checkpoint vision system



(b) Result with Matlab Image Processing Toolbox: Note that small holes and thin links in the original image are gone, and the principal axes are marked

Figure 2 Result from a Binary Image Processing Experiment

Experiment 4: Gray Scale Image Processing

In this experiment, the students study the effectiveness of neighborhood operators such as low- and high-pass filters on image enhancement and edge detection. They test various image processing algorithms and operators on the parts they have chosen for their vision task. For example, the students seek edge detection algorithms which, when combined with a proper lighting scheme, produce the best edges for locating the chip pins. This experiment needs two lab sessions. Matlab Image Processing Toolbox is used in the lab.

Experiment 5: Segmentation

For this experiment, the students mainly work on edge-based segmentation techniques using built-in procedures for contour finding and line finding. Some of the contour finding routines offered by machine vision companies [14,15] locate objects by finding an outline within the input image that matches a pre-trained outline of the object of interest. This is very useful for model-based object recognition. An example is illustrated in Figure 3. Similarly, line finding tools compute the location of lines in the images. The students use these procedures to extract the contour of a chip in the input image. This experiment needs two lab sessions.

Experiment 6: Object Recognition

After the image is segmented, the task of object recognition is attempted. In consistent with the background of the students, the statistical approaches rather than the syntactical approaches, are experimented for recognition. The students classify the objects by comparing the measured features with the template features of the object, using criteria such as the minimum distance and the maximum likelihood classification. It involves two stages: viz, the training and the classification. In the training stage, the features of object models such as the door on a floppy disk are obtained. In the classification stage, the measured parameters are compared with the trained parameters to determine the status of the door (refer to Figure 3). This experiment needs two lab sessions.

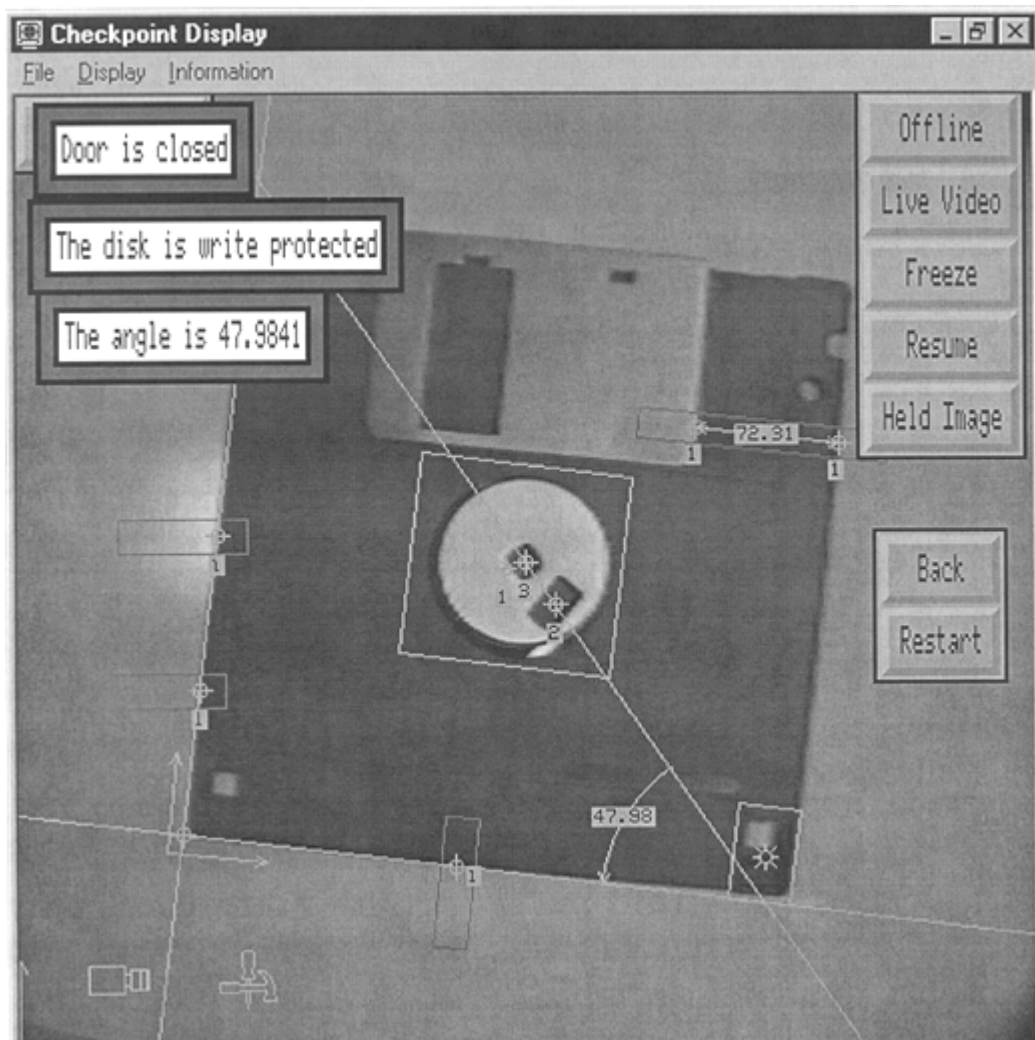


Figure 3 Result from an experiment using Cognex CheckPoint 900C vision system

Class Project : Integration of Machine Vision Sub-tasks

Before conducting a classification task, a lighting setup must be chosen, the camera must be calibrated, the image must be preprocessed and segmented, and the features must be extracted. In this last experiment, the students review the entire process of a machine vision task by reworking their core task with the selected image processing and analysis techniques.

The students revisit previous experiments and make necessary modifications or changes

to their original designs to improve the performance of their methods on the machine vision task of their choice. This project normally needs four weeks to complete.

The above discussion underlines the design-oriented and hence open-ended nature of the proposed experiments.

C. DISCUSSION

We have developed an undergraduate Machine Vision laboratory from scratch, with the help of funds from the National Science Foundation, the Cognex Corporation, and Florida Atlantic University. More specifically, the NSF provided funding to purchase the computers and network equipment, the Cognex donated multiple sets of their state-of-art vision system, and FAU provided matching funds as well as course release and TA supports for the lab development.

With the facility, we have offered the senior-level course (Introduction to Machine Vision) a number of times, with an average enrollment of 20 students. The feedback from students has been very encouraging. An important aspect in the successful offering of this course has been the synergy and dedication of the teaching assistants. Sustained effort is made is to correlate the theory part tightly with the lab part as well as to fully use the potential of Matlab simulation, as it offers immediate responses to students in helping to understand intrinsic concepts behind complicated machine vision algorithms.

Every student in engineering disciplines at FAU has to complete a sequence of two Engineering Design courses. The introduction of modern undergraduate lab courses in machine

vision provides valuable instrumentation and background experience for engineering design projects. The lab facility is also available to engineering design students.

In addition, the College of Engineering offers Fundamentals of Engineering to university students in their first two years of college education [9]. One of the primary objectives of this course approach is to recruit and retain engineering students. A good vehicle to attract lower division engineering students is robotics and computer vision, because of their visual appeal. Students can learn engineering principles using the facility provided by the proposed lab. Thus, the lab is made available to the students from Fundamentals of Engineering, such that specifically designed demonstrations and simple experimentations that can be completed in a couple of weeks. FAU has been actively engaged in the dual enrollment program of high school students that aims to attract high school students to engineering disciplines. To promote this endeavor, a companion course to Introduction to Machine Vision, viz., Picture Processing has been offered during the summer semesters to the gifted students of the local high schools, using the equipment provided in the machine vision laboratory. For the past three summers, this course had an average enrollment of 20 students. The response to the course has been very positive, and if we had more workstations, we could enroll more students per offering.

To facilitate increased participation of the part-time students in the lab activities, a few of the vision workstations have been set up as host PCs for remote access using remote-control software. With the help of packages such as PCAnywhere™ and Carboncopy™, the remote user takes control an available host PC and its resources [16]. In this way, all experimental data files (acquired at the lab site) can be accessed and program segments can be executed through networks. However, due to the limited bandwidth of the Internet, running complete vision experiments at home using a Modem is still not practical. As the campus LANs widens, one may be able to achieve this objective in the near future.

REFERENCES

1. J.F. Barnes, *A Machine Vision Application Teaching Laboratory*, NSF funded ILI project, 1995.
2. R.L. Carroll, *An Interdisciplinary Robotics, Computer Vision, and Automated manufacturing Undergraduate Laboratory*, NSF funded ILI project, 1990.
3. Y. Chen, *Development of Interdisciplinary Undergraduate Laboratory for Robotics, Machine Vision and System Integration at Indiana University*, NSF funded ILI project, 1991.
4. W. Clement and K.A. Knowles, "An Instructional Robotics and Machine Vision Laboratory," *IEEE Transactions on Education*, Vol. 37, No. 1, Feb, 1994, pp. 87-90.
5. M. Shah and K. Bowyer, "Mentoring Undergraduates in Computer Vision Research," *IEEE Transactions on Education*, Vol. 44, No. 3, Aug. 2001, pp. 252-257.
6. K. Bowyer, G. Stockman, and L. Stark, "Themes for Improved Teaching of Image Computation," *IEEE Transactions on Education*, Vol. 43, No. 2, May 2000, pp. 221-223.
7. J.A. Robinson, "A Software System for Laboratory Experiments in Image Processing," *IEEE Transactions on Education*, Vol. 43, No. 4, Nov. 2000, pp. 455-459.
8. J. Campbell, F. Murtagh, and Munevver Kokuer, "DataLab-J; A Signal and Image Processing Laboratory for Teaching and Research," *IEEE Transactions on Education*, Vol. 44, No. 4, Nov. 2001, pp. 329-335.
9. K.K. Stevens, *Curriculum Reform – A White Paper*, Florida Atlantic University, Boca Raton, 1997.
10. D. Vernon, *Machine Vision*, Prentice-Hall, 1991.

11. R.C. Gonzalez and R.E. Woods, *Digital Image Processing*, Addison Wesley, 1993.
12. J.A. Rehg, *Introduction to Robotics in CIM Systems*, Prentice Hall, 1997.
13. A.K. Jain, *Fundamentals of Digital Image Processing*, Prentice-Hall, 1999.
14. Dolan Jenner, *Illumination Solutions for Machine Vision and Microscopy*, 1996.
15. Cognex, *Programmable Vision Engines Technical Description*, 1996.
16. T. Stevenson, "Remote-Control Software: How to be in 2 Places at Once," *PC Magazine*, Aug. 1994.

APPENDIX: SYLLABUS

EEL4930/COT4930 Introduction to Machine Vision

| | |
|-------------------------|---|
| Catalog Description: | This 3-credit course covers fundamentals of machine vision and their applications in various areas such as manufacturing, medicine, and entertainment. |
| Textbook: | Machine Vision, Ramesh Jain, Ragnachar Kasturi, and Brian G. Schunck, McGraw-Hill, 1995. |
| References: | Machine Vision, David Vernon, Prentice Hall, 1991 Image Processing Handbook, John C. Russ, CRC Press, 1992. |
| Coordinators: | Dr. Hanqi Zhuang, Professor of Electrical Engineering |
| Goals: | To introduce engineering undergraduate and graduate students to fundamentals, design and analysis concepts, and implementation issues of machine vision. Through theoretical studies and hands-on work with machine vision software and hardware, the students will gain familiarity with machine vision algorithms and their applications. |
| Prerequisite by Topics: | Programming with any high-level language |
| Grading policy: | See attached |
| Lecture Hour: | Friday, 9:00 – 10:50 AM |
| Lab Hour: | Friday, 2:00 – 4:50 AM |
| Office Hour: | Wednesday, 8:00 – 11:30 AM |

Note:

- This is a course developed under a project sponsored jointly by National Science Foundation, Florida Atlantic University, and Cognex Corporation, a machine vision equipment manufacturer.
- The course is a mixture of lecturing and lab experimentation. There will be a sequence of lectures that gives students analytical tools to solve machine vision problems. There will also be (a) a number of programming assignments that are aimed at familiarizing with practical machine vision algorithms and (b) one term project that uses an integrated approach for solving one of the typical machine vision application problems.

Topics:

- Introduction to Computer Vision
- Illumination and Sensors
- Image Acquisition and Representation
- Fundamentals of Digital Image Processing
- Segmentation
- Image Analysis
- Image Compression
- Object Recognition
- Case Studies

Experiments: Refer to lab manual

Grading policy

| | | |
|----|-------------------|-----|
| 1. | Test 1 | 20% |
| 2. | Final/Project | 25% |
| 3. | Homework | 10% |
| 4. | Lab | 45% |
| | a. Matlab reports | 15% |
| | b. Cognex reports | 15% |
| | c. Test | 15% |