Vision-Guided Motion

Presented by Tom Gray
Overview

• Part I
  – Machine Vision Hardware
• Part II
  – Machine Vision Software
• Part II
  – Motion Control
• Part IV
  – Vision-Guided Motion – The Result
Harley Davidson Example
Vision-Guided Motion Overview

- Capture Image
- Locate Object
- Determine $XY\theta$
- Transform $XY\theta$
- Send Data
- Make Move
Overview

• Part I
  – Machine Vision Hardware

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Part I – Machine Vision

Hardware

• Components of a SmartSensor
• How a CCD works
• Image Acquisition:
  – Environmental Protection
  – Triggers
  – Lighting
  – Lenses
SmartSensor Components

- CCD or CMOS for image capture
- RAM for memory storage
- FLASH for non-volatile storage
- Circuit Board for Components
- Image Processor
- Communications/IO Ports
CCD Technology

- CCD - Charged Coupled Device
- An array of diodes that turn Photons into Electrons
- More photons produce more electric charge
CCD Manufacturing
CCD Structure

- Image area
- Metal or ceramic package
- Connection pins
- Gold bond wires
- Bond pads
- Serial register
- On-chip amplifier
CCD Conveyor Analogy
CCD Layers

- **Plan View**
  - Channel stops define columns
  - One pixel

- **Side View**
  - Transparent horizontal electrodes define rows.
  - They are used to transfer the charge during readout.
  - Electrode insulating oxide
  - N-type silicon
  - P-type silicon
CCD Charge Shifting
CCD vs. CMOS

- CMOS sensors connect standard transistors and wires to every pixel. Each pixel value is read independently.
- CMOS sensors have lower light sensitivity.
- CMOS sensors are slower and more susceptible to noise.
- CMOS sensor can be produced on standard silicon lines and are thus cost effective.
• Red, Green and Blue light combine to form every color in the spectrum.
CCD - Capturing Color

- The light is filtered before it hits the CCD
- The most expensive systems use 3 CCDs
- A rotating filter can allow only one CCD
- A Bayer filter improves speed and cost
Image Acquisition

- Environment
- Triggers
- Lighting
- Lenses
Acquisition - Environment

• Controllable
  – Temperature
  – Wash-Down

• Maintainable
  – Grease
  – Dust

• Difficult
  – Smoke
  – Flying Debris
Acquisition - Triggers

• Hardwired I/O
  – Almost every vision system requires a sensor to trigger the inspection

• Communications
  – Commands from Motion Controllers, PLCs and PCs can also trigger inspections
Acquisition - Lighting

• The goal of lighting is to increase the contrast of the features you want to inspect
• Successful lighting involves a combination of up front design and experimentation
• Fortunately light generally travels in straight lines.
Lighting - Direct
Lighting - Darkfield
Lighting - Backlit
Lighting - Diffuse
Lighting – Co-Axial DOL
Lighting – Polarized/Filtered
Acquisition - Lenses

• Lenses selection is primarily driven by:
  – Field of View/Resolution
  – Object Distance
  – Depth of Focus

• Lens sizing charts help with field of view and object distance

• Telecentric, Aspherical or Zoom lenses add extra capability
Calculating Resolution

\[ \frac{2 \text{ in}}{640} = 0.0031 \]
<table>
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<th>Lens</th>
<th>LNS-02FNO</th>
<th>LNS-04FNO</th>
<th>LNS-08FNO</th>
<th>LTC-16F</th>
<th>LTC-25F</th>
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<td>1.3 (2mm)</td>
<td>0.8 (5mm)</td>
<td>0.1 (55mm)</td>
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<td>12.0</td>
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<td>3.0 (10mm)</td>
<td>1.9</td>
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<td>0.8 (5mm)</td>
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<td>7.7</td>
<td>3.6</td>
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<td>1.0 (6mm)</td>
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<td>32.0</td>
<td>14.9</td>
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Part II – Machine Vision Software

- Binary Thresholding
- Sub-pixel Values Intensity, Gradient, Centroid

Image Processing Tools:
  - Intensity
  - Edge Finding
  - Precision Measurement
  - Blob Analysis
  - Object Location
  - Color Matching.
Binary Thresholding
Sub-Pixel Values - Intensity

- Linear Interpolates to find an edge at an intensity level
- Adjusting the lighting can effect the edge value
Sub-Pixel Values - Gradients

- Fit parabola to gradient values
- More resistant to small lighting changes

\[ x = p + \frac{g_p - g_{p-1}}{2g_p - g_{p-1} - g_{p+1}} \]

\[ X = \text{Edge Location} \]
\[ p = \text{Pixel Position} \]
\[ g_p = \text{Gradient between } p \text{ and } p+1 \]
Sub-Pixel Values - Centroid

• The center of an object can also be located to sub-pixel precision with a simple centroid calculation.

• 1/10 to 1/100 of a pixel can be achieved

\[
\begin{align*}
\bar{x} &= \frac{1}{N_{\text{pixels}}} \sum_{\text{pixels}} x_{\text{pixel}} \\
\bar{y} &= \frac{1}{N_{\text{pixels}}} \sum_{\text{pixels}} y_{\text{pixel}}
\end{align*}
\]
Intensity

- **Algorithm**
  - Binary Threshold of pixels
  - Count the percent of light pixels
  - Compare with an acceptable value

- **Applications**
  - Determine if the lens cap is on
  - Determine that a coating has been applied
Edge Finding/Counting

- **Algorithm**
  - Determine Pixel Values along a line
  - Count an edge each time the values cross the threshold
- **Application**
  - Connector Quality
  - Short-Shot Detection
Precision Measurement

- **Algorithm**
  - Perform Edge Detection at multiple locations
  - Exclude outliers and average the values
- **Application**
  - Rivet hole location
  - Knife blade quality
Blob Analysis

- **Algorithm**
  - Binary Threshold
  - Image Preprocessing
  - Group touching pixels
  - Filter and sort results

- **Application**
  - Candy Bar Sorting
  - Plywood Knot Check
Object Location

• **Algorithm**
  – Find Edge Points
  – Create Edge Segments
  – Compare with learned Segments

• **Application**
  – Pick and place robot
  – Label location
Color Matching

• Algorithm
  – Teach multiple colors in RGB space
  – Detect an average color in an area
  – Compare with trained list

• Application
  – Print Registry
  – Gatorade Color Check
Machine Vision Software Demo
Overview

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Part III – Motion Control

• Architectures: Standalone, PC-based, Integrated

• Information Flow: Motion Controller, Drive/Amplifier, Motor, Mechanics.

• Feedback Loops: Torque, Velocity, Position, Application Level
Architecture - PC-Based

- Encoder
- Carbide Tips
- Grinding Wheel
- 15:1 gearbox
- Drive
- 1st Machine
- 2nd Machine
- 3rd Machine
- Multiple cards in each computer
- CPU
- Multiple cards in each computer
- Multiple cards in each computer

- 1st Machine
- 2nd Machine
- 3rd Machine

- Encoder
- carbide tips
- grinding wheel
- 15:1 gearbox
- Drive
- 1st Machine
- 2nd Machine
- 3rd Machine
- CPU
- multiple cards in each computer
Architecture - PLC Based

Row of 10 Batteries
Photo Sensor
Conveyor
Chain Drive
Armature
PLC
PMC/Drive
Architecture - Integrated

- Belt & Pulley
- Measuring Wheel
- Cutting Wheel
- Encoder
- Servo Motor/Drive/Controller
Info Flow - Motion Controller

- **Input**
  - Stored Program Commands
  - Serial/Ethernet Commands

- **Output**
  - +/- 10 V signal (servo)
  - 5V TTL pulses (stepper)
Info Flow - Drive/Amplifier

• **Input**
  – +/- 10 V signal
  – 5V TTL pulses

• **Output**
  – Commutated Current to motor windings
Info Flow - Motor

• Input
  – Commutated current to motor windings

• Output
  – Rotary or linear motion
Info Flow - Mechanics

• Input
  – Rotary or Linear Motion from motor

• Output
  – Rotary or Linear Motion with mechanical advantage.
Info Flow - Feedback Device

- **Input**
  - Encoder Pulses
  - Resolver Position

- **Output**
  - Quadrature signal
  - Analog Position Signal
Feedback - Torque Loop

Command signal -> $K_{Amp}$ -> Amp

[Diagram of a feedback loop with a command signal, an amplifier, and a mechanical output]
Feedback - Velocity Loop

Diagram showing the velocity loop with the following components:
- $K_{FF}$
- $K_p$
- $K_{Amp}$
- $K_{Tach}$

The diagram includes connections marked with arrows indicating the flow of the velocity command.
Feedback - Position Loop
Feedback - Application Logic

Application Logic

External Inputs

K_Tach

K_P

K_PI

K_PP

K_PD

K_PP

K_PI

K_PD

K_Tach

T_Amp

E

E
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Part IV – Vision-Guided Motion

- Communications: Ethernet, Serial, Hardwired I/O
- Coordinate Transformations/Mapping
- Vision-Guided Motion Review
- Candy bar demonstration
Communications

- The Vision Sensor must be able to send coordinates to the motion controller
- The Motion controller must be able to accept commands
- This means drivers

Ethernet

Serial I/O
Coordinate Transforms

- The vision pixel coordinates must be converted to real world coordinates
- Done by:
  - Vision Sensor
  - Additional PC
  - Motion Controller
Vision-Guided Motion Review

1. Capture Image
2. Locate Object
3. Determine \(XY\Theta\)
4. Transform \(XY\Theta\)
5. Send Data
6. Make Move
Demonstration
Thank You

http://www.howstuffworks.com
Parker Compumotor
Michael Schreiber – DVT
Brent Carlson – NRCC
Simon Tulluch - INGT