Development of a Novel Fast Rotation Angle Detection Algorithm using a Quasi-Rotation Invariant Feature Based on Sobel Edge

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***Abstract*—In this paper, we proposed a fast algorithm to detect a rotated angle of a High Definition (HD) image that features an overall framed image without using a multiple iteration like the trigonometric function. The well-known method, the Coordinate Rotation Digital Computer (CORDIC) involves a simple shift-addition iterative procedure to perform rotation angle detection, which uses between two points only, causing an inefficient operation to process a certain image. In our algorithm, Sobel edge is used as a pre-process to simplify the information on the image in a gray scale form. Then, a binary conversion of the extracted image in a 1×n set of points that only depend on an angle of distribution on the same radius from the center of the image in an extreme line of the circular boundary. The set of features of the original and the rotated image, the rotation angle is evaluated for comparison. The detectable angle is limited only to an angle below 9 degrees in the side of its accuracy, but the execution time is about 11 times much faster in comparison to the method of rotation matrix based on CORDIC. It was simulated using Matlab R2012a and the testing environment was based on Intel Core i5 3.3GHz CPU.**

***Index Terms*—Rotation Angle Detection; Digital Image Process; Quasi Rotation Invariant Feature.**

I. INTRODUCTION

In the recent research of real time process for computer vision, designing effective recognition is a major issue. It plays a significant role in a wide range of applications that include Advanced Driver Assistance System (ADAS), such as the application that requires fast process time to materialize the prevention of an unexpected danger by analyzing various objects, such as traffic lanes, traffic signage, vehicles and pedestrians in real time approach [1-6]. In a moving vehicle on an unstable road condition, a camera is attached to the vehicle to capture translational motion as well as its physical features. If the image is immediately corrected in a certain rotation, it leads to a more efficient result that recognizes the object, which will limit the latency of the system. Therefore, a rotated angle effective with an appropriate processing speed is much needed for the implementation of rotation correction.

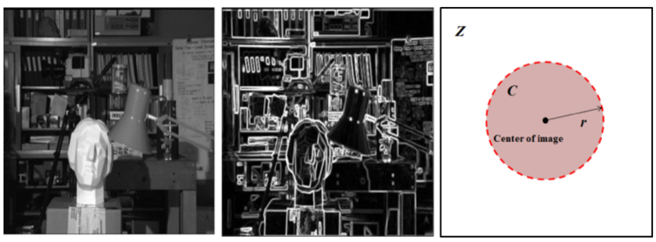
Coordinate Rotation Digital Computer (CORDIC) is a conventional hardware approach described by J. E Volder [7] to detect the angle between two points with simple iteration calculation. It is capable of computing complex function, such as trigonometric that is being used for various real time approaches in the placement calculation of mobile robot [8], image processing and communication systems [9], and computational neuroscience [10]. Besides, a basic design of reconfigurable CORDIC based on a unified CORDIC [11] has been not proposed recently [12,13] to involve high reconfiguration overhead and results in low hardware utilization efficiency. There are also methods to reduce its computational latency by minimizing the critical timing [9,14] and reducing number of iterations [15]. However, in spite of many improved researches above, CORDIC requires longer processing time in calculating much information for High Definition (HD) images that match the points from the rotated points. To compensate these disadvantages, we introduced a novel algorithm that is suitable to compute rotated angle of the HD images by extracting the features of overall image with simpler computation process without trigonometric function.

This paper is organized as follows. Section II discusses the initial input images in a concise manner on a gray scale based on Sobel edge algorithm as one of the most popular methods to form basic feature of the image. In Section III, the experimental results show the analysis of accuracy and its execution time. Finally, Section IV concludes this paper.

II. MODIFICATION OF IMAGE PROCESSING

A. *Sobel Process*

An image processing starts with Sobel edge of gray scale image, a popular edge detection method to simplify features of objects. It computes the approximation of the gradient of the image intensity as the function of discrete differentiation operator. The Sobel algorithm [16] has used various applications and our algorithm has the advantage of compatibility in using it in pre-processing of pattern recognition.



(a) (b) (c)

Figure 1: Extraction of (b) Sobel edge image from (a) gray scale image. (c) sub-region boundary

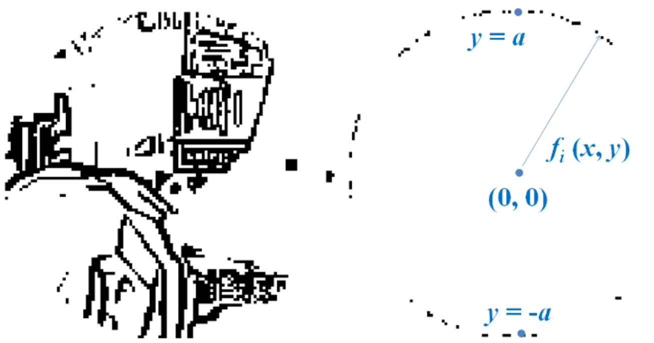
Gray scale image of Casted Plaster is extracted using Sobel image, as shown in Figure 1(b) with two operators of horizontal A_x and vertical direction A_y of Equation (1).

$$A_x = \begin{pmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{pmatrix}, \quad A_y = \begin{pmatrix} -1 & -2 & 1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{pmatrix} \tag{1}$$

B. Binary Conversion Process

The Sobel processed image has a lot of information and is difficult to assure the features for rotation detection that has the scale between 0 and 255 pixels. The image will be processed on the extraction of the sub-region from a center of image in the Casted Plaster as shown in Figure 1(c). The features of the image should be maintained by comparing the original image for the rotated image with the arbitrary angle as having the rotation invariant (RI) property. Further, the circular boundary is the needed segment to extract its features on the rotation axis. We assume that the rotation axis is the center of the image, as shown in Figure 1. On the other hand, the variable C represents a collection of pixel points in a circular boundary, and region Z consists of a set of points for the total area of Casted Plaster. If an image rotates with some angles, the points in the region C are still covered by the bounded region.

In Figure 1(b), it shows that the Sobel processed image still consists of many points with gray scale values from 0 to 255, making it difficult to analyze the rotation angle. Thereby, Figure 2(a) shows the binary conversion image with the value of either 0 or 1 only from the Sobel edge of Figure 1(a) on the circular boundary of Figure 1(c). Its threshold level is set as 127 as one half the value of the gray scale between 0 and 255 pixels.



(a) (b)

Figure 2: (a) Binary conversion image from the Sobel edge, (b) a set of the points from polar boundary from (a).

C. Extraction of Image Features for Rotation Invariant

If the image f_{Image} of Figure 1(a) is rotated and results in the f'_{Image} with an arbitrary angle θ, it will be defined as a rotation matrix $\hat{R}$ as shown below.

$$\hat{R} f_{\text{Image}} = f'_{\text{Image}} \left(\hat{R} = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \right) \tag{2}$$

Normally, in detecting the rotated angle, each components of f_{Image} should fall in the category of a rotated angle between 0 to 360 degrees, and the rotated angle should have a matched value by counting the components between the original image and the rotated image. Further, its rotation was calculated using the trigonometric function of CORDIC method [7-15]. However, it is not appropriate to detect the rotation angle of HD image especially in real time application, because it consists of multiple iteration process. So, we proposed a novel rotation detection method to minimize the tedious process without complex calculation or much iteration processes.

As shown in Figure 2(a), the binary process is still difficult to apply directly in the rotation angle detection due to various unintended neighboring sampled points. In spite of the rotation of the image, the original features of the image should be maintained with RI property. Also, it needs an additional filtering method to extract the points that have a binary value only of 1 for red colored dotted line of the circular boundary of Figure 1(c) and, the result of Casted Plaster is represented as shown in Figure 2(b). The points can be summarized as a set f_{RI} as shown in Equation (3).

$$f_{\text{RI}} = \{ f_0, f_1, f_2, \ldots f_{2a}, \ldots f_{4a-1} \} \tag{3}$$

The first component f_0 as a set f_{RI} is located at $x=a$, $y=0$ in the origin of the image, and the rest of the components are arranged in a clockwise direction from f_0.; 'a' is the radius of sub-region C. This can be expressed as Equation (4) from Equation (2).

$$\hat{R} f_{\text{RI}} = f'_{\text{RI}} \tag{4}$$

D. Novel Rotation Detection Method from the Rotation Invariant Feature

It is inefficient to detect the rotated angle of the image by computing in rotation matrix from Equation (4). Let us consider a $4a \times 4a$ cyclic permutation matrix $\hat{P}$ to modify the formula in a simpler method. The matrix $\hat{P}$ is only limited to a clockwise direction for detection of positive angle. The negative angle, the matrix should be transformed to an inverse matrix.

$$\hat{P} = \begin{pmatrix} 0 & 0 & \cdots & 0 & 1 \\ 1 & 0 & \ldots & 0 & 0 \\ 0 & \ddots & \ddots & \vdots & \vdots \\ \vdots & \ddots & \ddots & 0 & 0 \\ 0 & \ldots & 0 & 1 & 0 \end{pmatrix} \tag{5}$$

Although the permutation matrix of Equation (5) can be replaced as Equation (6) with the power of α which corresponds to the rotation angle; α is the positive integer value. In the case of a negative angle, α is the negative integer value.

$$\hat{P}^{\alpha} f_{\text{RI}} = f'_{\text{RI}} \tag{6}$$

In a condition of α=1, the components of f_{RI} can be shown in a motion of one cyclic shift from $f_0, f_1, f_2, \ldots f_{2a}, \ldots f_{4a-1}$ to $f_{4a-1}, f_0, f_1, f_2, \ldots f_{2a}, \ldots f_{4a-2}$. This is a better approach without the complexity of calculation, including the trigonometric function or a multiple iteration process for certain angle detection in the various points of the image. The rotation angle is obtained θ_r through the product of the values of α by n from Equation. (7).

$$\theta_r = n\alpha \tag{7}$$

When the radius a for Figure 2(b) is 57, the cyclic shift of 1 pixel (α=1) is approximately equal to the rotated angle of 1 degree (n=1). The parameter 'n' means that it is rotated to an angle in a one cyclic shift set. On the other hand, to detect the condition of $\hat{P}^{\alpha} f_{\text{RI}} - f'_{\text{RI}} = 0$, variable α should be circulated from 0 to $4a$-1. This circulation calculation is only once to match the two sets between $\hat{P}^{\alpha} f_{\text{RI}}$ and f'_{RI}.

While the rotation matrix includes the CORDIC algorithm, it requires a multiple iteration process [7-15] to detect only one pixel, and it should carry out an uncountable repetitive task on the HD image.

Additionally, with a wider boundary, the rotation angle can be divided into more precise rotation angle. However, the smaller boundary is much limited to detect a rotation angle.

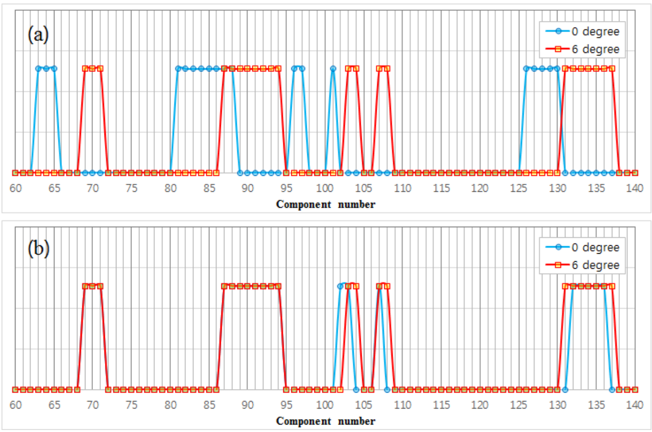


Figure 3; (a) f_{RI} histogram of Casted Plaster from the original image and 6 degree rotated image, (b) the matched result for condition of α =6 at f_{RI} with f'_{RI}.

Figure 3 shows the f_{RI} histogram of the Casted Plaster with the partial result of histogram of a 6-degree rotated image by comparing it to its original image in an angle ranging between 60 and 140 degrees from Figure 1(a). It means that the center of the image or the rotation axis for image rotation is represented by the original point. It was well matched with the cyclic shift of α = 6 that is represented in a blue and red line segment respectively, as shown in Figure 3(b). While the other features under the set of f_{RI} can be verified in a stable condition that maintains the feature f'_{RI} of this rotated image. However, for this specific α value in a cyclic shift, Equation (7) does not compensated those equivalent to a zero value with non-matched region ranging from 100 to 110 and also from 130 to 140. This non-matching phenomenon is basically caused by Sobel edge that is only affected on vertical and horizontal direction of the image without any diagonal directions. Thus, this feature shows quasi RI property for image rotation, that could involve in partial abnormal points in comparing it with the original image. The feature of the rotation angle should not be compensated with α condition of Equation (7). As a result, the relationship of Equation (6) should be transformed to satisfy the minimum value of Sum of Absolute Difference (SAD) for cyclic shift of α order between f_{RI} and f'_{RI}.

III. Experimental Results

The proposed algorithm was evaluated using various samples in 90 images with window size of 256 × 256 as shown in Figure 4.

Figure 5 shows the box plot results of the rotation detection our proposed algorithm with various rotated samples of angles 3, 6, 9, 12, 15 and 20 degrees. Further, on the samples, the average values of rotated angles of 3, 6, 9, 12, 15, and 20 degree individual are 3, 5.9, 8.8, 11.5, 14.4, and 19.1, respectively. Aside from 3 degrees, all samples are exactly matched to the target area. Further, the results has a ±1 degree tolerance below on an angle difference from the target angle both for 6 degrees and 9 degrees. However, beyond 9 degrees, the distributions are gradually increasing with increasing angles. There are two problems about accuracy decrease. The one is Sobel edge effect, the angle is getting wider on the region of 1st and 3rd percentile of the box plot, as it does not depend on diagonal properties of the image but rather only on the horizontal and vertical directions. On the other hand, Sobel image of the rotated image is slightly distorted: When comparing with the original image, and with wider angle rotation, the distortion tends to increase more. The second drawback is that it relates to the circular boundary as shown in Figure 1(c). We assumed that the angle difference of components between f_i and f_{i+1} is approximately to 1 degree with the boundary of a = 57 to make a 1 degree cyclic shift. However, each angle points is not corresponded exactly to an integer angle value. Thereby, as the angle becomes wider, the distribution is getting worse until it approaches to the segment of π/4 angle, in which it will then decrease symmetrically between π/4 and π/2. Moreover, for an angle wider that of 9 degrees, it will decrease the accuracy with the non-matching points caused by Sobel edge about rotated image. The results show that if Sobel edge of rotated image is modified as having RI property without image distortion in comparison of the original image, the accuracy can be improved compared to the result of Figure 5.

Figure 4: 90 sample images with sizes of 256 × 256

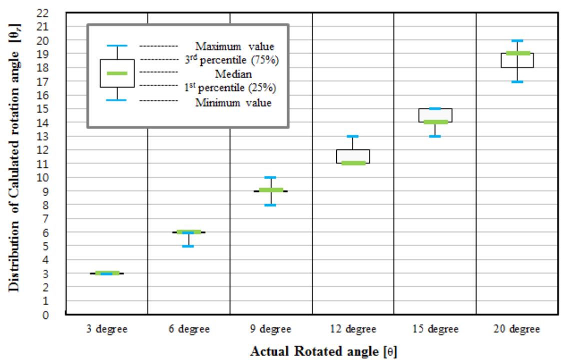


Figure 5: Box plot results of polar histogram for a 3, 6, 9, 12, 15, and 20 degree

With this result, the detectable angle of our proposed algorithm is limited only below 9 degrees with an error distribution condition of ±1 degree. But, in real time application it can process 180 degrees with an assumption of 20 frames per second.

Table 1
Average Speed of algorithms (millisecond)

Algorithm	Matlab
Rotation matrix (CORDIC)	143
Proposed algorithm	12

The measured relative execution time of our proposed algorithm and the rotation matrix method are shown in Table 1. The sample size did not changed after the Sobel edge extraction, as shown in Figure 4. Matlab R2012a was utilized to validate the execution time of the proposed algorithm in the environment of Intel Core i5 3.3 GHz CPU. In the case of the rotation matrix, the matching of the two sets between the original image and the rotated image needed a trigonometric function process to compute using CORDIC [7], which is extracted using gray scale image as shown in Figure 1(a) with threshold value of 125 without Sobel edge. The execution time is about 19 times faster compared to the rotation matrix. It shows that this result uses only one calculation process from a quasi-rotation invariant feature for the overall image in detecting the angle without involving too much iteration process. However, CORDIC requires more in computing the rotated angle of all points in the sample image. In actual scenario, there are several advances in the field of CORDIC [7-15]. The iteration process should basically guaranteed to detect the exact rotated angle, and it shows to reduce the iteration to $(3n/8)+1$ for n bit precision, including the scale factor calculation and compensation in hardware approach method[9]. However, the improved iteration results in the execution calculation estimated over 53 ms from the results as shown in Table 1, with an n iteration of the same environment.

In spite of the fast process speed, our proposed algorithm could be vulnerable to noise, because the means rotation axis is changed from the original rotation axis. In real time process of moving camera, the rotation axis might be possible to infinitesimally shift in frame to frame scheme. Our proposed algorithm consists of the sets of RI features about an angle θ only, the noise is caused by a too low accuracy because it does not dependent on distance. If a set is included to a two-feature both angle θ and distance r property, it will improve its noise tolerance.

IV. CONCLUSION

In this paper, we proposed a novel algorithm to detect an angle of rotated image. This approach is realized by using a quasi-rotation invariant feature of overall image which is only dependent on angle θ without involving any complexity in calculation or too much iteration process. It is more efficient to detect the rotation angle of HD image because of a faster processing rate. It is verified to the rotation angle detection with a limitation of 9 degrees with the error distribution condition of ±1 degree, it has no effects with Sobel edge algorithm. Further, the execution processing time is 11 times faster in comparison to the rotation matrix method based on CORDIC, our algorithm is expected to be feasible enough to be applied in real time.

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REFERENCES

[1] J. C. McCall, M. M. Trivedi, Video-Based Lane Estimation and Tracking for Driver Assistance: Survey, System, and Evaluation, IEEE Trans. Intel. Trans. Syst. 7(2006) 20-37.

[2] D. Kim, S. Moon, J. Park, H. Kim, K. Yi, Design of an Adaptive Cruise Control / Collision Avoidance with Lane Change Support for Vehicle Autonomous Driving, ICROS-SICE International Joint Conference, Fukuoka, Japan, (2009) 2938-2943.

[3] K. Shimura, K. ohtsuka, G. Vizzari, K. Nishinari, S. Bandini, Mobility analysis of the aged pedestrians by experiment and simulation, Patt. Recognit. Lett. 44(2014) 58-63.

[4] L. Oliverira, U. Nunes, Context-aware Pedestrian Detection Using LIDAR, IEEE Intelligent Vehicles Symposium University of California, San Diego, USA, (2010) 773-778.

[5] V. A. Butakov and P. Ioannou, Personalized Driver/Vehicle Lane Change Models for ADAS, IEEE Trans. Vehicular Tech., 64 (2015).

[6] C. Guo, J. Meguro, Y. Kojima, and T. Naito, A Multimodal ADAS System for Unmarked Urban Scenarios Based on Road Context Understanding, IEEE Trans. Intel. Trans. Syst., 16 (2015).

[7] J. E. Volder, The CORDIC Computing Technique, IRE Trans. Electron. Comput, vol. EC-8, 3 (1959) 330-334.

[8] P. Vyas, L. Vachhani, K. Sridharan, and V. Pudi, CORDIC-Based Azimuth Calculation and Obstacle Tracing via Optimal Sensor Placement on a Mobile Robot, IEEE Trans. Mechatronics, 21 (2016).

[9] R. Shukla and K. C. Ray, Low Latency Hybrid CORDIC Algorithm, IEEE Trans. Computers, 63 (2014).

[10] M. Heidarpour, A. Ahmadi, and R. Rashidzadeh, A CORDIC Based Digital hardware For Adaptive Exponential Integrate and Fire Neuron, IEEE Trans. Circuits and Syst., 63 (2016).

[11] J. S. Walther, A unified algorithm for elementary functions, in Proc. 38th Spring Joint Comput. Conf., Atlantic City, NJ, USA, (1971) 379-385.

[12] S. Aggarwal and P. K Meher, Reconfigurable CORDIC architectures for multi-mode and multi-trajectory operations, in Proc. IEEE ISCAS, Jun. (2014) 2490-2494.

[13] S. Aggarwal and P. K Meher, and, K. Khare, Concept, Design, and Implementation of Reconfigurable CORDIC, IEEE Trans, Very Large Scale Itegr. (VLSI) Syst. 24 (2016).

[14] B. Lakshmi and A.S. Dhar, Low Latency VLSI Architecture for the Radix-4 CORDIC Algorithm," IEEE Region 10 Colloquium and the 3rd Int'l Conf. Industrial and Information Systems (ICIIS), Kharagpur, India, (2008) 1-5.

[15] D.S. Phatak, Double Step Branching CORDIC: A New Algorithm for Fast Sine and Cosine Generation," IEEE Trans. Computers, 47 (1998) 587-602.

[16] K. Nick and N. Vasanthavvada, R. L. Baker, Design Image Edge Detection Filter Using the Sobel Operator, 23 (1988).