Machine Vision Projects with NI myRIO - PREVIEW

This courseware title will be released in its entirety in early 2015. This preview of the material is available now for professors and students to review and test.

With the preview material you will learn fundamental concepts necessary to create a myRIO vision application in LabVIEW as listed below.

Specific PREVIEW Topics

1. Acquire an image of a coin and measure the diameter
2. Measure a camera's pixel aspect ration
3. Determine camera to object distance
4. Calculate the field of view
5. Calibrate a camera to use real world units
6. Correct lens distortion and tangential distortion

Full List of Topics to be Covered in Complete Version

Part I

1. Application Development Flow
2. Camera Set-up
3. Image Buffer Memory Management in LabVIEW

Part II

1. Acquire a calibrated image from a webcam
2. Detect and count objects passing by field of view
3. Identify and sort objects by shape
4. Identify and sort objects by color
5. Inspect a part for missing pieces
6. Auto-pan the webcam to track objects by color
7. Read a legacy meter that lacks a digital data communications interface
8. Manage inventory with handwritten labels and barcodes
9. Inspect an object for texture defects
10. Inspect an object compared to golden template
11. Measure depth information from stereo webcams
12. Measure optical flow

Final Version will Contain

Full Lab Exercise Manual PDF
LabVIEW Project Files
30+ Detailed Instructional Videos

Required Software

NI LabVIEW
NI LabVIEW myRIO Module
NI LabVIEW Vision Development Module

Required Hardware

NI myRIO
USB Webcam
Machine Vision Projects with NI myRIO

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1 Application Development Flow

1.1 Synopsis

The machine vision projects in this manual generally follow a well-defined application development flow from original concept through validation of the application on the NI myRIO target. The particular details vary considerably from one project to the next, but the overall development flow remains the same.

In this project you will gain experience with the machine vision application development flow based on NI Vision Assistant and NI LabVIEW for the NI myRIO hardware target.

**NOTE:** The application development flow described here may also be used to create a desktop application in case you do not have access to the NI myRIO target.

1.2 Objectives

1. Gain experience with the machine vision application development flow
2. Implement a simple machine vision application to measure a coin’s diameter.

1.3 Deliverables

1. Hardcopy of all LabVIEW block diagrams and front panels that you develop
2. Screen captures of NI Vision Assistant script and individual step dialog boxes
3. Lab report or notebook formatted according to instructor’s requirements

1.4 Required Resources

1. NI Vision Assistant
2. NI LabVIEW
3. NI myRIO
4. Ruler with millimeter and centimeter marks
5. Several coins of various sizes
6. Caliper
7. Black felt fabric
8. Webcam
9. Table-top copy stand

1.5 Preparation

Figure ??? visualizes the application development flow as an eleven-step procedure. Familiarize yourself with these important considerations for each step of the development flow:

1. Define the requirements of the machine vision application
   - Processing objectives, e.g., measurement and gauging, classification and sorting, and bar code recognition
   - Throughput measured in parts processed per second
   - Minimum feature size and number of pixels allocated to this feature
   - Size of the field of view
   - I/O devices for part sensing, position control, and information display
2. Configure the image acquisition system

- Determine the minimum feature size in physical units such as millimeters
- Determine the number of pixels to allocate to the minimum-sized feature, and thereby obtain the required spatial resolution in millimeters per pixel
- Select the camera resolution and camera-to-object distance to achieve the required spatial resolution, field of view (FOV), and frame rate
- Arrange the lighting system to obtain high contrast for the features of interest and to suppress distracting background features that complicate subsequent software processing and add unnecessary computational cost
- Use grayscale images for efficiency unless color is required for the application; color images tend to slow down the display, especially at higher resolutions

3. Acquire representative images

- Connect the camera to the desktop
- Use Vision Assistant to collect images over the range of possible conditions
- Use manual camera settings, especially focus; record the settings for later use
- Collect an image of one or more calibration targets using the same camera settings

4. Calibrate the camera when the application requires real-world units

- Use the calibration target image(s) collected in the previous step
- Use the simplest calibration technique that achieves the required measurement accuracy
- Do not disturb the image acquisition setup once calibrated

5. Develop the processing script

- Use the stand-alone version of NI Vision Assistant
- Begin with the color-to-luminance step (unless the application requires color, of course)
• Evaluate the performance using the representative images collected earlier
• Use the minimum number of steps that satisfies the requirements
• Periodically evaluate the computational effort of each step with the Vision Assistant “Performance Meter”

6. Create a new NI myRIO LabVIEW project
   • Remember to connect the camera to NI myRIO

7. Configure the Vision Acquisition Express VI
   • Select the “Continuous acquisition with in-line processing” option
   • Adjust the camera video mode and attributes to match the settings recorded in Step 3
   • Click “Test” to confirm that the image looks correct
   • Enable the frame rate output, if desired

8. Configure the Vision Assistant Express VI
   • Open the Vision Assistant script created in Step 5
   • Remove the color-to-luminance step (assuming the camera is in grayscale output mode)
   • Click through the steps to confirm correct operation
   • Select the necessary input controls and output indicators
   • Enable the “Create Destination Image” option
   • Move the Express VI inside the while-loop structure
   • Create the needed controls and indicators

9. Add block diagram code for I/O devices
   • Use available onboard devices as needed, e.g., LEDs, accelerometer, and switches
   • Refer to the NI myRIO Project Essentials Guide for detailed instructions on a wide range of useful external devices such as proximity sensors and LCD display

10. Validate the finished application
11. Deploy the VI as a stand-alone application

- Refer to Appendix B of the PEG

In the next section you will gain experience with the various software tools and techniques associated with this development flow. Finish up this section by investigating the available video modes of your webcam.

Study the video [Camera Defaults](https://youtu.be/t2xlhTp7-rM, 3:51) to learn how to use NI-MAX to select the camera resolution, frame rate, and output image type as either color or grayscale, and then save these settings as the default for other applications. The default settings may be defined independently for the webcam connected to the desktop and to NI myRIO. Also learn how to determine the frame rate for the displayed and acquired images for a given video mode and output image type.

Connect your webcam to the desktop and then record and tabulate the frames per second (fps), both displayed and acquired, as reported by NI-MAX for each of available video modes of your webcam as well as the two types of output (color and grayscale), if available. Connect the webcam to NI myRIO and repeat; the video modes are likely to be different on the desktop than those on NI myRIO. At what resolution do you begin to see a difference between RGB and grayscale frame rate? Does the video mode with the highest stated frame rate for a given resolution in fact have the highest measured frame rate? Also investigate the impact on frame rate of manual versus automatic settings, especially exposure.

**Tip:** Keep this table handy for future machine vision projects so that you can quickly choose a video mode to balance the competing requirements of throughput (frame rate) and spatial resolution.

### 1.6 “Coin Caliper” Machine Vision Application

Gain experience with the various software tools and techniques associated with the machine vision application development flow by following along with a detailed video tutorial to implement the “Coin Caliper,” a simple application to measure and display the diameter of a single coin placed in the center of the webcam’s field of view.
Acquire representative images

- Gather at least five coins of different denominations, and at least three additional coins of a single denomination.

- Determine as accurately as possible the diameters of the coins you have available. Precision calipers would be appropriate, if available, otherwise search the Internet for the specifications of your coins. Tabulate the diameters of each of your coin denominations.

- Follow along with the video [Sample Images (Coin Caliper)](https://youtu.be/lPEzd_Jvjc8, 4:17) to learn how to acquire representative coin images in the stand-alone version of NI Vision Assistant; select Windows “Start” and then select “All Programs | National Instruments | Vision | Vision Assistant.” Adjust your webcam setup to obtain images similar to those presented in the video, and choose a video mode with reasonably high resolution. Remember to set the focus to manual.

- Collect images of at least five different coins and at least three additional images of the same coin denomination (to evaluate measurement repeatability). Also collect an image of a metric ruler as a calibration target. Record the video mode and camera settings that you adjusted. Screencap the Vision Assistant image browser that shows all of your images at once.

- Remember to save all of your images to disk.

Calibrate the camera

- Follow along with the video [Camera Calibration (Coin Caliper)](https://youtu.be/ZVsI3_BvdYQ, 3:01) to learn how to perform “Point Distance Calibration,” the simplest available calibration that ignores lens distortion and other nonideal effects. Calibrate the camera in the center of the image where the coins will be placed.

- Use the distance measurement tool to measure the length between two ruler marks in the center of the image and report the percent error. Repeat for two other lengths near the left and right edges of the image. Comment on the measurement accuracy in the image center compared to the edges.
Develop the processing script

- Follow along with the video Processing Script (Coin Caliper) (youtu.be/I0roHVhwcuA, 2:54) to learn how to create a processing script based on the “Max Clamp” virtual calipers to measure the diameter of a single coin presented to the region of interest (ROI) in the center of the image.

□ 5 For each coin image record and tabulate the measured coin diameter reported by “Max Clamp,” the actual coin diameter, and the percent error of the measurement.

Develop the base LabVIEW myRIO project

- Follow along with the video NI myRIO Project (Coin Caliper) (youtu.be/EL0nc2p25q0, 1:26) to learn how to create a new LabVIEW project for the NI myRIO target.

  **NOTE:** You can also use the desktop as your target if you do not have access to NI myRIO. Simply create a new LabVIEW VI or project as usual and then continue with the same development flow.

- Connect the webcam to the NI myRIO USB port.

- Follow along with the video Vision Acquisition Express VI (Coin Caliper) (youtu.be/6ygi7v21FpQ, 3:31) to learn how to configure the Vision Acquisition Express VI for continuous in-line processing using the same video mode and camera settings used previously to acquire the representative images. Enable the frame rate indicator output.

□ 6 Screencap the front panel diagram when for a single coin in the display. How well does the image match your previously acquired images? What frame rate is reported?

- Follow along with the video Vision Assistant Express VI (Coin Caliper) (youtu.be/6uxKf46o6fQ, 4:33) to learn how to configure the Vision Assistant Express VI with the processing script that you developed earlier, check the script performance with the “Performance Meter,” install the Express VI inside the while-loop structure, and attach controls and indicators. Run the VI and debug the code until the application works properly.
7. Screencap the front panel for several coins. Compare the measured diameters to the known diameters. Report the typical frame rate, too.

Follow along with the video [I/O Devices (Coin Caliper)](https://youtu.be/UXy1LH-uLXY, 3:01) to learn how to add the NI myRIO onboard LEDs to indicate whether the coin diameter is larger or smaller than a threshold value. This very simple example illustrates how to add I/O devices to the application.

**Validate the application**

8. Test your completed “Coin Caliper” application. How robust is the application? For example, how much variation do you see in the diameter measurement with the coin “just sitting there” in the display? How do changes in illumination affect the measurement?

**Deploy the VI as a stand-alone application**

Follow the video [Deploy a Stand-Alone Application](https://youtu.be/JXoJECRS-e0, 8:29) to learn how to deploy the “Coin Caliper” as a stand-alone application on NI myRIO. After completing this process the “Coin Caliper” will run automatically when you power-on the NI myRIO.

**Add an external information display**

9. Extend the dual-LED display technique described in the most-recent video to use all four LEDs as a bargraph indicator for the measured coin diameter. Review your coin collection and determine the minimum coin diameter $D_{\text{min}}$ and the maximum coin diameter $D_{\text{max}}$. Disable LEDs for a measured diameter less than $D_{\text{min}}$, enable all LEDs for a measured diameter greater than or equal to $D_{\text{max}}$, and illuminate a proportional number of LEDs for a measured diameter between $D_{\text{min}}$ and $D_{\text{max}}$. 
2 Camera Setup

2.1 Synopsis

Camera setup constitutes an important early step in the development of every machine vision application. Everything hinges on the minimum feature size and the number of pixels to allocate to this size; these two values define the required image spatial resolution which in turn can be adjusted by a suitable camera-to-object distance. Camera setup also involves calibration to allow the machine vision application to make physical measurements in real-world units instead of pixels. Calibration can also correct, or at least mitigate, various nonideal effects such as a misaligned image sensor and lens distortion.

In this project you will learn how to set up your camera to acquire calibrated images with a desired spatial resolution and field of view.

2.2 Objectives

1. Measure a camera’s pixel aspect ratio
2. Determine the camera-to-object distance to achieve a desired image spatial resolution
3. Calculate the field of view (FOV)
4. Calibrate a camera to use real-world units
5. Correct lens distortion and tangential distortion
2.3 Deliverables

1. Hardcopy of all LabVIEW block diagrams and front panels that you develop

2. Screen captures of NI Vision Assistant script and individual step dialog boxes

3. Lab report or notebook formatted according to instructor’s requirements

2.4 Required Resources

1. NI Vision Assistant

2. NI LabVIEW

3. NI myRIO

4. Ruler with millimeter and centimeter marks

2.5 Preparation

*Spatial resolution* describes the distance spanned by two adjacent pixels. The fixed spatial resolution of the camera’s image sensor maps onto the object plane with a variable image spatial resolution $R_S$ defined by the the camera lens and distance from the object plane. The available *field of view*, or FOV, is likewise determined by the camera distance. Establishing the correct spatial resolution constitutes an important consideration for every machine vision application. Begin with the minimum feature size $S_F$ (in physical units such as millimeters) that must be imaged with at least $N_F$ pixels. Divide $S_F$ by $N_F$ to obtain the required spatial resolution $R_S$.

▶ Study the video [Camera Setup](https://youtu.be/F0S0rdnyGo, 9:11) to learn how to use the minimum feature size $S_F$ and the required number of pixels $N_F$ to determine the spatial resolution $R_S$ and consequently the necessary camera distance and resulting FOV.
Laboratory Project 2. Camera Setup

Study the video [Acquire an Image in NI Vision Assistant](youtu.be/Utu2gtwIDr0, 3:29) to learn how to acquire a webcam image, select the image resolution, adjust the webcam attributes such as focus and contrast, and measure the distance between two features.

2.6 Pixel Aspect Ratio

Set up your camera to image a metric ruler with a field of view (FOV) of between 10 and 20 centimeters. Place the ruler in the horizontal direction. Use another window to serve as an alignment aid so that the ruler marks follow a single image pixel row.

- Measure the horizontal image spatial resolution $R_{SH}$.
- Orient the ruler in the vertical direction and then measure the vertical image spatial resolution $R_{SV}$.
- Calculate the ratio of the two spatial resolutions. How close (in terms of percentage) is this pixel aspect ratio to unity? In other words, to what degree does your camera’s image sensor appear to have square pixels?

2.7 Spatial Resolution, Camera Distance, and FOV

- Measure and tabulate the image spatial resolution for at least four camera-to-object distances. Use limiting values such as the closest you can get while still maintaining sharp focus and the furthest you can get at the limits of your camera stand as well as several in-between values. State the external reference mark that you used on the camera. Calculate the camera constant $K$ and the distance $d$ between the reference mark and the projection center. Confirm that the calculated value of $d$ is reasonable by estimating the position of the camera lens with respect to your reference mark.

- Plot the camera distance and the two FOV components as a function of spatial resolution for your camera. Include plot markers to show your measurement points. Save this plot as a convenient way to set up your camera system for other projects. State the image sensor array dimensions $N_H$ and $N_V$ for your camera.
Set up the camera to image the (horizontal) ruler so that 1 cm contains 80 pixels. Calculate the image spatial resolution $R_s$ in millimeters per pixel, the necessary camera-to-object distance $D$, and the horizontal field-of-view component $FOV_H$.

Measure the actual image spatial resolution and compare it to your target value with a percent error calculation. How well does the actual value match your intended value?

Adjust the ruler position so that the 0 cm mark appears at the left edge of the image; the right edge of the image now displays the horizontal FOV. Record this value, numerically compare to your target value, and comment on the degree of agreement.

2.8 Real-World Units

Up to this point you have manually translated measurements in pixel units to physical units based on your recorded spatial resolution. You can easily calibrate the camera so that measurements appear directly in any desired physical or real-world units. NI Vision Assistant provides a number of camera calibration tools of increasing sophistication to meet the needs of your particular machine vision application, and you will investigate two of them in this section.

Point distance calibration

The point distance calibration is the simplest technique and requires negligible computational effort. This calibration assumes that the image sensor plane is perfectly aligned with the object plane (zero tangential distortion) and that the lens is likewise perfectly free of distortion.

Study the video [Camera Calibration (Coin Caliper)](youtu.be/ZVsI3_BvdYQ, 3:01) to learn how to select two points on a ruler to calibrate the camera.

Use the same method described in the video to calibrate your camera based on the image of a horizontal ruler with the 0 mm mark visible at the left-hand side of the image. Estimate the maximum error between the calibrated ruler overlay and the ruler itself, and screencap the ruler image at this location.
Grid calibration

The grid calibration uses an array of uniformly-spaced dots to characterize the lens distortion over the entire field of view. Tangential distortion may optionally be characterized, as well. Grid calibration fits a 2-D polynomial to the measured dot locations and therefore reduces the errors associated with the simple point distance calibration. NI Vision Assistant provides convenient tools to evaluate the performance of the correction and to select an appropriate balance between performance and computational effort.

▶ Study the video [Grid Camera Calibration](https://youtu.be/BUezu7S0-dE, 6:42) to learn how to print a dot grid target and then calibrate the camera according to the dot grid.

▶ Print the dot grid on a laser printer. Measure the distances between the alignment marks to confirm that the dot grid has been printed accurately. Measure in both the horizontal and vertical directions.

▶ Smooth the paper to be as flat as possible on the camera copy stand base.

Follow along with the steps in the video to set up a grid calibration for your camera. Record the percent distortion and mean error for the five available distortion models.

**NOTE:** The camera calibration step must be repeated any time that you change the camera configuration. Also be aware that the calibration is only valid for objects that are in the same plane as the dot grid, i.e., calibrating on the dot grid and later refocusing on a much thicker object will yield incorrect results.

Try some measurements of your ruler. Include ruler positions at the center of the image and at the edges where the distortion corrections are more noticeable. How do these measurements compare to the mean error value reported by the grid calibration procedure?

▶ Intentionally introduce tangential distortion by tilting the camera relative to the object plane; expect to see perspective distortion as imaginary lines intersecting the dot grid now converge rather than remaining parallel.
□12  Re-calibrate your camera and select the option to correct tangential distortion. Screencap both the uncorrected and corrected images for comparison.

□13  Again, try some measurements of your ruler. Discuss the ability of grid calibration to deal with perspective distortion.
A  MXP and MSP Connector Diagrams
Figure A.1: MXP (myRIO eXpansion Port) connector diagram.
Figure A.2: MSP (miniSystem Port) connector diagram.
Build a Stand-Alone Application

During development you normally connect NI myRIO to your computer with a USB cable. After development is complete you can easily deploy your project as a stand-alone application stored on the myRIO solid-state hard drive that starts automatically when you power up the myRIO; no USB cable required. Study the tutorial [Deploy a Stand-Alone Application](youtu.be/JXoJECRS-e0, 8:29) to learn the step-by-step procedure to create a build for the real-time (RT) target, deploy the build as the startup application, and how to disable the startup application, if necessary.
C Video Tutorial Links