Lappeenranta-Lahti University of Technology

School of Engineering Sciences

Department of Data-centric Engineering

COIN DETECTION AND MEASUREMENT

Course: Digital Imaging And Image Preprocessing [BM40A1201]

Group Members
Olivier Kanamugire [redacted]
Bright W. Nuakoh [redacted]

Supervisors
Dr.Xin Liu
Deng Li
Rong Gao

January 15, 2025

Contents

1 Introduction

1.1 Background

As automation and digital technologies become more incorporated into daily activities, the detection and measurement of coins have become important applications across multiple sectors, including banking and automated vending machines. This initiative seeks to create a reliable imaging measurement system that accurately determines the number and types of coins visible in a captured image. By employing a calibrated imaging setup, the project highlights the relationship between imaging technology and its role in precise object detection and classification.

Accurate identification and measurement of coins require a methodical strategy that utilizes image analysis methods and machine learning techniques. By defining and fine-tuning the imaging configuration, we can guarantee that the image quality is suitable for the measurement process, leading to dependable and precise outcomes. The project's focus on supplementary measurements highlights the ever-changing nature of real-world conditions, such as changes in lighting and focal distance, which can greatly influence the precision of measurements.

1.2 Objectives

The primary objective of this measurement project is to develop a comprehensive system capable of estimating the number and types of various coins from a given image. The detailed information about specific objectives is presented below:

- *Study and Practice of Imaging Setup Calibration:* Understanding the principles of imaging setup characterization and calibration allows for optimizing image quality, which is crucial in detecting and measuring small objects, such as coins.
- *System Implementation Using Provided Data:* The project will utilize the given datasets and imaging parameters to implement an effective coin detection and measurement algorithm. This forms the backbone of our practical application.
- *Experimental Design for Additional Measurements:* To guarantee the system's reliability, a structured experimental approach will be implemented to accommodate different lighting scenarios or modifications in the imaging setup, including

adjustments in focal length. This involves figuring out the best way to organize and gather extra data under these changed conditions.

- *Collection of Extra Experimental Data:* Based on the initial results and changes in conditions, extra experimental data will be collected. This step is crucial in validating the reliability of the detection and measurement processes.
- *Data Correction Using Calibration Information:* Once extra data is gathered, correction methodologies will be employed to enhance the quality of the results, utilizing previously characterized calibration information from the imaging setup.
- *Evaluation of Measurement Error and Uncertainty:* A critical aspect of measurement engineering is understanding the accuracy and reliability of obtained results. Therefore, measurement error and uncertainty will be evaluated based on corrected measurement results and reference data.
- *Documentation of the Work:* Finally, a comprehensive report will document the entire process, from setup and implementation to results and evaluation, ensuring transparency and reproducibility of our findings.

1.3 Process Overview

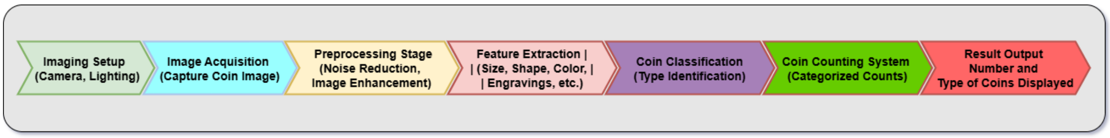

Figure 1.1: Pipeline of the work

The imaging setup consists of pre-calibrated equipment, including a fixed camera and lighting system, ensuring consistent and optimal image capture for accurate measurements. The measured target is a predefined set of coins with distinct characteristics such as diameter, color, and engravings, requiring the system to handle variations in coin types effectively. The primary purpose is to estimate the total number of coins in an image and classify them into their respective categories, such as denomination or type. Key requirements include robust handling of overlapping coins, accurate classification despite variations in lighting or orientation, and efficient, automated processing with minimal human intervention, ensuring reliability and scalability of the system.

2 Literature Review

2.1 Principles of Imaging Setup Characterization and Calibration

Understanding the principles of imaging setup characterization and calibration is essential for obtaining accurate and consistent image measurements. This approach requires refining the imaging system to guarantee an accurate depiction of the real world in the captured image. Calibration is a vital aspect that tackles factors like geometric distortions, color accuracy, and radiometric precision. Characterization aims to outline the performance metrics of the imaging system, confirming its appropriateness for particular applications.

Imaging Setup Characterization: Characterization of an imaging system involves the assessment of its optical properties, including resolution, contrast, and field of view. Numerous studies have highlighted the importance of characterization for effective imaging analysis. spatial resolution and SNR are crucial for applications requiring high detail, such as microscopy and machine vision. Similarly, assessing the dynamic range helps ensure the system can handle scenes with varying light intensities without significant loss of details.

Calibration Techniques: Calibration is essential for ensuring that an imaging system produces accurate and reliable images. Techniques vary widely depending on the application and technology. For example, Zhang et al. in [1] performed a comparative analysis of different calibration techniques, including flat-field correction and dark-frame subtraction, which are necessary for correcting systematic errors and improving image quality.

Geometric calibration involves correcting distortions introduced by lenses, ensuring straight lines in the real world are accurately represented in the image. Zhang's method [2] is widely used for geometric calibration, relying on a known calibration pattern, such as a checkerboard, to estimate intrinsic and extrinsic camera parameters.

Impact of Environmental Factors Environmental conditions can also impact the accuracy of imaging setups. Factors like temperature and humidity affect sensor performance and outcomes, underscoring the need for environmental controls in imaging setups.

3 Methods and Implementation

3.1 Image Preprocessing and Calibration Process

Given the image data $I(x, y)$, the bias $B(x, y)$, the dark current $D(x, y)$, and the flatfield $F(x, y)$, the goal is to calibrate the image to correct for these various factors (bias, dark current, and flatfield variations). The process involves using these corrections to improve the quality of the raw image $I(x, y)$. Image preprocesing is very key in this task, [3] showed how local features extraction can significantly improve the accuracy of the function.

3.1.1 Calibration Equation

The calibrated image $I_{calibrated}(x, y)$ is obtained by applying the following formula:

$$I_{calibrated}(x, y) = \frac{I(x, y) - \hat{B}(x, y) - \hat{D}(x, y)}{\hat{F}(x, y)} \tag{3.1}$$

3.1.2 Explanation of the Terms

- **Raw Image** $I(x, y)$: This is the uncalibrated image, which may contain noise and artifacts due to the bias, dark current, and variations in the flatfield.
- **Bias** $B(x, y)$: The bias term represents a systematic offset in the image, often introduced by the imaging system. It is typically a constant or slowly varying background signal that needs to be removed for accurate imaging.
- **Dark Current** $D(x, y)$: The dark current is the signal produced by the camera's sensor when no light is hitting it. It typically increases with exposure time and temperature. It must be subtracted from the raw image to account for this unwanted signal.
- **Flatfield** $F(x, y)$: The flatfield represents spatial variations in the sensor's response to uniform illumination. These variations are typically caused by differences in the sensitivity of individual pixels or optical distortions. To correct for these, the image is divided by a normalized flatfield.

- **Mean of Bias and Dark Current ($\hat{B}(x,y)$ and $\hat{D}(x,y)$):** The notation $\hat{B}(x,y)$ and $\hat{D}(x,y)$ indicates that the bias and dark current values are typically averaged over a set of images. This averaging helps account for any variations or noise that might be present in a single instance of the bias or dark frame. The hat symbol indicates that we are using an average or estimated value.

- **Normalized Flatfield ($\hat{F}(x,y)$):** The flatfield $F(x,y)$ is normalized so that its mean value is 1. This normalization helps ensure that the flatfield is consistent across all pixel values. The normalized flatfield is calculated by subtracting the mean of $F(x,y)$:

$$\hat{F}(x,y) = F(x,y) - \text{mean}(F) \tag{3.2}$$

  Here, mean(F) is the average of the flatfield image $F(x,y)$ over all pixels. By subtracting the mean, we ensure that the flatfield has a mean value of 1 across the image.

3.2 Implemented Functions: Inputs and Outputs

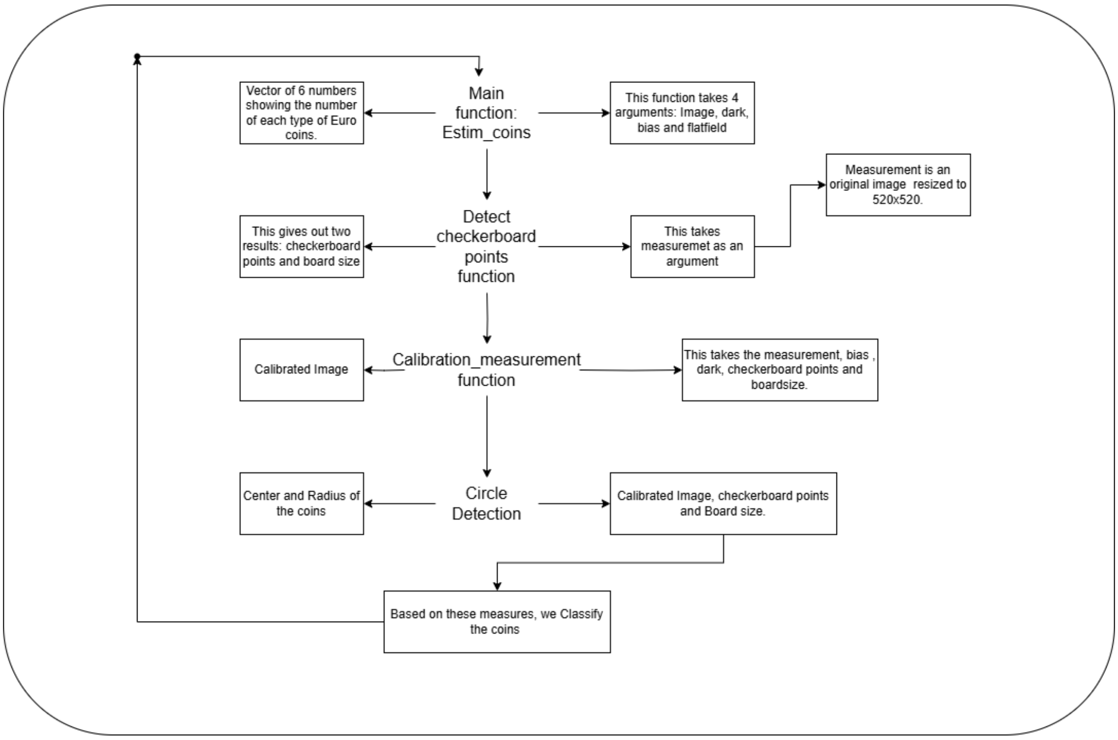

Figure 3.1: On the left side, we have the output of the functions. Functions in the middle and inputs on the Right-hand side.

4 Results and Discussion

4.1 Data Description

The dataset consists of images, dark images, biases, and flatfields.

Figure 4.1: (a)

Figure 4.2: (b)

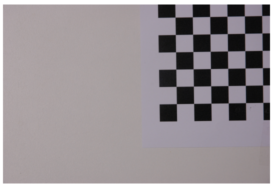

Figure 4.3: (c)

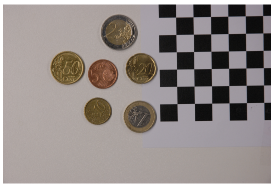

Figure 4.4: (d)

(a) represent bias frame, image taken with the shortest possible exposure time. (b) represents a dark frame, an image taken with the same exposure time and sensor settings as the raw image but with no light reaching the sensor. (c) flat-field an image captured of a uniformly illuminated surface. (d) represents original image.

4.1.1 Calibration of the Image

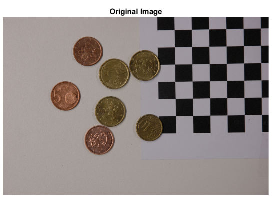

Figure 4.5: (a)

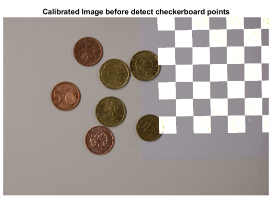

Figure 4.6: (b)

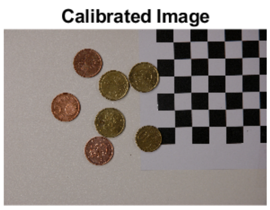

Figure 4.7: (c)

(a) is the original image. (b) calibrated image before detection (c) is the calibrated image after detection

4.1.2 Evaluation metrics

We have used mean absolute error and accuracy as our evaluation metrics.

- Overall Mean Absolute Error (MAE): 1.5556
- Accuracy 94.4653%

The matrix `original_data` is given as:

$$O = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 3 & 1 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 5 & 1 & 1 \\ 0 & 0 & 0 & 3 & 1 & 3 \\ 0 & 1 & 0 & 4 & 1 & 3 \\ 0 & 3 & 0 & 1 & 0 & 2 \\ 0 & 1 & 0 & 3 & 0 & 0 \\ 0 & 0 & 1 & 4 & 0 & 3 \\ 0 & 0 & 0 & 0 & 1 & 3 \\ 0 & 0 & 1 & 4 & 0 & 0 \\ 0 & 3 & 1 & 5 & 0 & 0 \\ 0 & 3 & 1 & 1 & 0 & 0 \end{bmatrix} ; P = \begin{bmatrix} 0 & 1 & 1 & 1 & 2 & 1 \\ 0 & 0 & 0 & 1 & 1 & 3 \\ 0 & 1 & 0 & 5 & 1 & 1 \\ 0 & 1 & 0 & 3 & 3 & 0 \\ 0 & 1 & 0 & 4 & 4 & 0 \\ 0 & 0 & 1 & 2 & 3 & 0 \\ 0 & 0 & 0 & 3 & 1 & 0 \\ 0 & 0 & 1 & 4 & 3 & 0 \\ 0 & 1 & 0 & 0 & 3 & 0 \\ 0 & 0 & 1 & 4 & 0 & 0 \\ 0 & 0 & 1 & 5 & 3 & 0 \\ 0 & 0 & 1 & 1 & 3 & 0 \end{bmatrix}$$

O is original and P is horizontally flipped predicted.

4.1.3 Comments and Analysis

Although the predicted results show some improvement over the original data, they are not quite as accurate as desired. Several factors could contribute to the suboptimal performance:

- **Preprocessing:** More careful preprocessing techniques, such as noise reduction, normalization, or advanced background subtraction methods, could improve the data quality. These steps are crucial for removing unwanted artifacts and ensuring that the data being processed is as clean as possible.
- **Measurement Accuracy:** The pixel measurements in terms of real-world units (e.g., centimeters or millimeters) are critical. If these measurements are not accurate, the results may be inaccurate as well. Using high-precision tools for measuring pixel sizes and ensuring that the calibration process is done correctly will have a significant impact on the final output.
- **Model Improvement:** The model used for processing the data might also need further refinement. This could include using better algorithms for the specific task or more sophisticated models to account for the complexities of the data.
- **Consistency in Calibration:** Inaccuracies in the calibration process, such as inconsistent scaling between raw data and real-world measurements, can lead to erroneous predictions. Ensuring that the calibration steps are consistent across all data points is essential for achieving reliable results.

5 Conclusion

There is a lot of misclassification between 20-cent coins and 5-cent coins because of their almost the same size. The method is limited to such precise measurements. With improved preprocessing, color calibration and accurate measurements of pixels (in cm or mm), the accuracy of the results could be greatly enhanced. More precise data collection, followed by careful calibration, is the key to significantly improving the prediction quality.

For our codes, you can refer to this link: `https://github.com/Wiredu2020/coin_detection`.

References

[1] T. Ueshiba, "A survey of camera calibration techniques," 2005. [Online]. Available: https://api.semanticscholar.org/CorpusID:195254713.

[2] Z. Zhang, "A flexible new technique for camera calibration," *Pattern Analysis and Machine Intelligence, IEEE Transactions on*, vol. 22, pp. 1330–1334, Dec. 2000. DOI: 10.1109/34.888718.

[3] D. Partha, "Coin detection: Https://github.com/durbarhp/coin-detection-and-estimation–digital-imaging-and-image-processing," Github code for Durbar Partha 2024.