2006-576: TEACHING A COMPUTER TO READ: IMAGE ANALYSIS OF ELECTRICAL METERS

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Teaching a Computer to Read: Image Analysis of Electrical Meters

Abstract

There exists a vast infrastructure of heritage analog and digital meters installed in commercial and industrial applications. These devices typically have no built-in means of automated reading. Modifying the equipment is not a viable option in many applications. With the low cost of USB digital cameras and the availability of LabVIEW™ VISION, a cost-effective method of reading multiple meters of assorted types can be created. Duplicating the process that a human performs while reading a meter display is daunting. However, this process is simplified by using virtual instruments (VIs), which perform essential functions such as edge, pattern and rotation detection. As part of an undergraduate research project, a computer, using LabVIEW™ Vision, together with a USB digital camera is used to read a digital multimeter (DMM) and an analog watt-hour meter. Circular edge detection, pattern searches, and rotation detection are used to locate dials and segments and to determine their values. Horizontal and vertical edge detection and region of interests (ROI) are used to identify and determine the values of a DMM's display. The ability to read meters with only minimal human interaction increases accuracy and speed. This feature and the ability to create visual data logging have many uses in educational and industrial applications. This paper presents techniques for identifying and reading meter data. The basics of reference images and their use in image analysis are explored in reading legacy DMM and analog watt-hour meters.

Introduction and Motivation

Various types of electrical meters are required and utilized to take many types of measurements in commercial and industrial applications. There exists a wide range of installed legacy meters which are capable of performing these measurements. The vast majority of these devices lack the ability to be remotely or locally monitored by computers. The ability to be monitored by a computer is becoming increasingly important as the convenience of remotely monitoring equipment outweighs the cost of visiting each piece of equipment. Modern measurement equipment is certainly capable of transmitting its acquired data either through wires of wirelessly. The infrastructure of existing equipment is slowly being replaced with this type of devices. However, the replacement of the installed base of legacy equipment is a costly and daunting task and may not be practical in many instances.

The use of cameras in manufacturing automation is well published and very successful. Most systems employ sophisticated and expensive vision equipment for the control of robotic equipment.[1,2] With the recent popularity of the universal serial bus (USB), a plethora of formidable image capturing devices have emerged. These devices have very high resolution and very low cost. These features make them very attractive for many data acquisition applications as well. Together with sophisticated yet simple to use LabVIEW software, powerful and elegant instrumentation systems can be created.[3]

As part of an engineering technology undergraduate research project at Penn State Berks, a webcam was used to capture images of various electrical meter displays for the purpose of extracting the displayed readings. Both digital (LCD) and analog (dials) were used. The LCD of a handheld digital voltmeter was used for the digital display tests. A typical residential Watt-hour meter was used for the analog display tests. The webcam was controlled by and the images were analyzed by LabVIEW VISION software.

Hardware Overview

Figure 1. RSR 926 Digital Multimeter

For this undergraduate research project, common, readily available meters were used. Figure 1 shows the RSR 926 DMM that was used for the digital display work. This meter is regularly used in the laboratories at Penn State Berks. The CL200 General Electric watt-hour meter shown in Figure 2 was used as the analog meter subject. This particular meter was located at the home of the student researcher and co-author. Neither of these meters had any type of computer interface. No electrical connections, modifications or attachments of any kind were to be made to either meter. This minimizes the risk of electrical shock and eliminates the need for isolating devices. The use of a use of a digital camera (webcam) was proposed to meet these requirements.

Figure 2. GE CL200 Watt-Hour Meter

The webcam used for this project is the Logitech QuickCam Pro 4000 shown in Figure 3. At the time of the project, this camera was available for about $80 US. This camera has 640x480 video resolution with an advanced VGA CCD sensor and high-quality 1.3 mega pixel (software interpolated) photo resolution.[4] The QuickCam Pro 4000 connects to the PC via the USB port. This camera is also Directshow® compatible as is required by LabVIEW VISION.[3]

Figure 3. Logitech QuickCam™ Pro 4000 USB Video Camera

The resolution and speed of the QuickCam is more than adequate for the meter reading application. The camera is powered via the USB port so no additional power supply or wire

connections are needed. For the watt-hour meter reading, the QuickCam was connected to a laptop computer so that it could be used outdoors.

Software Implementation

The webcam images were acquired and analyzed with LabVIEW VISION software. This software has the USB drivers required for communication with the QuickCam Pro 4000. The real power of the LabVIEW VISION software is the image analysis algorithms (Virtual Instruments (VIs)). These VIs contain the building blocks for extracting the meter data from the acquired images of the displays. When properly calibrated, the software determines which segments of the seven-segment LCD digits are turned on or where the analog meter needle is pointing.

Digital Multimeter

For the digital multimeter, the display consists of four, seven-segment liquid crystal display digits. The task of the software is to determine which segments of each digit are turned on. Once this is known, the displayed value can easily be determined.
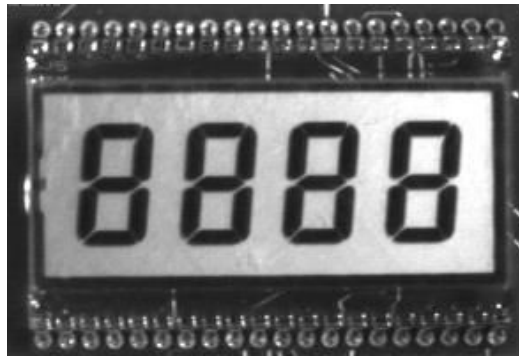

Figure 4. Sample Image Needed for Image Analysis Reference

The VIs supplied with LabVIEW™ VISION require a reference image that has all seven segments of *every* digit turned on as shown in Figure 4. This is not possible with a three and one-half digit multimeter as can be seen in Figure 5. The most significant digit is either 1 or not displayed if it is zero. To satisfy the reference image requirement, a high resolution picture was taken with the meter displaying 188.8kΩ. This picture was then altered using photo editing software to create an image displaying 888.8kΩ. The result of this photo editing process is shown in Figure 6. This altered image was then used as the reference image for the LCD reading software.

Figure 5. Maximum Segments Active for 3½ Digit DMM

Figure 6. Altered DMM Display Used for Image Analysis Reference

As shown in Figure 7, the reference image is prepared with a Region Of Interest (ROI).[5] The ROI is used by LabVIEW™ VISION VIs to determine boundaries inside which to perform the image analysis.[6] A snapshot of the DMM is taken with the measured value displayed. Only two points need be identified to the relative size of the DMM in the snapshot. The reference image is then re-sampled or scaled to be the same relative size as the DMM in the snapshot.
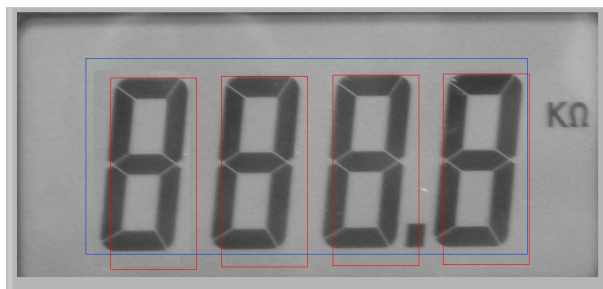
Figure 7. Reference Image with ROIs Selected

Figure 8. Webcam Image of DMM with Digit ROIs selected

A ROI is created based upon the known relative location of the displayed value on the LCD face and the relative size of the DMM in the snapshot as shown in Figure 8. This ROI is then an input to the *IMAQ Get LCD ROI* VI which is supplied with LabVIEW's VISION software. The output of this VI is then a set of ROI for each seven segment display.

Figure 9. Front Panel of DMM Reader VI

The *IMAQ Read LCD* VI is which also comes with LabVIEW's VISION software then uses the ROI for each seven segment display to determine each segments status and digit. This is

preformed by doing three edge detections, two horizontal and one vertical. The horizontal edge detections are preformed at 1/3 and 2/3 the height of the ROI to determine if the vertical elements are active. The vertical edge detection search is preformed to determine if the horizontal elements are active.[6] Figures 9 shows the LabVIEW DMM Reader VI front panel. Notice that the proper reading is extracted despite considerable reflected glare on the display cover. Figure 10 show the front panel and block diagram respectively for the DMM Reader VI.
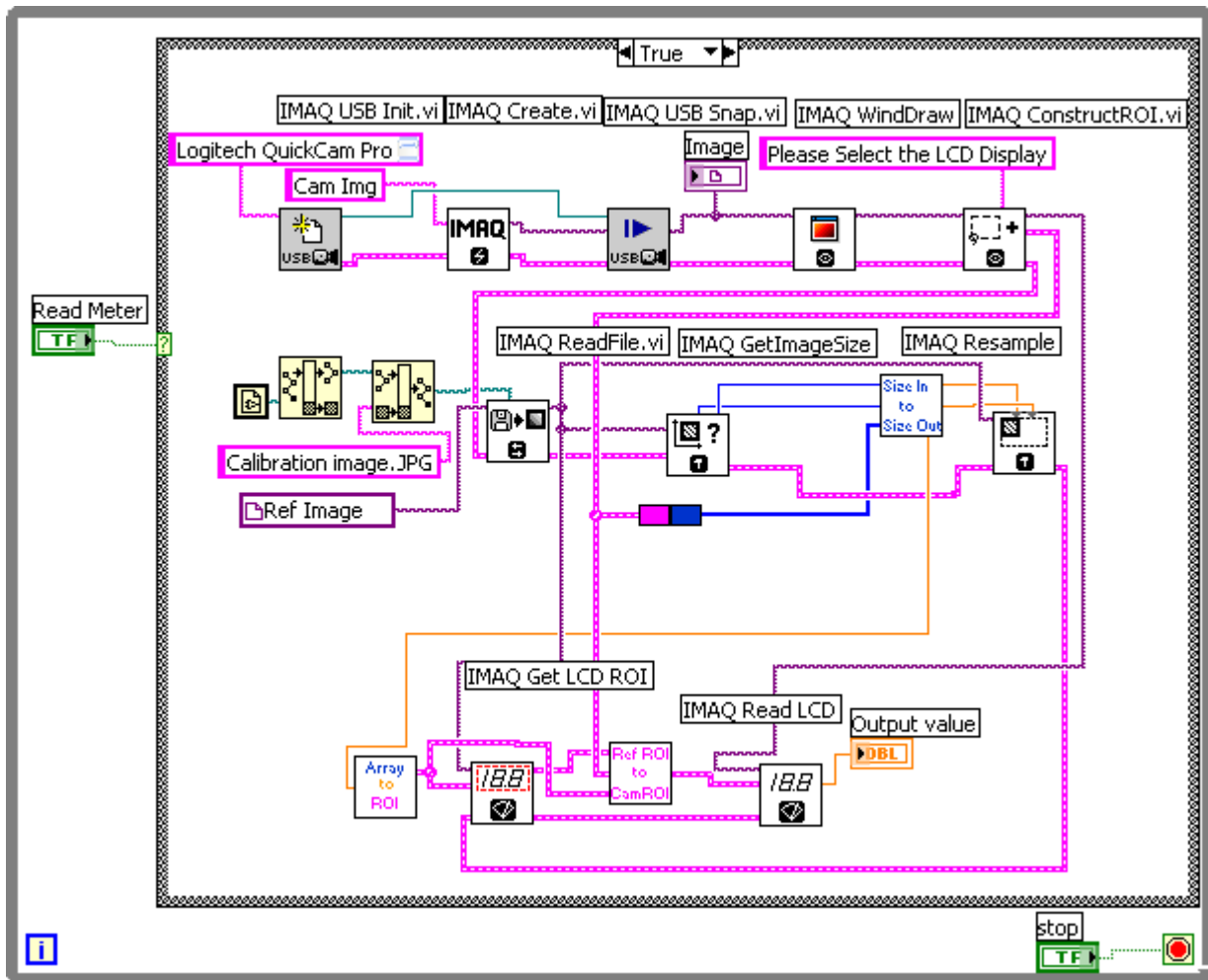
Figure 10. Block Diagram of DMM Reader

Watt-hour Meter

Analyzing a watt-hour meter's face presents a whole set of challenges that are not found with analyzing a DMM LCD screen. There where no VIs available with the LabVIEW VISION software that would directly identify all of the dials on the front of a watt-hour meter by just selecting a single ROI. Therefore, an image detection algorithm based on the unique analog dial characteristic was developed for this project.
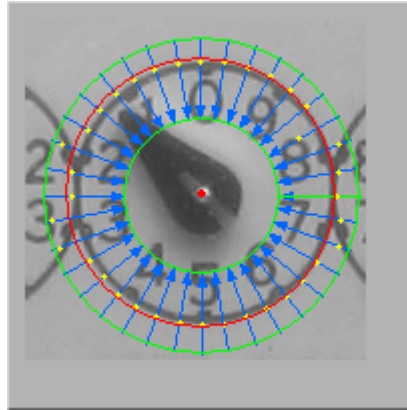
Figure 11. Annulus ROI Selection with Circular Edge Detection Lines

For the multi-dialed watt-hour meter, one dial is needed for sizing purposes using an *annulus ROI*. Using this annulus ROI, the LabVIEW VISION VI searches for a circular edge as shown in Figure 11. The dial outer radius is then used by another VI which draws two reference images. As shown in Figure 12, one reference image is a dial *ring* and the other is a dial *pointer*.
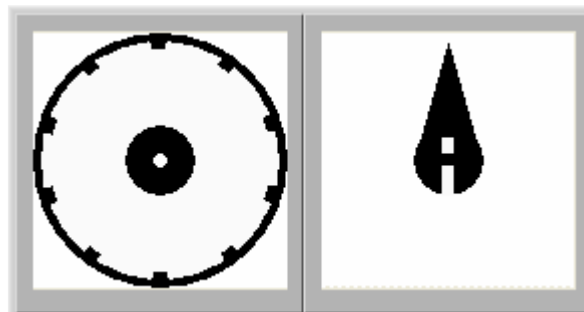

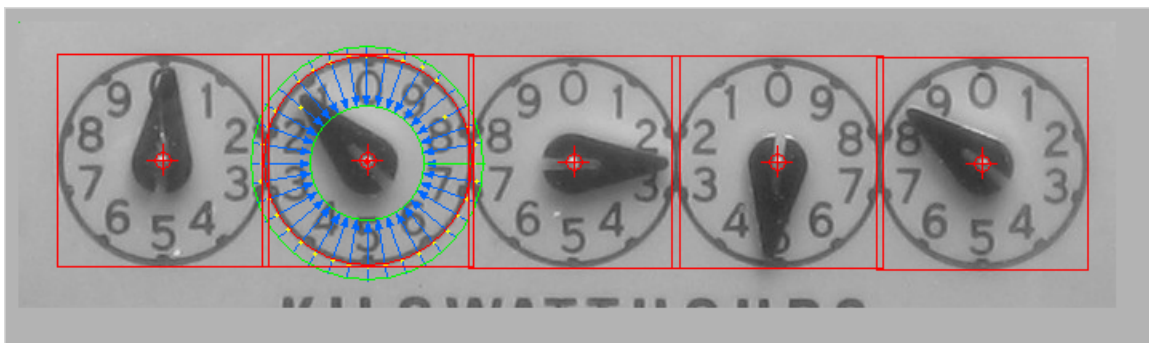Figure 12. Dial Ring and Pointer Reference Images

Figure 13. Detail of Identification of Ring Patterns on the Meter Face

The dial ring is used to perform a pattern search of the watt-hour meter face image to identify the locations of any and all similar dials on the meter as shown in Figure 13. Once the dial locations are determined, a best-fit line is determined based on the center of all of the dials. An angle of rotation is then determined which is the camera's offset angle with the watt-hour meter.

Each of the dials has a *rotation detection test* preformed on it using the reference pointer created using the dial diameter. Here each dial image is rotated until it most closely matches the reference dial image. The angle found requires some quick scaling to determine the pointer's position and hence the indicated value of that dial. Figure 14 shows the block diagram for the Watt-hour Meter Reader VI.
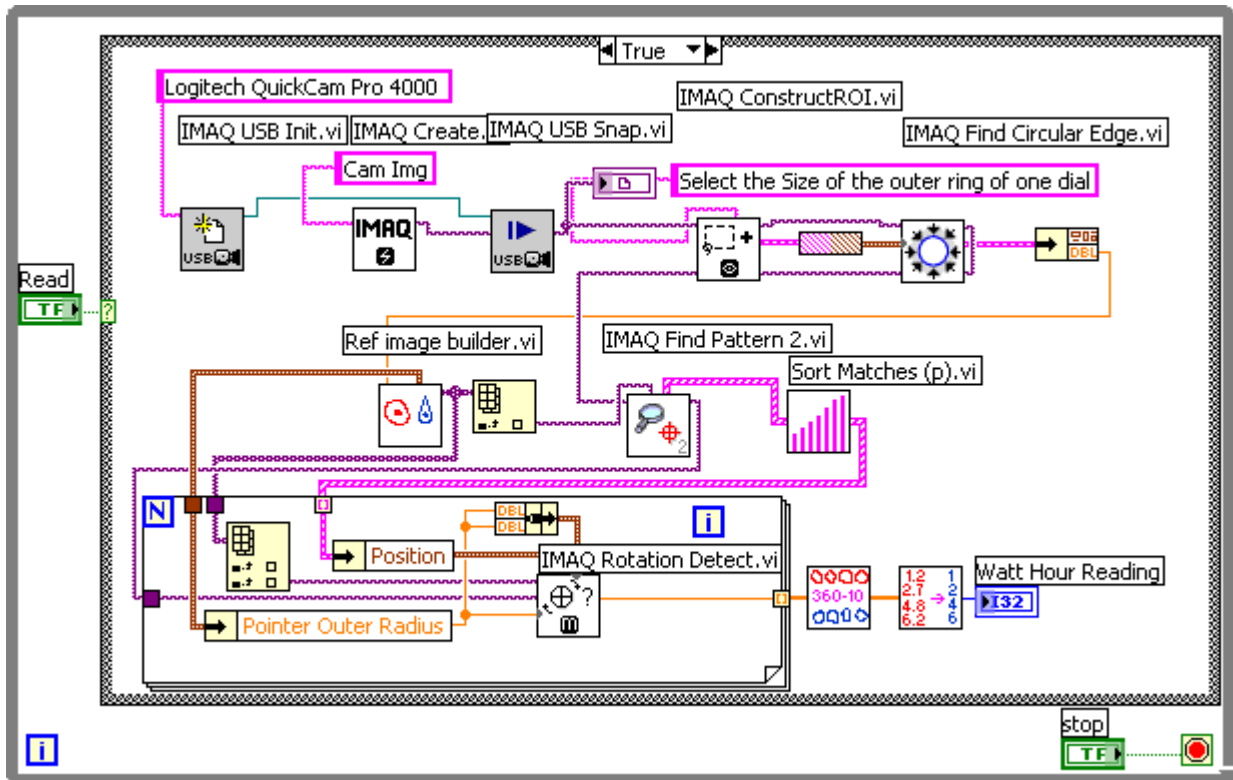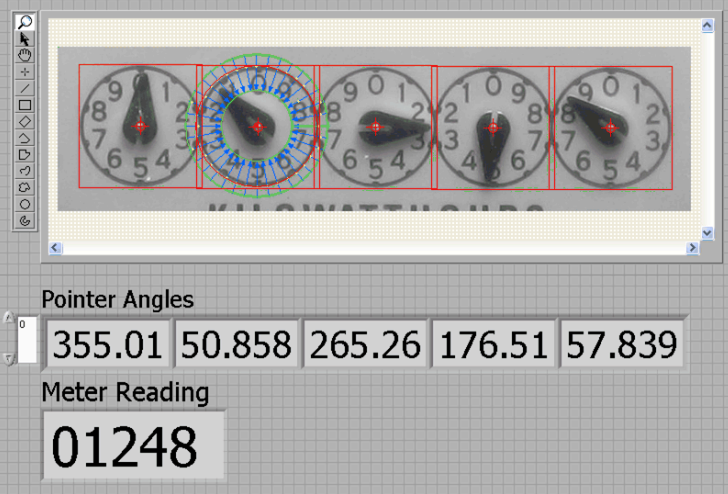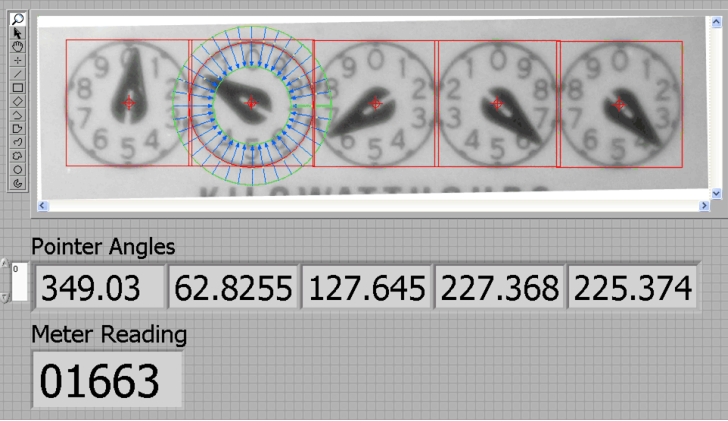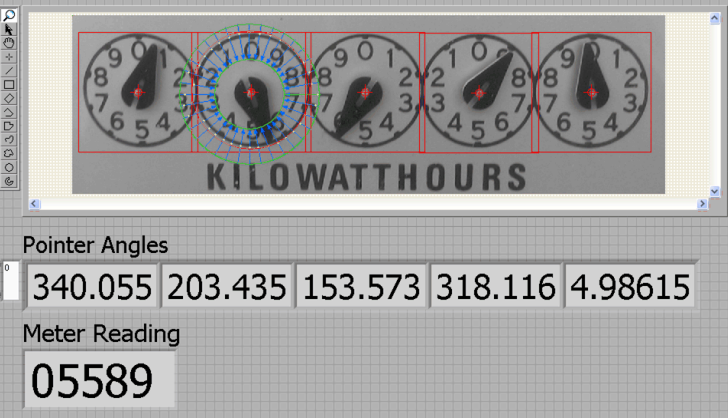

Figure 14. Block Diagram of Watt-hour Meter Reader VI

The Watt-hour meter reading software was tested with various levels of ambient lighting and at different ranges with very good results. The algorithm used to locate and read the dials within the region of interest was found to be very insensitive to image quality. Table 1 shows some examples of results from reading the Watt-hour meter in different conditions. Notice that even when the dial images are quite blurred, the algorithm correctly extracts the proper needle position. Total processing time is less than 1 second from the beginning of image acquisition to the display of the extracted meter reading.

Table 1. Results for Watt-hour Meter Reading VI

LabVIEW Meter Reader VI Result	Actual Visual Reading
  Pointer Angles 355.01 50.858 265.26 176.51 57.839 Meter Reading 01248	1248 kWh
  Pointer Angles 349.03 62.8255 127.645 227.368 225.374 Meter Reading 01663	1663 kWh
  Pointer Angles 340.055 203.435 153.573 318.116 4.98615 Meter Reading 05589	5589 kWh

Summary and Conclusions

A method of acquiring displayed information from various electrical meters to a computer without the need for a direct connection or expensive equipment has been investigated and presented. A simple, common, and easily usable digital camera is the only piece of measurement hardware needed to acquire the information from the electrical meter. The use of LabVIEW's VISION software enables the user to create an application which is able to analyze and extract the information displayed on the target meter. As shown in the example applications, the user can create sophisticated image recognition applications by identifying the uniqueness of the image to be studied. This uniqueness is then exploited to extract the desired information.

As shown in the examples for each meter type, the defining features can be extracted from images with significant blurring or reflected glare. This is very important especially for applications such as the Watt-hour meter in which the meter is located outdoors where lighting conditions can vary considerably. The image searching algorithms are also tolerant of slight image rotation as long as the desired image features remain within the defined region of interest.

Applications for camera systems using image recognition are numerous. Tedious and error-prone meter reading by a human is eliminated with this system. The use of the digital camera allows a very large isolation zone between the camera electronics and the target meter. This isolation allows the reading of very high voltage meters or those in confined or hazardous environments. Also, large banks of legacy meters such as those found in process plants can be read simultaneously with one stationary camera. Setups like this could serve as the primary means of process measurement or as backup to hard-wired meter systems.

References

1.   Shiver, A., Needler, M., and Cooney, E., "Integrating Data Acquisition Tools to Accomplish an Automation Course Project," Proceedings of the American Society for Engineering Education Annual Conference and Exposition, 2003.

2.   Liang, Z., "Teaching Robot Vision in Manufacturing Technology," Proceedings of the American Society for Engineering Education Annual Conference and Exposition, 1996.

3.   National Instruments support, "Acquiring Images in LabVIEW Using a USB Camera," website: http://digital.ni.com/public.nsf/allkb/274a74a901399d0486256f32007295f9

4.   Logictech Quickcam Pro 4000 product website: http://www.logitech.com/index.cfm/products/details/US/EN,CRID=4,CONTENTID=5042

5.   National Instruments support, "IMAQ Vision Algorithms," website:http://digital.ni.com/public.nsf/allkb/D6B6B5D928C186B486256F4D00046CFC

6.   Hanks, J., App. Note 125, "Using Edge Detection in Machine Vision Gauging Applications," National Instruments, 1998.