A Method for Rectifying Inclination of Panoramic Images

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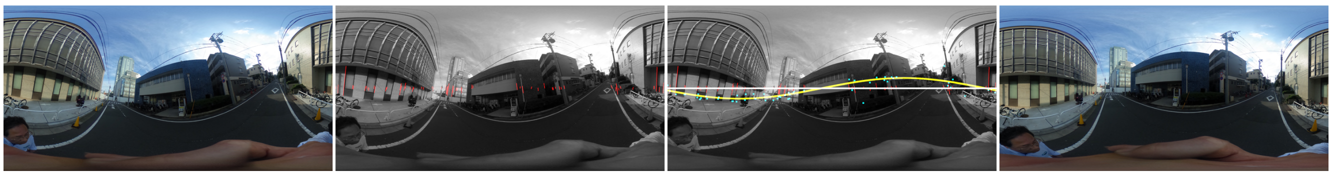

Figure 1: An experimental result: a) inclined panorama, b) extracted segments, c) estimated curve, d) rectified panorama.

ABSTRACT

We propose a method for transforming inclined panoramic images into upright posture as if they were captured up straight. The method rectifies images automatically using neither additional information nor external instructions, while it enables panoramic images of both indoor and outdoor scenes to stand upright robustly. It helps unskilled people to make high quality panoramic images used for widespread applications including city navigation and real estate easier.

CCS CONCEPTS

• **Computing methodologies → Image processing**; *Image-based rendering*; *Virtual reality*.

KEYWORDS

panoramic image, image correction

ACM Reference Format:

Naoki Kawai. 2019. A Method for Rectifying Inclination of Panoramic Images. In *Proceedings of SIGGRAPH '19 Posters.* ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3306214.3338558

1 INTRODUCTION

Image based VR systems using panoramic images [Chen 1995] such as Google Street View [Anguelov et al. 2010] and many other applications have been used on a daily basis. Several omnidirectional cameras have been on sale recently, and they have enabled consumers to take panoramic pictures as easily as taking photos using standard cameras or smartphones. However, it is still difficult to take panoramic images in an exactly vertical posture, and inclined panoramas reduce the quality of VR applications. Although it is possible to rectify the inclination by manual operations as well as by inverse transformation of the camera posture recorded by acceleration sensors, it is desirable to stand images upright using neither external data nor hand-operation. Although [Jung et al. 2017] presented a method for rectifying panoramic images to be upright, the results still contain measurable errors. We propose a method for rectifying panoramic images more accurately.

2 METHOD

The inclination of panoramic images originates in the posture of the camera identified by the angle from the vertical direction and the axis of rotation. Therefore the inclination can be canceled by inverse transformation if we know the angle and the axis. The scenes include many vertical structures which appear as vertical lines in equirectangular projection if they were captured vertically. However, their gradient[1] varies according to the location due to the inclined camera posture. We analyze such distribution of gradient to find the angle and the axis of the rotation.

2.1 Overview

Figure2 illustrates the outline of the entire process. The process consists of three steps: extracting segments, estimating rotation, and image correction.

2.2 Extracting Vertical Structures

The method first detects edges by applying Canny edge detector over the image. As extracted edges are just a collection of pixels, we next convert them into representation which is suitable for analyzing the posture. We call this representation segments. We pay attention to the segments which originate in vertical structures and are located on a centered horizontal line.

The method applies connected-component analysis on detected pixels to make a set of connected-components. Because the components appear over the image regardless of their location, shape and direction, they include edges on ceilings and floors, or textures which prevent us from analyzing the inclination. We eliminate undesirable components under the conditions listed below.

- eliminate components NOT located on a centered horizontal line.

[1] We define a gradient of a line as an angle from vertical direction of the image.

SIGGRAPH '19 Posters, July 28 - August 01, 2019, Los Angeles, CA, USA

ACM ISBN 978-1-4503-6314-3/19/07.
https://doi.org/10.1145/3306214.3338558

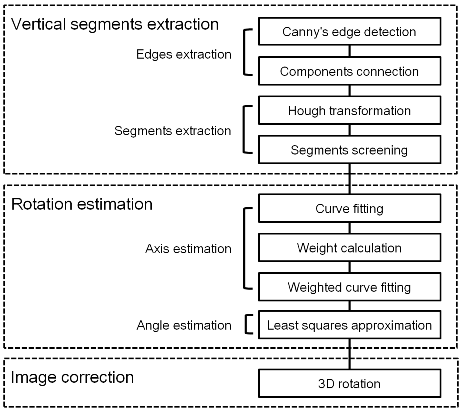

Figure 2: Process overview.

- eliminate components with a large gradient.
- eliminate components consisting of a small numbers of pixels.

The first condition eliminates edges on ceilings and floors and keeps only vertical structures beside the horizon. It is based on an assumption that edges of vertical structures standing on floors or on the ground pass a centered horizontal line of the equirectangular image if the inclination was relatively small. The second condition eliminates edges in an inappropriate direction other than almost vertical ones. Each component is previously approximated to a line segment using Hough transform to evaluate its gradient. The last condition eliminates tiny fragments. They have an inaccurate gradient due to spacial discreteness which disturbs subsequent analysis. Thus the edges are screened and each of those remaining is represented as a segment identified by its location and gradient. An example of a set of screened segments is shown in Figure1 b).

2.3 Estimating Rotation

The arrangement of selected segments shows that their gradient swings left and right once along the centered horizontal line. Since the horizontal location in equirectangular images indicates an azimuth in the scene, a series of gradients can be assumed as a periodic function of azimuth. Once the function is estimated, its phase, namely, the location where the maximum gradient appears indicates the axis of the camera rotation. Alternatively, the amplitude of the function, namely, the maximum gradient indicates the rotation angle of the camera. The method fits a simple cosine curve described in equation (1) to gradient $g(x)$ at horizontal location x.

$$g(x) = A\cos\left(\frac{2\pi x}{W} - \phi\right) \tag{1}$$

The cycle of the function is equal to the width of the image W, and we need to estimate the unknown amplitude A and phase ϕ. The method estimates them by means of weighted least squares approximation which applies least squares approximation twice. The first approximation accumulates the squared error between $g(x)$ at the segment location x and gradient the segment actually has while changing both A and ϕ gradually, to find the combination of A and ϕ which has the minimum accumulated value. Since outliers decrease accuracy of the curve fitting, the method introduces weight ω to reduce the influence from outliers. A weight ω for each segment is defined as:

$$\omega = \begin{cases} \left\{1 - \left(\frac{d}{\Omega}\right)^2\right\}^2 & (|d| < \Omega) \\ 0 & (|d| > \Omega) \end{cases} \tag{2}$$

where d denotes the error between estimated function and the actual gradient the segment has, and Ω denotes the predefined allowance. The method applies least squares approximation over again, while multiplying ω this time to improve the curve fitting. Figure 1 c) shows the fitted cosine curve with the gradient of each segment plotted as cyan dots.

Since a simple cosine function is different from the actual gradient behavior, the estimated amplitude will be incorrect while the phase can be estimated correctly. Therefore the method takes only phase ϕ and uses it to estimate a reliable rotation angle α by weighted least squares approximation once again. A segment can be rotated in three-dimensional space by a specific angle α around the axis directs to ϕ. This time, the method accumulates the squared gradient of rotated segments while changing α, and finds α that minimizes the accumulated gradient.

2.4 Correcting Image

The location of each pixel in an equirectangular projection and its three-dimensional direction can be converted mutually, and the method rotates the entire image by α around the axis directs to ϕ in three-dimensional space. Each pixel in the destination image searches the corresponding location in the original image by applying inverse transformation of the estimated rotation, and obtains its color from the original pixel.

3 RESULT AND CONCLUSIONS

We took 20 indoor and 20 outdoor scenes as panoramic images using RICOH THETA S in hand, and tested the proposed method with them. The method rectifies all the sample images properly. We also found repeating the method improves the accuracy. Figure 1 d) shows a result after applying the proposed method twice on Figure 1 a). The maximum gradient of vertical structures in the original images ranges from 6 to 20 degrees and averages 11.4 degrees. The method reduced the maximum gradient to 1.7 and 0.7 degrees on average, by applying the method once and twice respectively. The results show that our method works more accurately than the previous method [Jung et al. 2017] which leaves 1.29 degrees on average after almost 4 iterations.

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