Madali: Structured Light Scanning

Wednesday, February 10, 2021 3:39 PM

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Traditional cameras and image sensors can only obtain two-dimensional images, lacking depth information, which imposes great limitations on the perception and understanding of real objects. In recent decades, with the continuous development of high-definition, high-speed image sensors and computing capabilities, three-dimensional surface imaging technology has achieved remarkable results in research, engineering, and business. In particular, the structured light three-dimensional surface imaging technology has been applied to various places.

For every major visual effects movie, the principal actors' bodies and heads are scanned before or during production using the types of scanners. The resulting 3D scans are used to build digital stunt doubles for actors, to aid in creating realistic aging transformations, or to provide a starting point for morphing into a computer-generated creature.

The principle of structured light scanning. The object is illuminated with a plane of light that intersects the surface of the object as a deformed stripe, which is observed by an offset camera. The projector and camera are accurately calibrated so that 3D locations can be recovered by triangulation. Source

Projecting a narrow band of light across three dimensions in the shape of a surface produces a line of illumination that appears distorted from perspectives other than that of the projector and can be used for an exact geometric reconstruction of the surface shape.

A faster and more versatile method is the projection of patterns consisting of many stripes at once, or of arbitrary fringes.A sinusoidal fringe is generated by computer programming, and the sinusoidal fringe is projected to the object to be measured through a projection device. The camera is used to capture the degree of curvature of the fringe modulated by the object, the pattern appears geometrically distorted due to the surface shape of the object.

This article mainly describes the principle and implementation of the three-dimensional surface imaging technology of light-composition, especially the phase measuring profilometry (PMP).

Compared with encoding structured light methods such as Binary code and Gray code, PMP does not require complex encoding, and the algorithm can calculate the height value according to the information of each pixel, so as to achieve full-scale high-precision measurement. In the phase method, the following steps are usually included :

1. Project a structured texture image (usually a sinusoidal grating pattern) onto the surface of the object to be measured.
2. Record raster images phase-modulated by the height of the object.
3. Use grating analysis technology to extract the phase.
4. Use a suitable phase unwrapping algorithm to obtain a continuous phase distribution that changes in proportion to the height of the object.
5. The calibration system maps the expanded phase distribution to the real-world three-dimensional coordinate system.

Generation of Sinusoidal Pattern

Phase measurement profilometry needs to project sinusoidal grating patterns with different phases onto the surface of the object.

The LCD projector can use a personal computer to control the projected image. The sinusoidal grating image is generated by projection software, which provides an efficient structured light projection scheme. We assume that the resolution of the LCD projector is ***R x C.*** For each column c in the generated sinusoidal grating image, ***c=0,1,2,...,C-1***, there are:

[illegible]

F_{n}(r,c) is the pixel value at (r,c) in the raster image after phase shifting k steps. In our example, k={1,2,3 ,4}, p is the grating period in pixels, δ is the phase shift increment.Figure below shows the sinusoidal raster images generated by the software.

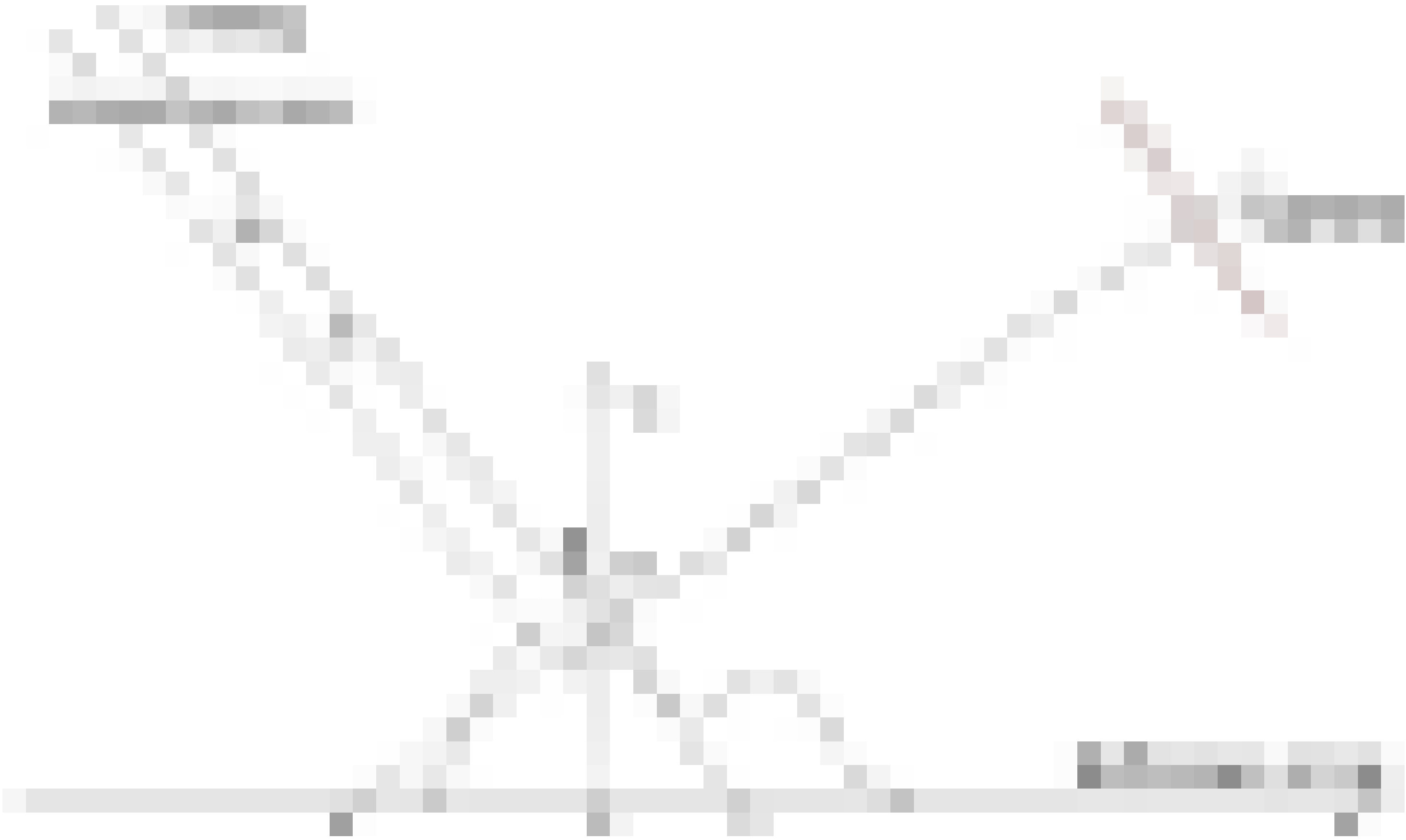
Each image is shifted by a quarter of a period to the right from the previous image. Image By Author

Phase Measuring Profilometry

The sinusoidal grating image generated by the projection module is projected onto the surface of the object placed on the reference plane, and the refracted light is captured by the image acquisition module (Camera).

The following figure shows the picture when 4 sine grating images with different phases are projected onto the surface of the object using the phase shift method when k=4..Image By Author

Since the projected sinogram changes in the same pattern in the column direction, the contour of the object can be constructed by the calculation results of each row.



[Source](#)

We assume that point O is the intersection of the optical axis and the reference plane, point O is used as the origin of the coordinate and the phase is 0.

The period of the sine grating image projected on the reference plane is **p_{o}**, the period of the original sine grating image is

$$p = p_o \cdot \cos\alpha$$

The sensor in the camera receives the light reflected at point **D** on the surface of the object, if there is no object, the same position in the sensor will receive the light reflected at point **C** on the reference plane. Correspondingly, the light refracted at point **D** on the surface of the object is the same as the light refracted at point **G** on the horizontal plane without an object. So the phase of the projected image at point **D** is equal to the phase at point G, and there are:

$$\phi_D = \phi_G$$

Where,

$$\phi_C = 2\pi OC/p_o$$

Is the phase value of the projected image at point C.

The phase difference between point D and point C is:

[illegible]

According to the geometric relationship, we get:

[illegible]

According to the above formula , we get:

[illegible]

OD is the height of the object at point O.

The general formula is:

[illegible]

Where,ϕo(x,y) is the phase at the point (x,y), and ϕr(x,y) is the phase on the reference plane at the corresponding point.

Phase Shift Profilometry

When the light is stable and the Camera is linear, the light intensity I(x,y) at a certain point (x,y) in the captured image can be expressed as the following formula :

[illegible]

Where,B(x,y) is the background light intensity, C(x,y) is the amplitude value of the sinusoidal grating, and ϕ(x,y) is the phase value modulated by the height of the object.

I(x,y) can be obtained by camera. In order to eliminate the B(x,y) and C(x,y) in the formula and get ϕ(x,y), we use aphase extraction algorithm called the phase shift method.

In the phase shift method, the phase will be moved k times, each time the same value is θ_{k}. The formula \ref{eq:2.6} can be written as:

[illegible]

Let,

[redacted]

Substitute in the above formula, we can get:

And,

So we get the phase value:

Then the surface height of the object can be calculated

The phase shift method uses the light intensity information of multiple images to calculate the phase of each point, so it has a certain anti-noise ability. But in the sampling process, the object is required to remain still, so it is not suitable for dynamic measurement.

Phase Unwrapping

At this time, the final continuous phase is not what we want, because the phase obtained by the phase shift technique is an inverse tangent function, so the original phase will be compressed in between [-π/2,π/2] with a period of π .

Thus there will appear repeatedly π gap wrapped phase map, and the removal of these drops it is called phase unwrapping technique.

According to Shannon's sampling theorem, in the correct two-dimensional phase distribution, the absolute value of the phase difference between each point and any point adjacent to it must be less than π to avoid aliasing. Therefore, when the phase difference between the reference point and its neighboring point is greater than π, phase unwrapping is required, and a value of ±2π needs to be added so that a continuous phase distribution can be obtained. This is the basic theory of phase unwrapping.

(a) One-dimensional phase distribution diagram, the phase value will be limited to 2π modulus. (b) After judging, add an integer multiple of the period 2π at each phase jump to obtain a continuously distributed phase map.

Generally, a two-dimensional phase expansion method can be expressed as the following formula:

[illegible]

Where, $\boldsymbol{\phi}$ represents the phase value after expansion, $\phi(x,y)$ represents the phase value in the original 2π modulus,ϕ_0 represents the phase value of the reference neighboring point, and Round[x] represents the integer value closest to x.

This basic rule is only applicable to phase diagrams with small noise and no inconsistency. Once the noise increases or there is discontinuity in the phase itself , resulting in discontinuities.

Conclusion

This lesson covers the basic, low-level operations and tools of image processing, which are necessary for understanding most of the commonly used methods and tools of computer vision

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