Barcodes and Symbology Basics for Machine Vision

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Introduction, Topics, and Goals

• Who I am
  • Introduce myself

• Who are you?
  • Show of hands in audience – MV people, Integrators, Bar Code users

• Topics we will cover
  • Definition, Reading, Marking/Coding, System Design, and Quality Control

• What we will achieve
  • Awareness of issues and constraints for bar code marking, reading and system design
  • Understand that code reading is a machine vision topic.
What are Barcodes?

- *Optical, machine readable, representation of data.*
- It all started with rail cars – then moved on to chewing gum and *everything* else.
- Typically contain a number
  - Index to a look-up
  - Identification number
- Can contain text
- There are many types…
- Called symbologies
Types of Barcodes – Typology of Symbologies

1D Bar Codes

- UPCA
- EAN-128
- Code 93
- Code 39
- Code 128
- Codabar

“2D Bar Codes”

- GS1 DataBar
- Code 16
- Code 49
- MaxiCode
- PDF 417
- Data Matrix

Stacked 1D codes and true 2D codes

Best code for Direct Part Marking
Who Uses Barcodes?

- U.S. Government
- Healthcare and Pharmaceutical
- Hardware and Office Products
- Distribution & Transportation
- General Merchandise and Apparel
- Industrial/Commercial
- Publishing
- Grocery & Foodservice
Why Barcodes Are Important

• **Provide an efficient method of product or item identification**

• Revolutionized retail since 1974
  • Checkout, stock management, asset tracking

• Essential for logistics
  • Package tracking, baggage handling….

• Allow item level track and trace and identification
  • ID documents, medical samples, industrial WIP tracking, life cycle management

• Powerful marketing tool
  • All those QR codes

• Support showrooming
  • You have all done this

• **Reliable Coding and Reading Systems are Mission Critical to Most Enterprises**
How Typical Barcodes Work

• Variable shapes that encode information
• Typical codes have
  • Bars
  • Spaces
  • Quiet Zones
  • A few symbologies encode with height

• Varying widths of bars and spaces encode information
  • Example: UPC Code bars and spaces can be 1 to 4 units wide
  • UPC Code encodes each character in 7 units of bars and spaces
Encoding Examples

Examples of encoding data

GS1-Code 128

ITF
1D Code Reading

• Scan with a laser and measure reflected signal
• Or image with a imaging sensor

• Create a scan reflectance profile

• Detect threshold crossings
• Create a space/bar List
• Pass to a decoder
• Essentially an analog process
2D Code Construction - Data Matrix

- 4 Physical Components
  - Solid border
  - Broken border/clock pattern
  - Data storage
  - Quiet zone

- Consists of evenly spaced “cells” (squares or dots)
- Each “cell” represents either a “0” or a “1”
- Binary – therefore “Digital” in the common tongue.
Data Matrix has Error Correction

- Built in error correction allows the code to be read with ~20% damage making it the ideal symbology for DPM applications.

- Reed-Solomon algorithm for error correction

- Origins in NASA Deep Space Network

- Voyager 1 still phoning home from > $2.1 \times 10^{10}$ km (138 AU) – at 160 bps
## Pros and Cons of Different Codes

### Making Good Choices

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1D Codes</strong></td>
<td><strong>Limited content</strong></td>
</tr>
<tr>
<td>• Simple readers (low cost)</td>
<td>• Unidirectional</td>
</tr>
<tr>
<td>• Large infrastructure in commerce</td>
<td>• Readers can not read 2D codes</td>
</tr>
<tr>
<td>• Well understood marking methods</td>
<td>• Requires high contrast marking</td>
</tr>
<tr>
<td>• High read rates</td>
<td>• Not suitable for Direct Part Marking</td>
</tr>
<tr>
<td></td>
<td>• Analog reading can produce error</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2D Codes</strong></td>
<td><strong>Requires imaging reader</strong></td>
</tr>
<tr>
<td>• <strong>Compact codes</strong></td>
<td><strong>Require task specific lighting</strong></td>
</tr>
<tr>
<td>• <strong>High potential code content</strong></td>
<td><strong>Requires slightly higher resolution printing and imaging</strong></td>
</tr>
<tr>
<td>• <strong>Includes error correction</strong></td>
<td><strong>Marking/printing requires more care</strong></td>
</tr>
<tr>
<td>• <strong>Omni directional reading</strong></td>
<td></td>
</tr>
<tr>
<td>• Imaging readers can decode 1D codes</td>
<td></td>
</tr>
<tr>
<td>• High end readers can do OCR etc.</td>
<td></td>
</tr>
<tr>
<td>• Read at low contrast</td>
<td></td>
</tr>
<tr>
<td>• Potential for Direct Part Marking</td>
<td></td>
</tr>
</tbody>
</table>
Key Code Properties

Narrow Element Width
The nominal width of the narrowest bars in the code
Other terms commonly used for narrow bar width:
- X-dimension
- Mil size
- Module width

Cell Size
The nominal width of the individual black or white cell
Other terms commonly used for cell size:
- Mil size
- Module size
- Z-Dimension

Essential for code specification – overall size by itself does not mean much

Specified in “Mil. = 0.001” (primarily in the US) or millimeters
Typical Laser Code Readers

- Hand held
- Embedded
- Tunnel Scanners
Laser Reader Basics

• How it works
  • Drags a laser dot across the code
  • Digitizes reflectance signal
  • Creates a scan reflectance profile
  • Passes to decoder
Laser Bar Code Reading - Critical Parameters

- Depth of Field vs X size vs Scan Width
- Speed (read per second)
- Connectivity

**Depth of Field**

**Scan Width**

**Focal Point**

**MEDIUM DENSITY RANGE DATA**

<table>
<thead>
<tr>
<th>Size</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>.0075&quot;</td>
<td>2.5 to 5.5&quot; (64 to 140 mm)</td>
</tr>
<tr>
<td>.010&quot;</td>
<td>1.5 to 7.0&quot; (38 to 178 mm)</td>
</tr>
<tr>
<td>.015&quot;</td>
<td>1.5 to 8.5&quot; (38 to 216 mm)</td>
</tr>
<tr>
<td>.020&quot;</td>
<td>1.5 to 11&quot; (38 to 280 mm)</td>
</tr>
<tr>
<td>.030&quot;</td>
<td>1.0 to 12&quot; (25 to 304 mm)</td>
</tr>
</tbody>
</table>

**Spot size**

- 100%
- 60%
- 20%

**Focal Point**
Typical Imaging Reader

- Embedded
- Handheld
- Mini’s
- Smart Cameras
- Discrete Cameras

Image stretching optics for 1D codes
Imager Code Reading - Critical Parameters

- Resolution and FOV Calculations
- Inputs
  - Required Pixels/Element (Module Size)
  - Overall Code Size
  - Camera Resolution
- Suggested Minimums
  - 2D codes - 4 pixels per element
  - 1D codes – 2 pixels per element
- Sample calculation 2D code
  - Element size = 0.020”, Code Size = 0.40” (20 by 20 code)
  - Therefore maximum pixel size = 0.005” (0.020/4)
  - Code size in pixels is 80 by 80
  - Now you can work out how well the part needs to be fixtured at a given resolution
Decoding Multiple Codes With An Imager

- 1D / 2D
- Black on White
- White on Black
- Mirrored
- Low Contrast
- GS1 Check
- DPM
- Multi-code
Marking Methods

- **Label Printing**
  - Flexographic (Offset Printing)
  - Ink Jet (Thermal or Drop on Demand)*
  - Thermal Transfer (Print and Apply)*
  - Laser*

- **Direct Part Marking**
  - Laser*
  - Ink Jet*
  - Dot Peen*

**Good Practice**

- *Methods than can produce serialized labels
- Do not print red bar codes!
- Match the DPI to the desired X dimension
- Allow for ink bleed
- Use ladder orientation on curved surfaces
- Use rectangular Data Matrix codes when required
How To Encode Data So It Makes Sense

• It you know the code is a UPC then OK

• But what if you read a label and see this?

• In this case it is GS1 syntax. The embedded “tags” identify the data fields. Use them to extract meaningful data
  • (01) = Product ID
  • (17) = Expiration Date
  • (10) = Lot Number
GS1 Symbol and Format Definition

- GS1 = Global Standard 1. Formerly UPC and EAN
- GS1 symbols contain data fields with defined applications identifiers (AI) that identify the purpose of the data field and define the content format.
- Commonly used AIs:

<table>
<thead>
<tr>
<th>AI</th>
<th>Data Definition</th>
<th>Format (AI/data)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>GTIN</td>
<td>n2+n14</td>
</tr>
<tr>
<td>10</td>
<td>Batch or Lot Number</td>
<td>n2+an_20</td>
</tr>
<tr>
<td>11</td>
<td>Production Date (YYMMD)</td>
<td>n2+n6</td>
</tr>
<tr>
<td>15</td>
<td>Best Before Date (YYMMD)</td>
<td>n2+n6</td>
</tr>
<tr>
<td>17</td>
<td>Expiration Date (YYMMD)</td>
<td>n2+n6</td>
</tr>
<tr>
<td>21</td>
<td>Serial Number</td>
<td>n2+an_20</td>
</tr>
</tbody>
</table>

- Numeric digit
- Alphanumeric characters
- Fixed length of two numeric digits
- Variable length with a maximum of 20 alphanumeric characters

http://www.gs1.org/barcodes-epcrfid-id-keys/gs1-general-specifications

441 Pages of good information.........
The Quality Question – What Is The Answer?

Pain and Problems

Loss of Identity or Traceability

Process Downtime

Unreadable Codes…

Unreadable Codes…

Incorrect Text Format or Content

Incorrect Text Format or Content

Upset or Confused Customers

Vendor Compliance Penalties

Regulatory Issues

Incorrect Text Format or Content

Regulatory Issues

Incorrect Text Format or Content

Regulatory Issues
Verification Of 1D And 2D Codes

- Verification (also called Grading) is a Measurement
  its purpose is to:

  - Predict Readability – Trading partners, etc.
    - and/or
  - Monitor Marking System – Simple SPC
    - and/or
  - Confirm Conformance – Government, or Customer Specifications etc.

**Confirming that a code reads at point of marking is not verification.**

**Verification is the process of Grading your symbol to a defined specification.**
Q - Why Verify 1D And 2D Codes?

A - Because *all* marking/printing systems degrade over time and the code never gets better

Without verification, some “bad” parts escape into the process

With verification, we *prevent* bad codes from ever being made

**Trust but Verify!**

Just checking that the code can be read is not good enough. It must be read with an adequate margin
Without Standards There Is Chaos

<table>
<thead>
<tr>
<th>ISO 15416 1D codes</th>
<th>ISO 15415 Printed 2D codes</th>
<th>AIM DPM -1-2006/ISO 29158 Direct Part Marks</th>
</tr>
</thead>
</table>

Standards specify =

- Lighting wavelength and geometry
- Camera geometry
- Reflectance calibration
- Image processing
- Scan profile (1D) or grid (2D) determination
- Profile or grid analysis steps
- Overall grade determination
- Reporting scale and report content
GS1 Resources

GS1 General Specification

• 441 pages of compelling reading
• Essentially incorporated by reference in GS1 rules
• Basis of many Application Standards
• A lot of good information all in one place
• Marking methods, symbol size, symbol location, quality standards etc.
1D Verification - Imaging and Scanning

• Image generation
  • Image at 90 to the code
  • Light at 45 degrees
  • Prefer red (monochrome) light
  • At least 8 pixels per thin line
• Scan profile generation
  • Create reflectance (brightness) profiles with a synthetic aperture of (for instance) 50% of line width
• Scan repeats and pattern
  • 10 scans evenly spaced

Result is 10 scan profiles

![Figure 1 — Reference optical arrangement](image-url)
1D Code Grading Process

- Calculate number grades for 9 different measurements on each reflectance profile (9 numbers on 10 scans)
  - Reference Decode
  - Contrast
  - Minimum Reflectance
  - Minimum Edge Contrast
  - Modulation
  - Decodability
  - ........

- Score each scan with the worst score (10 numbers)
- Average the worst score numbers (1 number)
- This is the symbol grade (4 – good, 0 = really bad/fail)
- Standard uses number grades
- Translate to letter grades

<table>
<thead>
<tr>
<th>Numeric range</th>
<th>Alphabetic grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5 to 4.0</td>
<td>A</td>
</tr>
<tr>
<td>2.5 to 3.5</td>
<td>B</td>
</tr>
<tr>
<td>1.5 to 2.5</td>
<td>C</td>
</tr>
<tr>
<td>0.5 to 1.5</td>
<td>D</td>
</tr>
<tr>
<td>below 0.5</td>
<td>F</td>
</tr>
</tbody>
</table>
# 1D Code Defects

## 1D Verification Evaluation Parameters:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Example</th>
<th>Minimum Reflectance</th>
<th>Modulation</th>
<th>Symbol Contrast</th>
<th>Quiet Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decodability</td>
<td>Legibility per a reference decode algorithm</td>
<td><img src="image1.png" alt="Example" /></td>
<td>Reflectance of the darkest bar and the lightest space</td>
<td><img src="image2.png" alt="Example" /></td>
<td><img src="image3.png" alt="Example" /></td>
<td><img src="image4.png" alt="Example" /></td>
</tr>
<tr>
<td>Defects</td>
<td>Voids in bars or spots in spaces</td>
<td><img src="image5.png" alt="Example" /></td>
<td><img src="image6.png" alt="Example" /></td>
<td><img src="image7.png" alt="Example" /></td>
<td><img src="image8.png" alt="Example" /></td>
<td><img src="image9.png" alt="Example" /></td>
</tr>
<tr>
<td>Edge Determination</td>
<td>Detection of all bars and spaces using a global threshold</td>
<td><img src="image10.png" alt="Example" /></td>
<td><img src="image11.png" alt="Example" /></td>
<td><img src="image12.png" alt="Example" /></td>
<td><img src="image13.png" alt="Example" /></td>
<td><img src="image14.png" alt="Example" /></td>
</tr>
<tr>
<td>Minimum Edge Contrast</td>
<td>Minimum reflectance difference for any bar/space combination</td>
<td><img src="image15.png" alt="Example" /></td>
<td><img src="image16.png" alt="Example" /></td>
<td><img src="image17.png" alt="Example" /></td>
<td><img src="image18.png" alt="Example" /></td>
<td><img src="image19.png" alt="Example" /></td>
</tr>
</tbody>
</table>
2D Mark Quality Problems

- Improper or inconsistent mark dot/cell size
- Improper or inconsistent mark dot/cell location
- Improper overall mark geometry
- Mark or part surface damage
- Very low or inconsistent mark contrast
- Quiet Zone Violation
Off Line Verification Systems for 1D codes

- Off Line Systems

Desktop Verification System
Portable Verification System
Handheld Verification System

Provide Grade and Diagnostic Information
In-Line Verification Systems
Verification Systems for 2D codes

• Off Line Systems
  - Desktop Verification System
  - Portable Verification System
  - Handheld Verification System

• On Line Systems
Print Quality Verification

- Defects in the print quality of the symbol

Scan Reflectance profile for Linear symbols

2D Analysis for 2D symbols
Verification ≠ Validation

- **Verification** = Measuring the quality of the code to predict readability
- **Validation** = Checking the format and content of a code

- Verification = how neat and legible was the writing

- Validation = check on grammar and/or content
Checks the data structure based on the specified Application Standard. The example below is the GS1 data syntax. Error flagged on right: SSCC is required to contain 18 characters.

Data is structured Correctly

Data is not structured properly to the selected GS1 Application standards.
New Things (the TLAs)

• What is a TLA? –
• CIA, NSA, NRO, DHS…? 

• Market Wide Initiatives
  
  • GS1 – Global Standard 1
  • UDI - Unique Device Identifier (Medical Devices)
  • UID - Unique ID (Military Equipment)
  • SNI - Standard Numerical Identifiers (Drugs)
  • PTI - Produce Traceability Initiative (Farm Produce)
  • …….
Summary And Take Aways

• Code reading is mission critical to many enterprises
• Code reading is a machine vision application
• You have to think about lighting, imaging, resolution and signal
• Code quality is a key factor in successful system design
• Check quality at the point of marking
• Reading is not verifying
That’s All Folks

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