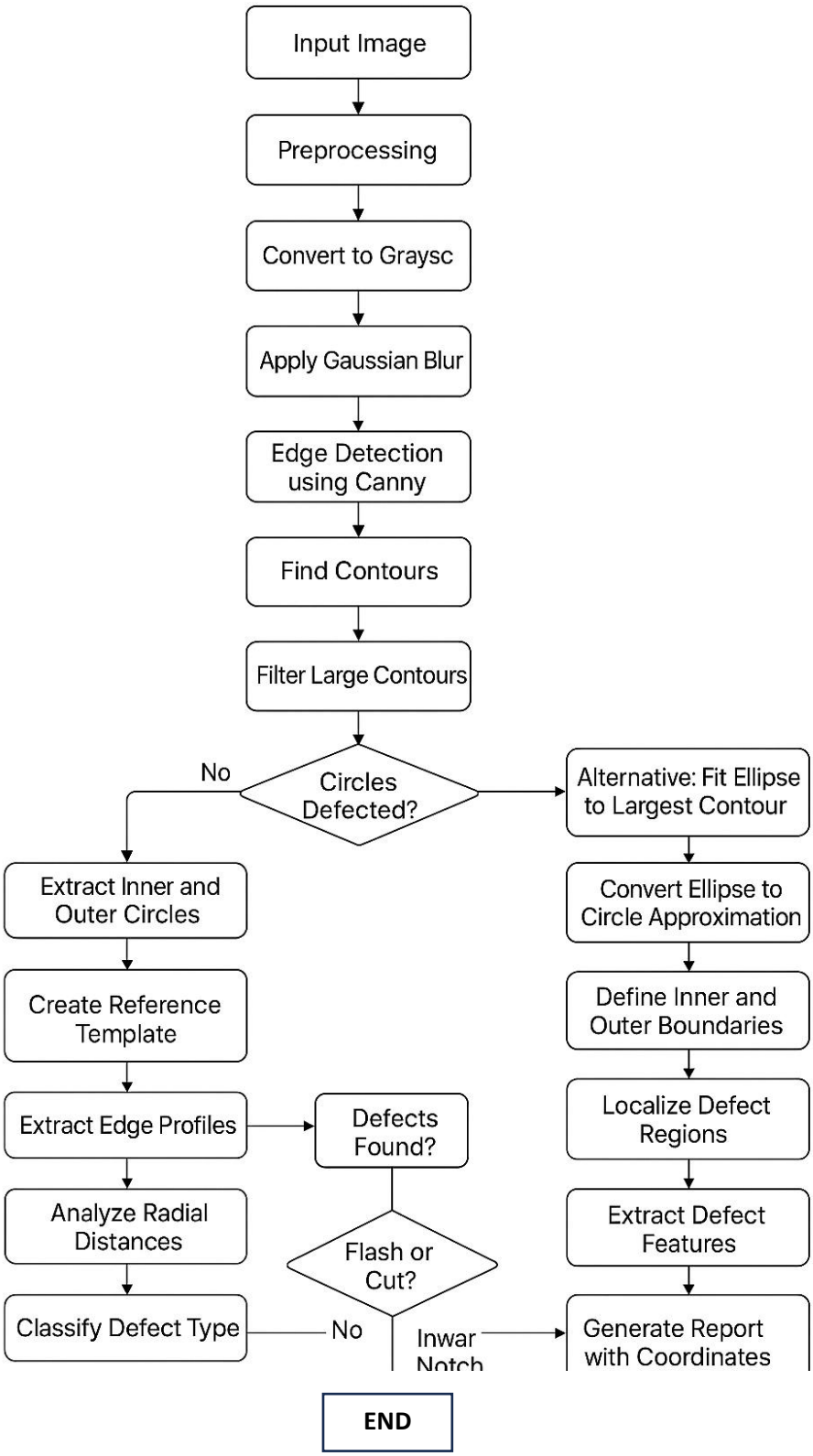
Vinyl Record Defect Detection Algorithm

Overview

This algorithm detects defects in vinyl records by analysing deviations from perfect circular shapes. It can handle various image conditions including different diameters, translations, and lighting conditions.

Flowchart:



Algorithm Breakdown

1. Image Preprocessing

- **Grayscale Conversion**: Convert input image to grayscale for easier processing
- **Gaussian Blur**: Apply blur to reduce noise and improve edge detection
- **Adaptive Preprocessing**: Handle different lighting conditions and image qualities

2. Circle Detection

- **Edge Detection**: Use Canny edge detection to find boundaries
- **Contour Analysis**: Find and filter contours by area to identify the record
- **Hough Circle Transform**: Detect circular shapes with different radii
- **Dual Circle Detection**: Identify both inner and outer circles of the vinyl record
- **Robust Estimation**: Handle cases where perfect circles aren't detected

3. Defect Detection Core Algorithm

3.1 Radial Profile Extraction

- Sample image intensities at regular angular intervals around expected circle
- Create high-resolution angular sampling (720 points) for precise detection
- Extract actual edge positions by finding maximum gradient points

3.2 Deviation Analysis

- Compare actual edge positions with expected perfect circle
- Calculate radial deviations at each angular position
- Use adaptive thresholding based on circle radius

3.3 Defect Classification

- **Flash Detection**: Identify outward bulges (positive deviations)
- **Cut Detection**: Identify inward notches (negative deviations)
- **Size Filtering**: Only consider defects above minimum size threshold

4. Defect Localization

4.1 Coordinate Mapping

- Convert angular positions to pixel coordinates
- Calculate exact (x, y) positions of defects
- Store defect boundaries and center points

4.2 Defect Characterization

- Measure defect size and severity
- Calculate maximum deviation from perfect circle

- Determine angular span of each defect

5. Classification System

5.1 Flash Classification

- **Criteria**: Positive radial deviation beyond threshold
- **Features**: Outward bulge, increased radius
- **Severity**: Measured by maximum deviation amount

5.2 Cut Classification

- **Criteria**: Negative radial deviation beyond threshold
- **Features**: Inward notch, decreased radius
- **Severity**: Measured by depth of cut

5.3 Multi-Circle Analysis

- Analyze both inner and outer circles independently
- Combine results for comprehensive defect report

Key Features

Robustness to Variations

1. **Different Diameters**: Algorithm scales thresholds based on detected radius
2. **Translation Invariance**: Works regardless of record position in image
3. **Rotation Invariance**: Angular analysis handles any record orientation
4. **Lighting Adaptation**: Edge-based detection robust to illumination changes

Advanced Capabilities

1. **Sub-pixel Accuracy**: Uses interpolation for precise edge detection
2. **Noise Filtering**: Multiple filtering stages remove false positives
3. **Adaptive Thresholding**: Thresholds adjust to record size
4. **Comprehensive Reporting**: Detailed defect analysis with coordinates

Performance Optimizations

1. **Efficient Sampling**: Optimized radial profile extraction
2. **Smart Search**: Limited search windows around expected positions
3. **Vectorized Operations**: NumPy arrays for fast computation

Algorithm Parameters

Configurable Settings

- deviation_threshold: Sensitivity for defect detection (default: 0.05)
- min_defect_size: Minimum defect size to report (default: 10 pixels)
- search_width: Range to search for edges (default: 20 pixels)

- num_angles: Angular resolution for analysis (default: 720)

Adaptive Parameters

- Edge detection thresholds adjust to image characteristics
- Circle detection parameters scale with image size
- Defect thresholds proportional to radius

Output Format

Detection Results

```
{
  "status": "good" | "defective",
  "total_defects": number,
  "outer_circle": {
    "center": [x, y],
    "radius": radius,
    "defects": [defect_list]
  },
  "inner_circle": {
    "center": [x, y],
    "radius": radius,
    "defects": [defect_list]
  }
}
```

Defect Information

```
{
  "type": "flash" | "cut",
  "x": pixel_x,
  "y": pixel_y,
  "angle_start": start_angle,
  "angle_end": end_angle,
  "max_deviation": deviation_pixels,
  "size": defect_size
}
```

Implementation Considerations

Dependencies

- OpenCV for image processing
- NumPy for numerical computations
- SciPy for interpolation
- Matplotlib for visualization

Error Handling

- Graceful handling of undetectable circles
- Validation of input images
- Robust parameter estimation

Scalability

- Efficient memory usage for large images
- Parallel processing capability for batch operations
- Configurable precision vs. speed trade-offs

Testing and Validation

Test Cases

1. Perfect circular records (should detect no defects)
2. Records with known flash defects
3. Records with known cut defects
4. Records with multiple defect types
5. Records with challenging imaging conditions

Performance Metrics

- Detection accuracy (sensitivity/specificity)
- False positive/negative rates
- Processing speed per image
- Localization precision

Future Enhancements

Potential Improvements

1. Machine learning classification for defect types
2. 3D surface analysis for deeper defects
3. Real-time processing optimization
4. Integration with manufacturing systems
5. Statistical quality control reporting

This algorithm provides a comprehensive solution for automated vinyl record quality control, capable of handling real-world manufacturing variations while maintaining high accuracy in defect detection and classification.