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Crop Monitoring Platform: A Case of Teaching Machine Vision through Undergraduate Research

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Dr. Stephen Parke earned the AA degree from Olivet Nazarene University in 1980, and the BSEE and MSEE degrees from Purdue University in 1982 and 1984, respectively. He interned with the IBM T.J. Watson Research Center, then spent the first several years of his career with IBM Microelectronics in Essex Junction, VT, where he worked in semiconductor R&D on five generations of IBM's memory chip technologies. In 1989, he was awarded an IBM PhD Fellowship and began full-time study at the University of California at Berkeley. He fabricated and studied nano-scale silicon-on-insulator transistors, and received the PhD degree from UC Berkeley in 1993. He transferred to the IBM Semiconductor R&D Center in Fishkill, NY where he became a team leader in the IBM/Toshiba/Siemens TRIAD multicultural technology development project. In 1996, he left IBM for an entrepreneurial academic start-up opportunity at Boise State University. He was the first EE faculty hired in the newly created College of Engineering. He initiated several university/industry partnerships to design, fund, construct, and equip the Idaho Microfabrication Laboratory and was the director of this lab for the first few years after it opened in 1998. He became ECE Department Chair at Tennessee Tech University in 2006, where he implemented ”The 20/20 Vision” for improved curriculum, research funding, lab facilities, and engagement with industry and alumni. Since 2010, Dr. Parke has been the Engineering Program Director at Northwest Nazarene University, in Nampa, ID and Professor of Electrical Engineering.

His research spans the areas of Multi-gated Nanoscale Silicon Transistors, Semiconductor Memories, low-power, radiation-tolerant integrated circuits, and flexible electronics. His research has been funded by NSF, Air Force Research Lab, Missile Defense Agency, NASA, and American Semiconductor. He has published and/or presented 50 co-authored research papers, and is a co-inventor on 15 US patents, including the DTMOS and FlexFET transistors, which have been commercialized. He has been the primary advisor for 15 graduate students during the past eight years. He has a passion and aptitude for entrepreneurism, technology transfer and economic development activities. He is a co-founder of American Semiconductor, Inc. along with his former grad students and continues to serve on its Board of Directors. He is a registered Professional Engineer in the State of Idaho.

He has actively served the IEEE Electron Devices Society for 20 years. He served ten years on the IEEE EDS Education Committee, and as Chair of the Graduate Research Fellowship Committee. He was the founding Chair of the Boise IEEE EDS Chapter in 1998, which went on to win the EDS Chapter of the Year award two times. As a result of these activities, he received the IEEE Millennium Medal in 2000. He is currently a Distinguished Lecturer in the EDS.

Crop Monitoring System: A Case of Teaching Machine Vision through Undergraduate Research

Abstract

Northwest Nazarene University, which is located in the Treasure Valley of Idaho, is developing a crop monitoring platform (CMP). The CMP, which uses a machine vision system, estimates fruit tree parameters such as tree canopy volume and canopy reflectance characteristics. This research project, conducted by undergraduate engineering students, is integrated with the teaching of machine vision in a Control Systems course. This paper presents a case for teaching machine vision through undergraduate research.

1. Introduction

Northwest Nazarene University (NNU) is a nonprofit Christian university located in the Treasure Valley, near Boise, Idaho. In 2010, NNU started its undergraduate engineering program, offering a Bachelor of Science in Engineering with concentrations in electrical, engineering physics, and mechanical engineering.

One of the core courses common to all engineering concentrations is Control Systems. Students learn about feedback control system, how they operate, and how they are applied in different systems. The course includes a one unit laboratory designed to reinforce the control systems concepts. Laboratory experiments include the development of a machine vision system (MVS). A MVS is used to recognize objects and then integrated with a simple robot to demonstrate the concept of visual feedback control. Several engineering universities have developed courses that include machine vision in the last few years. For example, Zhuang and Sudhakar[1] developed a machine vision laboratory to introduce students to the concept of machine vision. On the other hand, Liang[2] developed machine vision courses for manufacturing engineering technology.

In the summer of 2012, NNU received a grant, part of the 2012 Idaho Specialty Crop Block Grant[3], from the Idaho State Department of Agriculture to develop a crop monitoring platform (CMP). The main objective of this research grant is to develop a monitoring system that could assist crop management in Idaho. In addition, NNU also received a grant from the NASA Idaho Space Grant Consortium[4] to study applications using unmanned aerial systems (UAS). The UAS primarily serves in military applications but recently has begun meeting civilian applications[5, 6]. These grants have provided great undergraduate research opportunities. A MVS will be used to develop the CMP. Mounting the CMP to the UAS could provide a powerful tool for farmers in the future. This paper discusses the integration of this undergraduate research with teaching control systems, specifically machine vision.

2. Machine vision

2.1 Generic machine vision model

Machine vision can be defined as a combination of an imaging sensor with image processing to provide visual perception to machines. The typical components of a MVS are lighting, image acquisition system, and a processing unit, usually a personal computer. In addition, task-specific software is developed to perform image processing functions. Awcock[7] defined a generic model for a MVS, which could be adapted to different applications. The model, shown in Fig.1, is composed of four elements: scene constraint, image acquisition, image processing, and actuation.

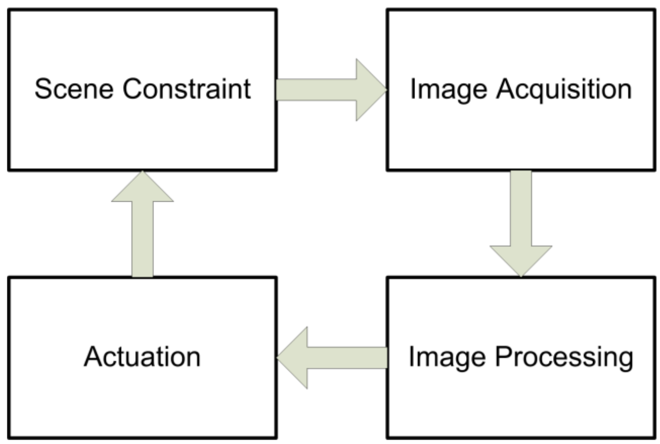


Figure 1. Generic machine vision model

1. Scene constraint is the environment where the MVS is deployed. It includes the lighting parameter, which affects the quality of the images.
2. Image acquisition is the hardware that transforms the scene reflection into a digital image. An RGB digital camera is commonly used for image acquisition especially if the desired object has a color contrast with respect to the background. Some applications require a special image acquisition system like a thermal camera or an infrared camera[8].
3. Image processing acts as the brain of the machine vision and is typically composed of pre-processing, segmentation, and feature extraction.
    a. Pre-processing – modify and prepare the raw image to produce an image data that is suitable for subsequent operation. An example is increasing the intensity of the image pixels.
    b. Segmentation - the desired object is differentiated from the background. The simplest application uses a color filter to segment the desired object.
    c. Feature extraction - the parameters of the desired object such as area, centroid, and eccentricity are determined.

4. Actuation is the interaction back to the scene. For example, in a robotic picking system[9], ripe fruit and its location are determined by the MVS and the picker is guided towards the fruit. This application of machine vision is commonly known as visual feedback system.

2.2 Integration of machine vision in control systems

In the Control Systems laboratory at NNU, there are two laboratory experiments related to machine vision system; a) Introduction to machine vision and b) Object tracking

2.2.1 Introduction to machine vision

In this laboratory experiment, students are introduced to the development of a MVS using a charge coupled device (CCD) color camera connected to a personal computer running RoboRealm. RoboRealm is an application software package for use in machine vision, image processing, and analysis. The objective of this experiment is to develop a simple MVS to recognize an object using its color and shape properties. With the advancement of computer and sensor technology coupled with the decreasing cost, a low-cost MVS can easily be developed as shown in Figure 2. This MVS is composed of a wireless color camera, video signal transmitter, USB video capture device, and a personal computer.

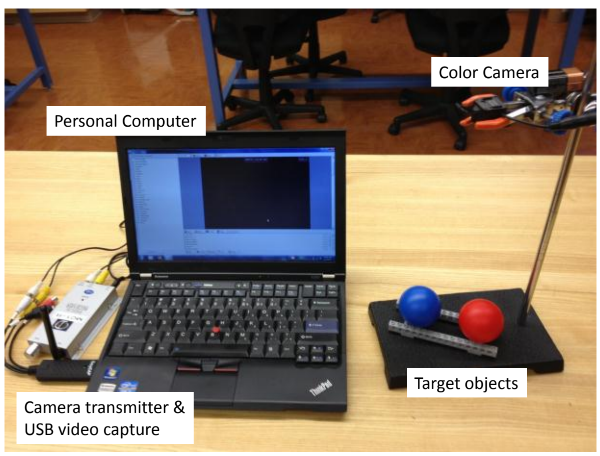
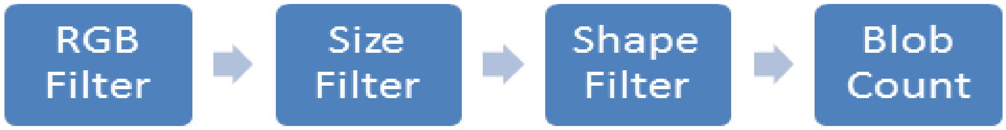
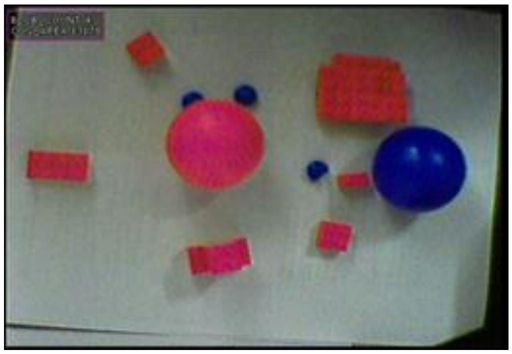


Figure 2. Machine vision set-up

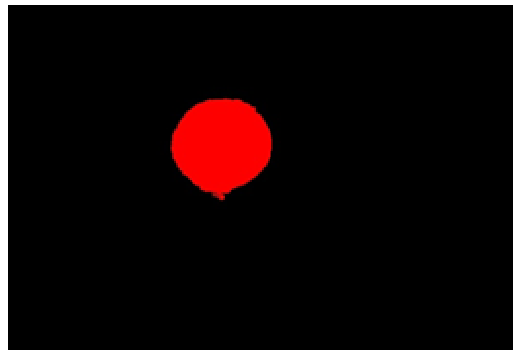
Figure 3(a) below shows the algorithm developed by one of the students to recognize a red ball mixed with other objects (Fig. 3(b)). The algorithm starts with a simple RGB filter to segment the red objects from the background. The filter is then followed by a size filter to remove smaller objects and then a shape filter is implemented to recognize the round ball, which is shown in Fig. 3(c). The blob count process counts the number of circular blobs in the image.



(a) Image processing for red ball recognition



(b) Raw color image



(c) Segmented image of red ball

Figure 3. Machine vision for red ball recognition

2.2.2 Object tracking

After the students learned the fundamentals of machine vision (2.2.1), they study how to integrate machine vision to control a robot. The objective of object tracking is to reinforce the concept of a feedback system using machine vision as the feedback block. In this case, the tracked object is used to control a mobile robot. Figure 4 shows a closed-loop control system using machine vision as a feedback block.

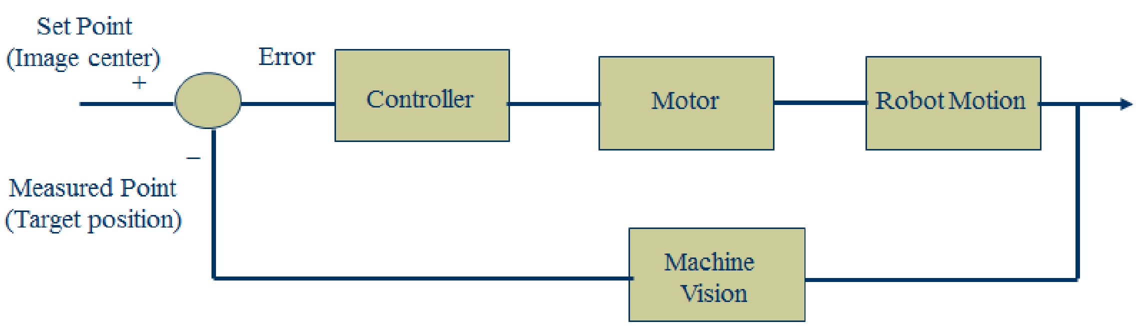


Figure 4. Visual Feedback Control

In this experiment, the image acquisition system is mounted on the center of a Lego cart robot. The goal is to move the robot towards the target, which is either a blue or red ball. Figure 5 shows the set-up for object tracking using the Lego cart with a wireless camera providing image data. The image processing for tracking the ball is also shown. An arbitrary set point is established for the image; in this case the center of the image. The MVS segments the ball and finds its location in the image. If the target is not in the center, the motors are activated to position the target in the center of the image. Once it is in the center the size of the ball is used to estimate the distance of the ball from the robot. This parameter is used to move the robot towards the ball.

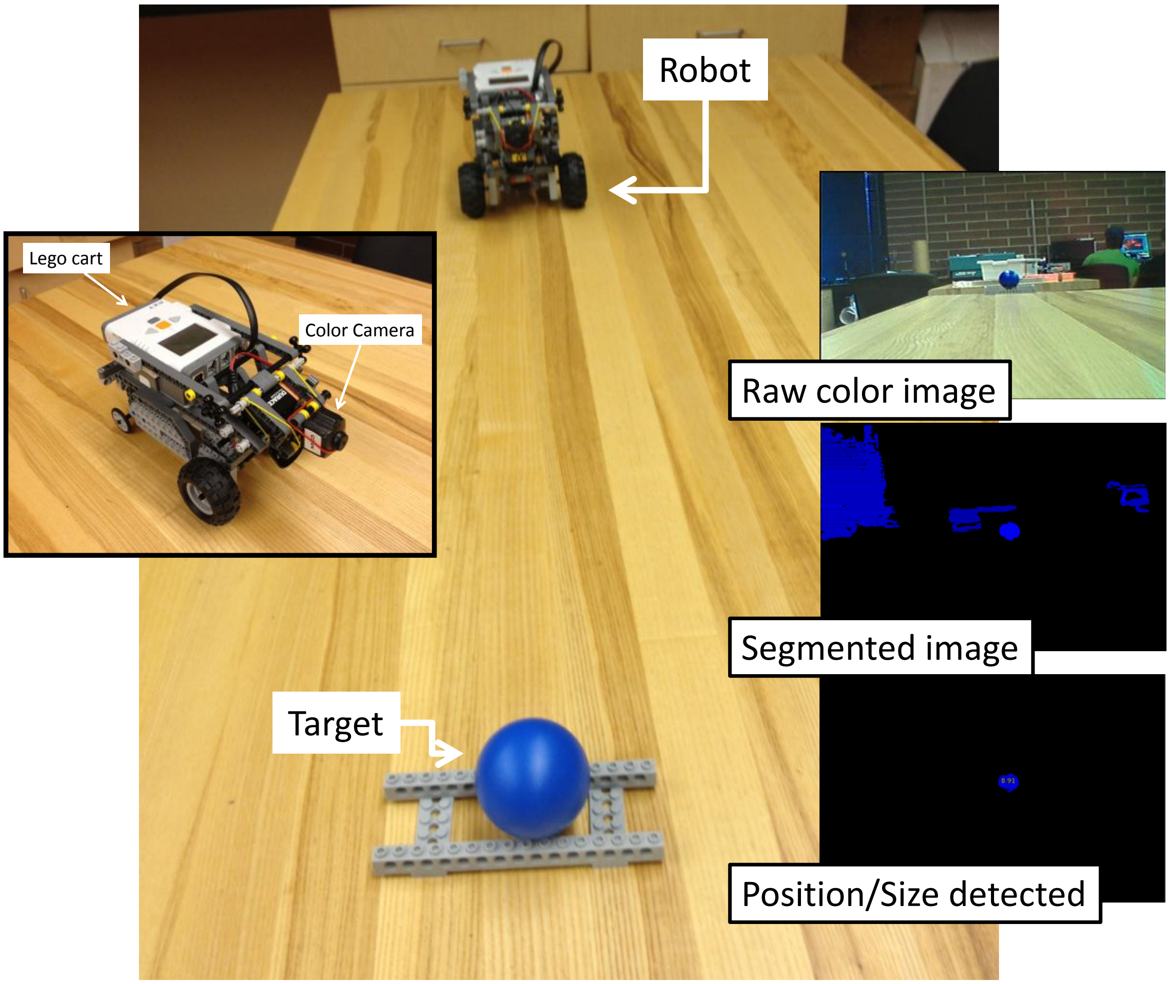


Figure 5. Object tracking using a Lego cart with a wireless camera

3. Crop monitoring system

3.1 Research objectives

In the summer of 2012, NNU was one of the recipients of the 2012 Idaho Specialty Crop Block Grant, which provides research funding specifically for specialty crops. Specialty crops include fruits, vegetable, and ornamental plants. The overall objective of this research is to develop a crop monitoring platform (CMP) to assess the conditions of a crop including crop dimension, normalized difference vegetation index, and canopy nutrient content. A MVS is used as the visual sensor for the CMP and includes both color and infrared images. The following section discusses how a tree canopy can be analyzed using a MVS.

3.2 Materials and methods

For the development of the CMP MVS, a multispectral CCD camera was used, which acquired both color and infrared images. The multispectral camera is connected to a PC using an Ethernet cable and images are acquired in real-time. Matlab, with its image processing toolbox, was selected for the development of the image processing and analysis portion of the MVS.

The specialty crop used in this initial research was the apple. Images of apple trees were acquired in one of the commercial orchards in Sunny Slopes, Idaho. The camera was positioned about seven meters from the tree and images were acquired during midday on a sunny, still day.

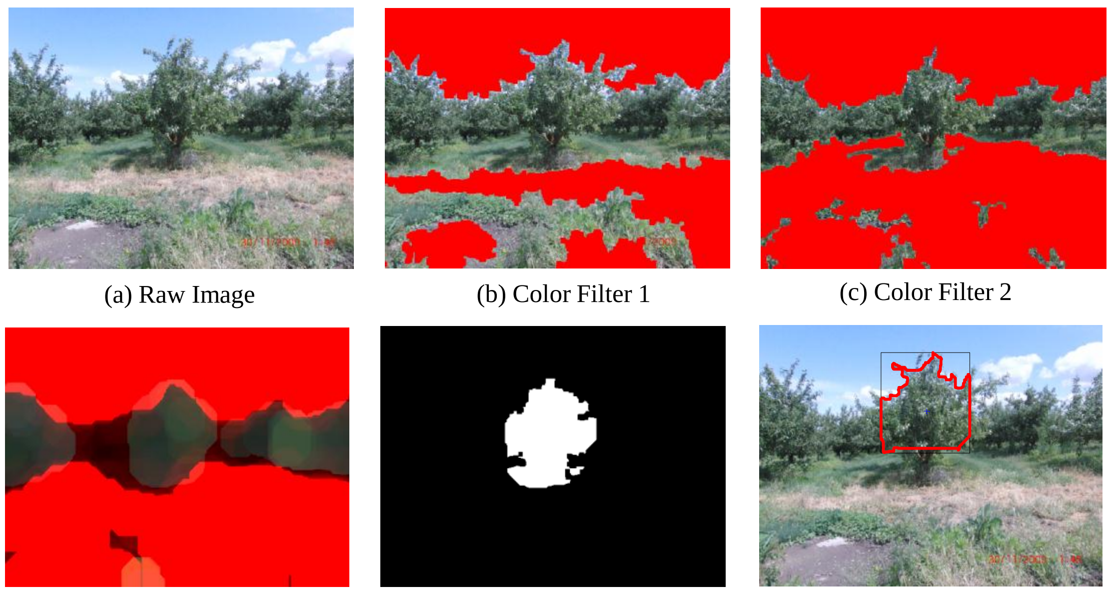
3.3 Results and discussion

Figure 6 shows the image processing for apple tree recognition. The raw color image (Fig.6(a)) shows an apple tree in the middle part of the image with other apple trees in the background. The first image processing step involves the use of a color filter (Fig.6(b) and (c)) to separate the sky and ground background. This step allowed students to compare how the controlled environment of the ball recognition in the classroom extrapolates to a natural environment condition involving the color filtering of a natural object under an uncontrolled lighting condition; reinforcing the influence of lighting. The color filtering is then followed by an erosion and dilation process to segment the middle tree from the other trees in the background (Fig. 6(d)). This was a challenge for the students because unlike the round ball and square blocks in the introductory machine vision experiments, the size and shape of the tree varies. Different techniques were investigated leading to the erosion and dilation process such as edge analysis and shape analysis[10]. A binary mask is then used to recognize the tree object and determine its features such as canopy width and height (Fig. 6(e)).

The developed image processing algorithm was able to recognize and measure features of the apple tree including height, width, and canopy volume. However, as previously mentioned, there are some issues that need to be resolved. These include lighting (time of the day, weather condition) and the position of the tree within the orchard. The erosion and dilation process is shape-dependent, and two-dimensional feature estimation is used to represent three-dimensional objects. These are challenges that the students encountered in the development process. From these issues, the following MVS and control concepts are strongly demonstrated:

1. Lighting control
2. Controlled environment versus uncontrolled environment
3. Color filter development
4. Morphological image processing
5. Camera calibration

Although these theories are not taught in the formal lecture setting, the students learn these concepts during the experiment and while developing the image processing and analysis software. Several researchers have demonstrated that immersing students in research-based activities expanded their learning opportunities. For example, Ferry and Otieno[11] introduced the concept of automation integration by using machine vision for an automated bottle and capping and sorting system. Likewise, Yeh and Hammond[12] developed an industry-based student project which used machine vision to guide a robot that picks-up a tire from a conveyor and places it in another fixture. By giving the students the chance to perform real-world problems, the students acquire techniques on MVS development and learn how to integrate it with other automation systems. It allows the students to think "outside the box". In the case of crop monitoring, the output will be used to manage crop production. For example, the features of the tree such as canopy volume could be used to control the amount of water applied to a particular tree based on its size. This is one type of applications of Precision Agriculture, where the crops are managed based on the crops' specific information.



(a) Raw Image (b) Color Filter 1 (c) Color Filter 2

(d) Erosion and Dilation (e) Masking (f) Feature Extraction

Figure 6. Image processing for tree recognition

4. Conclusion

One of the concepts taught in the Control Systems course in the engineering program of Northwest Nazarene University is MVS. In teaching MVS, two laboratory experiments are conducted to learn the fundamentals of a MVS and its role in feedback control systems. In addition, undergraduate students learn to apply the theory by conducting research in real-world problems. A MVS was developed for crop monitoring specifically to measure tree parameters such as canopy height and width. This paper has shown the added value of undergraduate research in teaching machine vision.

5. Acknowledgement

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