A REPORT

ON

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BY

T3- Camera Automation and Machine Vision

AT

Sasha Innoworks

A Practice School – I Station of

BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE
PILANI, PILANI CAMPUS

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A REPORT

ON

MACHINE VISION SYSTEM DESIGN FOR INDUSTRIAL AUTOMATION

BY

Team T3

Prepared in partial fulfillment of the Practice School-I Course Nos. BITS C221/BITS C231/BITS C241

AT

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Abstract Sheet

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Title: Machine Vision System Design for Industrial Automation
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Abstract

This report outlines the planned development of a machine vision system for automated inspection in pharmaceutical manufacturing. The project will focus on three core areas: a strategic camera selection methodology, optimized industrial lighting design, and camera programming using Basler's pylon SDK. We will develop a systematic framework to evaluate cameras based on resolution, speed, cost, and application-specific needs, analyzing sensor technologies (CMOS vs. CCD), shutter mechanisms, and interfaces (GigE, USB 3.0, Camera Link). The lighting system will incorporate ring, dome, and backlighting solutions to ensure high-quality imaging. Programming efforts will leverage the pylon SDK for precise control of camera parameters like exposure, gain, and frame rate. The anticipated system performance will target frame rates of 30-300 fps and resolutions up to 25 MP, suitable for label verification, fill level detection, and defect identification in pharmaceutical quality control applications.

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Chapter 1

Introduction

Machine vision systems will be critical in pharmaceutical manufacturing, where stringent quality control demands 100% inspection accuracy. The global machine vision camera market is projected to reach $9.2 billion by 2033, with a CAGR of 9.4% (**?**). This project will develop a comprehensive framework for camera selection, lighting design, and system integration tailored for pharmaceutical applications. It will address challenges like regulatory compliance (FDA 21CFR Part 11, EU GMP), cleanroom requirements, and high-precision inspection needs for tablets, capsules, vials, and blister packs. The study aims to enhance quality control, reduce costs, and ensure compliance through a systematic approach to machine vision system design.

Chapter 2

Literature Review

Recent studies emphasize systematic camera selection methods for industrial applications (2; 3). CMOS sensors have overtaken CCDs, offering higher frame rates (up to 194 fps) and lower power consumption, with Sony discontinuing CCD production in 2024 (4). Monochrome sensors provide 60% higher SNR for defect detection. Resolution calculations (FOV/Smallest Detail) suggest 4-pixel areas for detection and ±5 pixels for measurements (5). Lighting studies show a 40% improvement in defect detection with proper illumination (6). The pylon SDK offers precise camera control but is limited to Basler hardware (7). Pharmaceutical systems require high-speed, multi-camera setups for 400-600 units/min with ¿99.5% accuracy (8).

Chapter 3

Objectives

3.1 Primary Objectives

- Develop a camera selection framework that will evaluate resolution, frame rate, sensor type, and cost.
- Design an optimized lighting system that will incorporate ring, dome, and backlighting solutions.
- Implement camera control using the pylon SDK for exposure, gain, and frame rate optimization.

3.2 Secondary Objectives

- Ensure compliance with FDA 21CFR Part 11 and EU GMP guidelines.
- Optimize performance targets for 2-25 MP resolution and 30-300 fps.
- Support multi-camera integration (thermal, stereo, corrosion-resistant).
- Provide comprehensive technical documentation.

Chapter 4

Research Methodology

4.1 Phase 1: Requirements Analysis

We will analyze pharmaceutical inspection needs, machine vision technologies, regulatory standards, and existing camera selection methods.

4.2 Phase 2: Camera Selection Framework

We will define evaluation parameters (resolution, frame rate, sensor type, interface), develop resolution calculations, compare CMOS vs. CCD, evaluate shutter technologies, and conduct cost-benefit analysis.

4.3 Phase 3: Lighting Design

We will design multi-modal lighting (ring, dome, backlighting) with 5000K-6500K color temperature, CRI ¿80, and cleanroom compliance.

4.4 Phase 4: Camera Programming

We will develop Python-based camera control using pypylon, implement parameter adjustments, create multi-camera integration, and test performance.

4.5 Evaluation Metrics

We will assess frame rate (30-300 fps), resolution (2-25 MP), inspection accuracy, cost-effectiveness, regulatory compliance, and scalability.

Chapter 5

Proposed Camera Selection

5.1 Selected Camera Model

After extensive research and analysis of application requirements, we have identified the Basler ace2 a2A3840-45ucBAS as our primary camera choice for the machine vision system. This selection is based on the following specifications and requirements:

5.1.1 Application Requirements

The system requirements established through consultation with Alpha Techsys Automation include:

- Field of View (FOV): 8cm × 8cm
- Minimum feature detection accuracy: Not yet finalized (samples in procurement)
- Color capability: Required
- Interface: USB 3.0
- Object movement: Conveyor belt at 0.5 m/s
- Working distance: 40-75 cm (conveyor width: 80 cm)

5.1.2 Camera Specifications

The Basler ace2 a2A3840-45ucBAS offers the following key specifications that align with our requirements:

- Resolution: 3840 × 2160 pixels (8.3 MP)
- Frame rate: Up to 45 fps at full resolution
- Sensor type: CMOS color sensor
- Interface: USB 3.0
- Pixel size: 1.55 m × 1.55 m

5.1.3 Selection Rationale

This camera model represents an optimal balance between resolution and frame rate for our application. Given the maximum belt speed of 0.5 m/s, we require adequate frame rate capability to properly capture images without motion blur. While cameras with higher frame rates typically offer lower resolution, the ace2 a2A3840-45ucBAS provides the best compromise for our needs, falling within our target range of 30-60 fps.

5.1.4 Accessories and Components

Along with the camera, we will procure:

- Data cable: Standard (S) version - sufficient for our small room installation
- Power cable: Standard (S) version - adequate for short-distance applications
- Heat sink: Not required due to air-conditioned environment

The premium (P) cable versions offer enhanced robustness and noise immunity over long distances, but our compact installation space makes standard cables appropriate. The heat sink option, while lightweight (20-50 grams), is unnecessary given our climate-controlled environment.

5.2 Technical Justification

The selection process considered multiple factors including sensor technology, interface compatibility, environmental conditions, and cost-effectiveness. The USB 3.0 interface provides sufficient bandwidth for our application while simplifying integration compared to GigE alternatives. The CMOS sensor technology ensures low power consumption and high-speed operation suitable for conveyor-based inspection systems.

Chapter 6

Planned Results and Expected Findings

6.1 Camera Selection Framework

We anticipate that CMOS sensors will achieve up to 194 fps with 60% higher SNR compared to CCD alternatives. Resolutions of 2-5 MP will be suitable for defect detection, while 12-25 MP will be needed for precise measurements. GigE interfaces are expected to support 60 fps at 25 MP, while Camera Link will be suitable for line scan applications at 120 KHz.

6.2 Lighting System Design

The planned lighting system will incorporate ring lights (100-120 mm diameter, 5000K-6500K, CRI more than 80) and dome lights to reduce glare. Backlighting will aid fill level detection, and UV lighting (365-395 nm) will target micro-crack detection applications.

6.3 Camera Programming Implementation

The pylon SDK implementation will optimize exposure settings (60 s-6 ms), gain control (0.1-10.0), and frame rate management (30-300 fps). Multi-camera integration will support thermal and stereo systems, targeting less than 33 ms latency and ±1 ms synchronization accuracy.

6.4 Pharmaceutical Validation Targets

Label verification systems will target 99.7% accuracy at 45 codes/s. Fill level detection will aim for 94% accuracy at 400-600 vials/min. Defect detection capabilities will target identification of 0.25 mm cracks and particles less than 50 m in size.

Chapter 7

Discussion and Future Work

The proposed framework will balance resolution, speed, and cost considerations, with CMOS sensors and multi-modal lighting ensuring high-quality imaging capabilities. While pylon SDK will provide precise control, we acknowledge its limitation to Basler-only compatibility. The system design targets pharmaceutical requirements (more than 99.5% accuracy, 30-300 fps) and regulatory compliance needs. Future considerations will include addressing pylon's vendor lock-in limitations and environmental factors such as temperature variation effects.

Chapter 8

Conclusions and Recommendations

This project will advance a robust machine vision framework for pharmaceutical applications, targeting high inspection accuracy and regulatory compliance. We recommend proceeding with the complete framework development, exploring hyperspectral imaging capabilities, integrating Industry 4.0 features, and developing vendor-agnostic interfaces to enhance system flexibility and reduce dependency on single-vendor solutions.

Appendix A

Camera Specification Comparison

Table A.1: Comparison of Candidate Camera Models

Camera Model	Resolution	Frame Rate	Interface	Price Range
Cognex CIC-5000	5 MP	60 fps	GigE	$2,000-4,000
Basler ace2 a2A3840-45ucBAS	8.3 MP	45 fps	USB3	$1,500-3,500
Allied Vision Alvium	1-50 MP	20-164 fps	GigE/10GigE	$800-5,000
Teledyne DALSA	1-245 MP	10-300 fps	Camera Link	$3,000-15,000

Appendix B

Planned Lighting Specifications

B.1 Ring Light Design

Outer Diameter: 100-120 mm
Inner Diameter: 40-60 mm
LED Type: High-intensity white LEDs
Color Temperature: 5000K-6500K
CRI: more than 80
Power Consumption: 5-20W

B.2 Dome Light Design

Dome Diameter: 150-200 mm
Illumination Type: Multi-LED array
Color Temperature: 5000K-6500K
Brightness: 15,000-25,000 lux
Uniformity: more than 90%

Appendix C

Planned Thermal Camera Controller Code

```
import numpy as np
import cv2
import threading
import queue
from pypylon import pylon
from pypylon import genicam

class ThermalCameraController:
    def __init__(self):
        """Initialize thermal camera connection"""
        self.camera = None
        self.frame_queue = queue.Queue(maxsize=10)
        self.running = False
        self.capture_thread = None

    def connect(self):
        """Connect to thermal camera using pylon"""
        try:
            tl_factory = pylon.TlFactory.GetInstance()
            devices = tl_factory.EnumerateDevices()
            if len(devices) == 0:
                raise Exception("No thermal cameras found")
            self.camera = pylon.InstantCamera(
                tl_factory.CreateDevice(devices[0]))
            self.camera.Open()
            self.configure_camera()
            print("Thermal camera connected successfully")
            return True
        except genicam.GenericException as e:
            print(f"Failed to connect thermal camera: {e}")
            return False
```

```
    def configure_camera(self):
        """Configure thermal camera parameters"""
        try:
            node_map = self.camera.GetNodeMap()

            # Set acquisition mode to continuous
            acquisition_mode = pylon.CEnumerationPtr(
                node_map.GetNode(’AcquisitionMode’))
            if genicam.IsWritable(acquisition_mode):
                acquisition_mode.SetValue(’Continuous’)

            # Set pixel format to Mono16 for thermal data
            pixel_format = pylon.CEnumerationPtr(
                node_map.GetNode(’PixelFormat’))
            if genicam.IsWritable(pixel_format):
                pixel_format.SetValue(’Mono16’)

            # Adjust exposure time
            exposure_node = pylon.CFloatPtr(
                node_map.GetNode(’ExposureTime’))
            if genicam.IsWritable(exposure_node):
                exposure_node.SetValue(10000.0)  # 10ms exposure

            # Set gain
            gain_node = pylon.CFloatPtr(node_map.GetNode(’Gain’))
            if genicam.IsWritable(gain_node):
                gain_node.SetValue(1.0)  # Default gain

            # Set frame rate
            frame_rate_node = pylon.CFloatPtr(
                node_map.GetNode(’AcquisitionFrameRate’))
            if genicam.IsWritable(frame_rate_node):
                frame_rate_node.SetValue(30.0)  # 30 fps

        except genicam.GenericException as e:
            print(f"Configuration error: {e}")

    def start_capture(self):
        """Start continuous frame capture"""
        if not self.running:
            try:
                self.camera.StartGrabbing(pylon.GrabStrategy_LatestImageOnl
```

```
                self.running = True
                self.capture_thread = threading.Thread(
                    target=self._capture_loop)
                self.capture_thread.start()
                print("Capture started")
                return True
            except genicam.GenericException as e:
                print(f"Failed to start capture: {e}")
                return False

    def _capture_loop(self):
        """Capture frames and add to queue"""
        while self.running:
            try:
                grab_result = self.camera.RetrieveResult(
                    5000, pylon.TimeoutHandling_ThrowException)
                if grab_result.GrabSucceeded():
                    image = grab_result.Array
                    if not self.frame_queue.full():
                        self.frame_queue.put(image.copy())
                grab_result.Release()
            except genicam.GenericException as e:
                print(f"Capture error: {e}")
                break

    def get_frame(self):
        """Retrieve latest frame from queue"""
        try:
            return self.frame_queue.get_nowait()
        except queue.Empty:
            return None

    def stop_capture(self):
        """Stop frame capture"""
        if self.running:
            self.running = False
            if self.capture_thread:
                self.capture_thread.join()
            self.camera.StopGrabbing()
            print("Capture stopped")

    def disconnect(self):
```

```
"""Disconnect camera"""
if self.camera and self.camera.IsOpen():
    self.stop_capture()
    self.camera.Close()
    self.camera = None
    print("Camera disconnected")
```

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Glossary

- **CMOS**: Complementary Metal-Oxide-Semiconductor, a type of image sensor used in cameras.
- **CCD**: Charge-Coupled Device, an older image sensor technology.
- **GigE**: Gigabit Ethernet, a camera interface standard.
- **CRI**: Color Rendering Index, a measure of light source color accuracy.
- **SNR**: Signal-to-Noise Ratio, a measure of image quality.
- **pylon SDK**: Basler's software development kit for camera control.
- **FOV**: Field of View, the observable area captured by the camera.
- **USB 3.0**: Universal Serial Bus 3.0, a high-speed interface standard.