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# Adaptive Barcode Imaging System with Speed-Synchronized Exposure Bracketing

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## Abstract

This disclosure describes a system for reliable barcode decoding across articles with varied optical properties, such as matte labels and film-wrapped items, moving at production line speeds. The system employs an imaging device capable of capturing multiple images with different exposure settings for each article. Article speed information is used to dynamically select an optimal exposure bracket from a preconfigured set. A processing unit then performs decode arbitration across the captured images to obtain a successful read. Mechanisms for handling no-reads and preventing double counting of articles are also detailed, enhancing overall read rate performance for diverse packaging types.

## 1. Technical Field

[0001] The present disclosure relates to machine vision systems, specifically to methods and apparatus for improving the read rate of optical codes, such as barcodes, on articles moving along a transport path. More particularly, it concerns systems that adapt image acquisition parameters based on article characteristics and transport dynamics to accommodate varying optical properties of code carriers.

## 2. Technical Context

[0002] In automated material handling and production environments, articles often bear optical codes for identification and tracking. These articles can present a wide variety of surface finishes and packaging materials, such as matte paper labels, glossy printed surfaces, or items wrapped in transparent or semi-transparent films. Each of these surface types interacts with illumination differently, leading to varying levels of specular reflection, diffuse reflection, or light absorption. A single, fixed exposure setting on an imaging device may be optimal for one type of surface but suboptimal for others. For instance, an exposure setting ideal for a matte label might overexpose a film-wrapped article due to glint, while an exposure setting suitable for a film-wrapped article might underexpose a matte label, leading to poor contrast. This issue is compounded when articles are transported at high speeds, reducing the available integration time for image capture. The challenge is to reliably decode optical codes from this diverse range of articles without reducing throughput.

## 3. System Overview

[0003] The disclosed system enhances barcode read rates by adaptively selecting and applying exposure bracketing based on article transport speed. As shown in FIG. 1, articles are transported by a conveyor system (10). An article speed sensor (12) measures the instantaneous speed of each article. An illumination system (14) provides controlled lighting, and an imaging device (16) captures images of the articles as they pass through a read zone. A processing unit (18) receives speed data from the article speed sensor (12) and image data from the imaging device (16). The processing unit (18) determines appropriate exposure settings, controls the illumination system (14) and the imaging device (16) to acquire a bracketed set of images, processes these images to decode the barcode, and outputs the decoded data via a data interface (20). The system manages image acquisition and processing to ensure that each article is processed once, preventing double counting even when multiple images are captured.

## 4. Components

[0004] The system comprises several key components:

[0005]

- **Conveyor System (10)**: This system transports articles past the read zone. It typically includes a conveyor belt, rollers, and a motor drive. The conveyor speed can be constant or variable, dictating the article speed.
- **Article Speed Sensor (12)**: This sensor determines the linear speed of an article as it approaches or enters the read zone. It can be an optical sensor, such as a laser doppler velocimeter, a time-of-flight sensor, or a rotary encoder coupled to a drive roller of the conveyor. It provides speed data to the processing unit (18). The sensor may also provide article presence detection.
- **Illumination System (14)**: This provides light to illuminate the optical code on the article. It may consist of one or more LED arrays, laser line projectors, or diffuse light sources. The illumination system (14) is configurable to adjust intensity, pulse duration, and spectral characteristics under the control of the processing unit (18).
- **Imaging Device (16)**: This device captures images of the optical code. It typically comprises a camera with a lens, an image sensor (e.g., CMOS or CCD), and associated electronics. The imaging device (16) is capable of rapid image acquisition and can be configured to capture multiple frames with different exposure settings in quick succession. It communicates image data to the processing unit (18).
- **Processing Unit (18)**: This central control and data processing element is typically a dedicated embedded computer or an industrial PC. It executes algorithms for exposure selection, image acquisition control, image processing (including decoding), and data arbitration. It interfaces with the article speed sensor (12), illumination system (14), imaging device (16), and data interface (20). It stores configuration profiles, including exposure bracket sets and speed thresholds.
- **Data Interface (20)**: This component provides connectivity to external systems, such as a supervisory control system or a database. It can be an Ethernet port, serial port, or fieldbus interface, transmitting decoded data, no-read notifications, and system status.
- **Trigger Sensor (24)**: Often integrated with or distinct from the article speed sensor (12), this sensor detects the presence of an article entering the read zone and triggers the image acquisition sequence.

## 5. Operation

[0006] The system operates through a sequence of steps from article entry to data output.

[0007] Upon **start-up**, the processing unit (18) loads configuration parameters, including predefined exposure bracket sets and speed thresholds. The illumination system (14) is initialized to a standby state, and the imaging device (16) is prepared for image capture.

[0008] During **steady running**, an article transported by the conveyor system (10) first enters the detection zone of the article speed sensor (12) and trigger sensor (24), as depicted in FIG. 2.

[0009]

- **Speed Acquisition**: The article speed sensor (12) continuously or periodically measures the article's speed. This speed data is transmitted to the processing unit (18).
- **Bracket Selection**: Based on the measured article speed, the processing unit (18) selects an appropriate exposure bracket set. For instance, if the article speed exceeds a predefined threshold (e.g., 2 meters per second), a bracket set with shorter maximum exposures might be selected to minimize motion blur. Conversely, for slower speeds, a bracket set allowing for longer exposures can be chosen to ensure adequate illumination for difficult codes. A typical bracket set might include three exposure times: a short exposure (e.g., 0.5 ms) for reflective surfaces, a medium exposure (e.g., 2.0 ms) for general purpose, and a long exposure (e.g., 5.0 ms) for matte or low-contrast codes.
- **Image Acquisition**: When the trigger sensor (24) indicates an article is within the imaging device's (16) field of view, the processing unit (18) commands the imaging device (16) to capture a rapid sequence of images, each with a different exposure time from the selected bracket. This sequence is typically executed in quick succession, within a total time window designed to capture the article while it is fully within the field of view, for example, within 5 to 10 milliseconds. The illumination system (14) is synchronized with the imaging device (16) to provide appropriate light pulses for each exposure.
- **Image Processing and Decode Arbitration**: The captured images are transferred to the processing unit (18). Each image in the bracketed set is independently processed by a barcode decoding algorithm. If multiple images yield a successful decode, the processing unit (18) arbitrates among them. Arbitration rules might prioritize the decode with the highest decode quality metric (e.g., symbol contrast, unread error correction level, margin) or simply accept the first successful decode.
- **No-Read Handling and Article Tracking**: If no image in the bracketed set yields a successful decode, the processing unit (18) registers a "no-read" event for that article. To prevent double counting, a mechanism ensures that each physical article is associated with only one decode attempt cycle. This can be achieved by assigning a unique article ID (e.g., based on sequential trigger events) and maintaining a state for each ID (e.g., "pending decode", "decoded", "no-read"). Once an article has passed through the read zone and its decode status is finalized, it is marked as processed. Subsequent triggers or images from the same physical article, if any, are ignored for decode purposes, or are used only to potentially re-attempt a decode if the initial attempt failed, but within strict time windows to avoid processing the next article. This ensures that a single article moving through the read zone generates a single output event (either a successful decode or a no-read notification).

[0010] On **fault or interruption**, such as a conveyor stop or a sensor malfunction, the processing unit (18) detects the anomaly. It may pause image acquisition, log the fault, and signal an error state through the data interface (20). Upon resumption of normal operation, the system can clear its article tracking state or re-initialize to prevent misidentification or missed articles.

## 6. Example Embodiments

[0011] **Embodiment 1** In this embodiment, the article speed sensor (12) is an optical encoder attached to a conveyor drive roller. The processing unit (18) maintains a lookup table that maps measured encoder frequencies (corresponding to article speeds) to specific exposure bracket profiles. For instance, speeds below 1.5 m/s use a bracket of [1ms, 3ms, 5ms], while speeds between 1.5 m/s and 4.0 m/s use [0.5ms, 1.5ms, 3ms]. When an article triggers the imaging sequence, the system captures three images at these specified exposures. The images are then processed in parallel, and the first valid decode with a quality score above a threshold of 70% is selected. If no image decodes, a "no-read" flag is set for that article ID.

[0012] **Embodiment 2** This embodiment utilizes a laser doppler velocimeter as the article speed sensor (12), providing a direct measurement of the article's surface velocity. The processing unit (18) employs a continuous function to dynamically adjust the exposure bracket. For example, the longest exposure time in the bracket might be inversely proportional to the measured speed, clamped between a minimum and maximum duration. The bracket could consist of two exposures: one fixed short exposure (e.g., 0.2 ms) for highly reflective surfaces, and a second exposure dynamically calculated as `Max(0.5ms, Min(5ms, K / speed))` where `K` is a constant. Decode arbitration prioritizes the image with the highest overall contrast as determined by image analysis metrics prior to full decode attempts.

[0013] **Embodiment 3** In this embodiment, article speed is inferred from a series of trigger events from two closely spaced proximity sensors (24) positioned upstream of the imaging zone. The time difference between activations of these sensors, combined with their known separation, yields the article speed. The system pre-selects one of five distinct exposure bracket sets based on five speed ranges. For example, very low speeds (<0.5 m/s) might enable a bracket with longer total integration time, potentially involving more than three exposures (e.g., five exposures from 1ms to 10ms). Decode arbitration in this configuration uses a voting system: if two out of three images decode the same data, that data is accepted. If all three decode different data or only one decodes, the system reports a "no-read".

## 7. Alternative Configurations

[0014] The article speed sensor (12) can be replaced by a direct integration with the conveyor drive controller, where the conveyor speed setting is communicated directly to the processing unit (18). The illumination system (14) could incorporate polarized light filters to mitigate glare from highly reflective surfaces, or employ structured light to enhance contrast on specific code types. The imaging device (16) might be a line scan camera, capturing image strips as the article moves, where multiple exposure settings are applied to different lines or frames within the line scan sequence. The processing unit (18) could be integrated directly into the imaging device (16) itself, forming a smart camera with on-board processing capabilities. Instead of fixed exposure times in a bracket, the system could employ automatic exposure control (AEC) algorithms that rapidly adjust exposure based on image histograms, then select the best image from a short burst of AEC-adjusted frames.

## 8. Parameter Variations

| Parameter | Range | Effect of Increasing Value | Effect of Decreasing Value |
|---|---|---|---|
| **Number of exposures in bracket** | 2 to 5 | Increased likelihood of finding an optimal exposure; higher processing load; longer total acquisition time. | Reduced processing load; faster acquisition; higher risk of missing optimal exposure. |
| **Exposure time range** | 0.1 ms to 10 ms | Better chance for dark/matte codes; increased motion blur at speed; potential for overexposure. | Reduced motion blur; better for bright/reflective codes; risk of underexposure for dark codes. |
| **Speed threshold for bracket change** | 0.5 m/s to 5 m/s | Fewer bracket changes; less adaptive to speed variations. | More frequent bracket changes; more adaptive; higher processing overhead for profile switching. |
| **Decode quality threshold** | 50% to 95% | Fewer false reads; more no-reads; higher confidence. | More successful reads; higher risk of false reads; lower confidence. |
| **Time window for article processing** | 100 ms to 1000 ms | Allows more time for re-attempts or complex arbitration; risk of overlapping with next article. | Faster throughput; less time for re-attempts; reduced risk of article overlap. |

## 9. Additional Implementations

[0016] The disclosed system can be extended to include article classification based on initial image analysis. For example, if a preliminary image analysis suggests the article has a highly reflective surface, the system could preemptively select a bracket weighted towards shorter exposures, or activate specific illumination patterns (e.g., oblique incidence) to further mitigate glare. The exposure bracketing mechanism can also be applied to color imaging, where different exposure settings are optimized for different color channels to enhance contrast for color-coded information in addition to barcodes. Furthermore, the system could integrate optical character recognition (OCR) alongside barcode reading, applying similar bracketing principles to optimize character recognition performance on varying background textures and lighting conditions. For high-speed applications with complex articles, predictive algorithms could be used to anticipate article type and speed based on upstream sensor data, allowing for pre-loading of optimal exposure bracket settings before the article even enters the imaging zone.

## 10. Figures

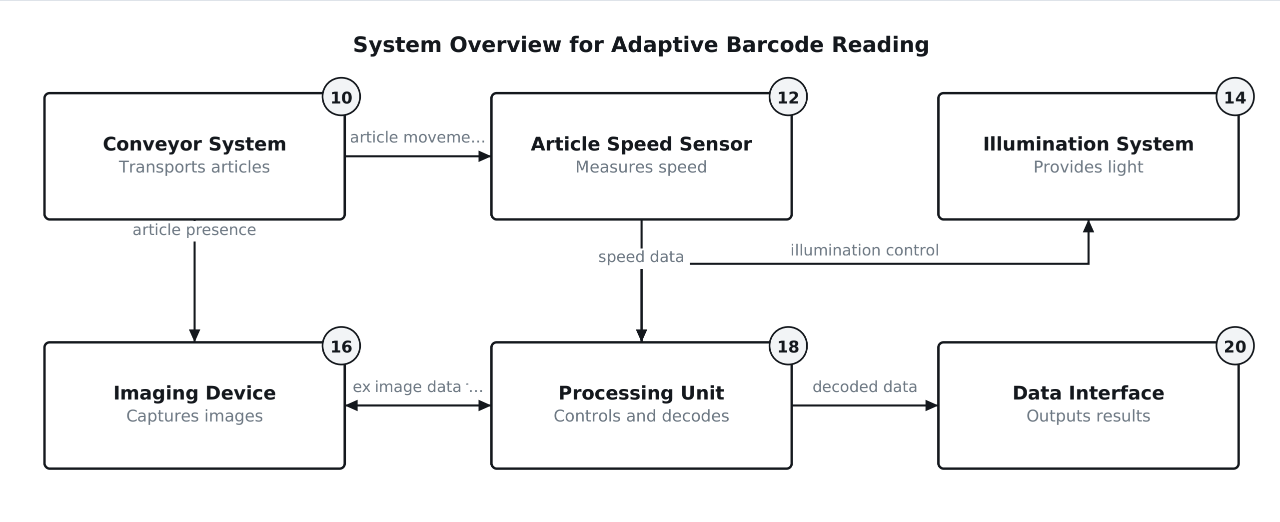


**FIG. 1** A block diagram illustrating the primary components and data flow within the adaptive barcode reading system. PNG

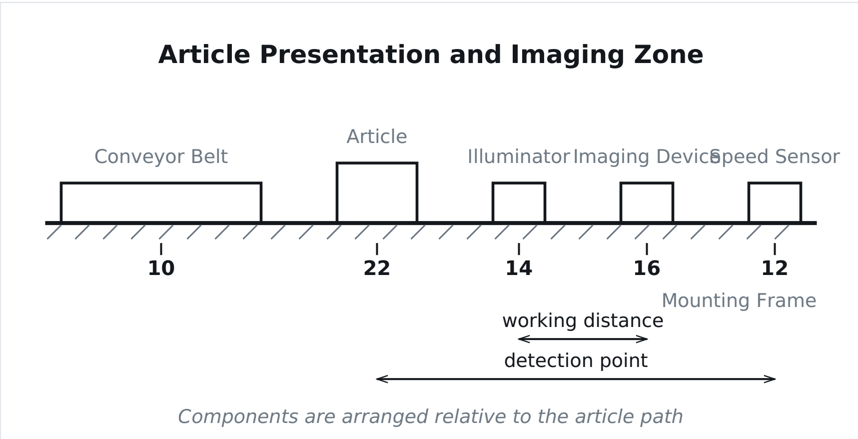


**FIG. 2** An elevation view showing an article on a conveyor as it passes through the imaging and illumination zone. PNG

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