Estimating One-Dimensional Barcode Image Orientation by Using 2D Fourier Transform: A CPU-Based Approach

Can Ali GÜLYURT[1*], Sümer Erkan KAYA[2]

[1] Asis Automation and Fueling System Inc., Istanbul, TURKIYE, Orcid ID: https://orcid.org/0009-0009-5053-6608, E-mail: a.gulyurt@asis.com.tr

[2] Asis Automation and Fueling System Inc., Istanbul, TURKIYE, Orcid ID: https://orcid.org/0009-0001-3979-742X, sumerkaya@asis.com.tr,

Received 12 January 2024
Received in revised form 15 March 2024
In final form 15 May 2024

Reference: Gülyurt, C., A., Kaya, S., E. Estimating One-Dimensional Barcode Image Orientation by Using 2D Fourier Transform: A CPU-Based Approach. The European Journal of Research and Development, 4(2), 199-205.

Abstract

Barcode detection and decoding are critical tasks in numerous industrial sectors, including inventory management, logistics, and retail. Despite the advancements in Artificial Intelligence (AI) and Machine Learning (ML), many existing barcode detection methods rely heavily on GPU-accelerated techniques or are confined by specific angle requirements, limiting their versatility and computational efficiency. In this paper, a novel approach for stabilizing barcode image orientations using the 2D Fourier Transform was developed, with an emphasis on CPU-based implementation.

Keywords: *Computer Vision, 2D Fourier Transform, One-Dimensional Barcode, Orientation Estimation*

1. Introduction

This research addresses the limitations associated with costlier GPU-dependent techniques then CPUs and angle-specific constraints present in several open-source barcode detection libraries, such as Zbar [1]. By exploiting the Fourier Transform, this approach enables robust decoding of barcodes at arbitrary angles, thus obviating the necessity for GPU resources and restrictive angle specifications. A comprehensive theoretical foundation of the Fourier Transform and its application to estimate the barcode orientation is provided. Additionally, detailed implementation procedures are presented to demonstrate the effectiveness and computational efficiency of the proposed approach. This study underscores the potential of Fourier Transform-based techniques in Image Processing, offering a promising alternative to GPU-dependent methodologies and angle-constrained approaches. The findings contribute to the advancement of barcode detection technology, with implications for enhancing efficiency and scalability in diverse industrial applications.

2. Material and Methods

The methodology for estimating the orientation of an image patterns of 1D barcodes involves several key steps: Pattern detection using CPU-based algorithms, computation of the 2D Fourier transform, analysis of the power spectrum, filtering of low-frequency components, and finally, line detection to estimate the orientation.

2.1 Barcode Detection Using CPU-Based Algorithms

The initial step in the process is to detect patterns within the image using computationally efficient algorithms that can be executed on a CPU. Given the constraint of avoiding expensive GPU-based computation. Edge Detection algorithms such as the Canny edge detector were used in detection part which was not the main focus of this research. These algorithms involves the application of Gaussian smoothing to reduce noise, calculation of intensity gradients, and edge thinning using non-maximum suppression. To identify significant features within the image, the Scale-Invariant Feature Transform (SIFT) algorithm was applied. These algorithms helped in locating Points of Interest that are invariant to scale and rotation, providing a robust basis for further analysis.

Once the significant features are detected, the next step is to transform the image from the spatial domain to the frequency domain. This is achieved using the 2D Fourier transform.

2.2 Fourier Transform

The Fourier Transform represents a signal as an infinite sum of sinusoidal functions, each with a specific frequency and amplitude. This representation allows for a comprehensive analysis of the signal's frequency content and enables various signal processing tasks such as filtering, modulation, and compression.

Mathematically, the continuous Fourier Transform of a function f(t) is defined as:

$$F(\omega) = \int_{-\infty}^{\infty} f(t)e^{-i\omega t}dt$$

Where $F(\omega)$ represents the transformed function in the frequency domain, ω denotes the angular frequency, and $e^{-i\omega t}$ is the complex exponential function.

From perspective of Digital Signal Processing the discrete verison of Fourier Transform is beneficial. The Discrete Fourier Transform (DFT) is a mathematical transformation that converts a sequence of N complex numbers from the time domain into the frequency domain. This theorem facilitates efficient signal processing techniques such as filtering and modulation.

In practice, the Discrete Fourier Transform (DFT) and its fast implementation, the Fast Fourier Transform (FFT), are widely used due to their computational efficiency. Fourier Transform can be perform on two dimension which is called The Two-dimensionel Fourier Transform.

Mathematically, the continuous Two-Dimensional Fourier Transform of a function f(x,y) is defined as:

$$F(u,v) = \iint_{-\infty}^{\infty} f(x,y)\, e^{-i2\pi(ux+vy)}\, dxdy$$

Where $f(x,y)$ is the image intensity function, and $F(u,v)$ represents the frequency domain of the image.

Then the power spectrum of the 2D Fourier transform is then computed to analyze the frequency content of the image.

2.3 Power spectrum

The power spectrum of the Fourier transform provides a measure of the distribution of power (or energy) of the image as a function of frequency. Mathematically, the power spectrum $P(u,v)$ is computed as the squared magnitude of the Fourier transform:

$$P(u,v) = |F(u,v)|^2$$

Where $|F(u,v)|$ represents the magnitude of the complex-valued Fourier transform $F(u,v)$, and is computed as:

$$|F(u,v)| = \sqrt{Re(F(u,v))^2 + Im(F(u,v))^2}$$

The power spectrum reveals how the power of the image is distributed across different spatial frequencies. High power at low frequencies (near the origin of the frequency domain) indicates the presence of large-scale, smooth variations in the image, while high power at high frequencies corresponds to fine details, edges, and noise.

The power spectrum is often visualized using a logarithmic scale to handle the wide range of power values and to make the low-power frequencies more discernible. The visualization typically centers the low frequencies at the middle of the plot for better interpretation (using a shift operation). The isotropy is beneficial to indicate the orientation of the 1-Dimensional shape since the barcode image has similar structure in all directions.

2.4 Filtering Low-Frequency Components

To focus on large-scale smooth variations in the image, we filter out high-frequency components. This is achieved by applying a low-pass filter to the power spectrum, retaining only the significant low-frequency components as shown in Figure 1. This step ensures the focus is concentrate on the dominant patterns and orientations within the image for the line detection.

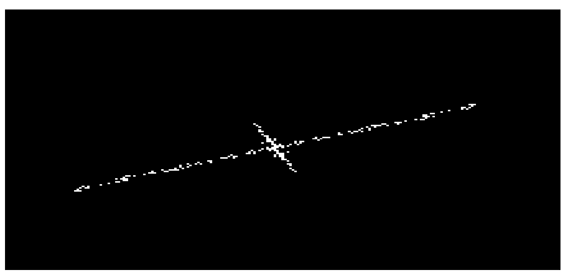

Figure 1: An example of Low Pass Filtered power spectrum image.

2.5 Line and Orientation Estimation

There are algorithms to identify lines and angle that represent the orientation of the image pattern from the filtered power spectrum image. The Hough transform is one of them and employed to demonstrate this purpose, which detects lines by mapping points in the frequency domain to a parameter space. Morphological operation may perform on the power spectrum image before the Hough Transform or any other algorithm to enhance the results as shown in Figure 2. By employing the equations of line tangent formulas relation between angle, lines and points can be establish.

$$\rho = x \cos\theta + y \sin\theta$$

Where ϙ is the distance from the origin and θ is the angle of the line. The orientation angle θ is calculated using the tangent formula

$$\theta = \arctan(\frac{u}{v})$$

Where u and v are the frequency components corresponding to the detected line's direction.

Finally, by determining of orientation, a rotation process is performed on the original image.

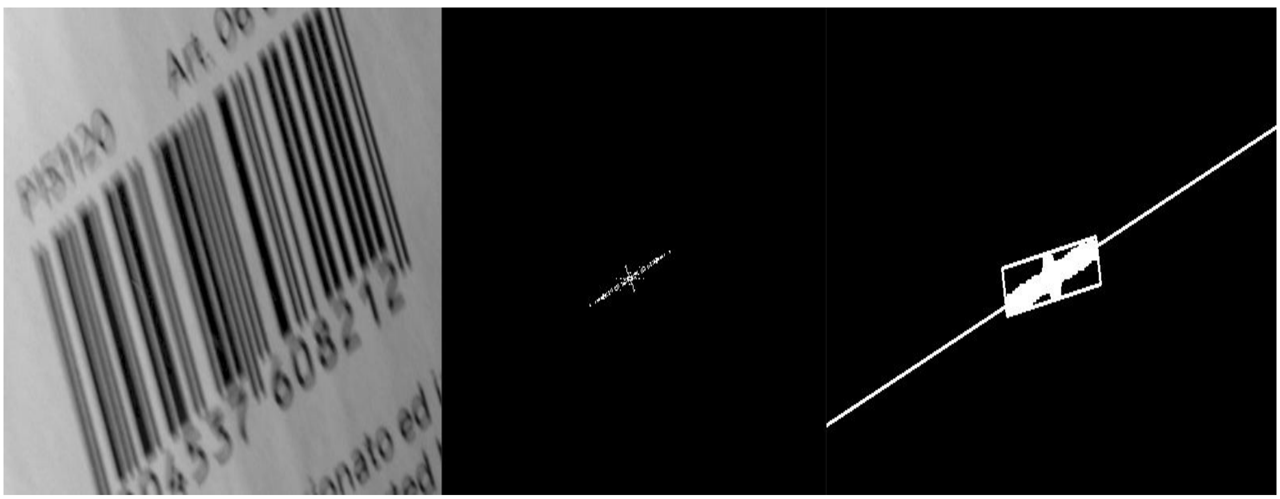

Figure 2: illustrates the entire process, shown sequentially from left to right.

2.6 Camera

The camera to satisfy the methods that described in this paper may vary. In this Project, one of Arducam's Global Shutter Camera Module[2] was used to obtain the 1-Dimensional Barcode images.

3. Results

The methodology was validated using synthetic images with known orientations and real-world images. The dataset was made out of 840 images. 60% of the images were belong to synthetic dataset and the rest gathered from the real-world images. The estimated orientations were compared against ground truth data.

The orientation performance was evaluated based on metric as angular error in degrees. From the result of the evaluations, it has seen that the errors on the orientation of the barcodes vary according to image and lighting quality. The maximum angular error measured as 11 degrees and the average error observed was 4 degrees. The errors were depending on the noise and blur of the image. Even the filtering that made on power spectrum worked with blurred and noisy images, these parameters still affected the accuracy. CPU processing time and resource utilization were specifically analyzed to emphasize the cost-effectiveness of the approach.

4. Discussion and Conclusion

This methodology outlines a comprehensive approach to estimating the orientation of 1D barcode patterns using CPU-based Computer Vision techniques. By leveraging the power spectrum of the Two-Dimensional Fourier transform and efficient line detection algorithms, the applied method provides efficient orientation estimates without the need for expensive GPU resources.

Even though the GPU based methods works robust and fast, these methods are sufficient for projects which has not enough budget to have GPUs. Furthermore it is possible to have these methods on low budget CPU devices such as Raspberry Pi. So these methods should be applied for low-budget devices.

These methods clarify that the noise and blur effects can be reduce during the power spectrum filtering. With new filter designs, noise and blur from the barcode images should be removed. Thus, there will be more increase on the accuracy estimation of the orientation.

Another important subject is the size of the images. Providing a robust resize method for image frames, will lead shorter execution time.

Last but not least, a new algorithm may be beneficial to decide which part of the barcode images that these methods will work on. This will increase both speed and accuracy of the project.

References

[1] https://pypi.org/project/zbar/

[2] https://www.arducam.com/product/arducam-full-hd-color-global-shutter-camera-for-raspberry-pi-2-3mp-ar0234-wide-angle-pivariety-camera-module-b0353/