Depth Detection Through Interpolation Functions

A New Method

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ABSTRACT

There are some different methods used for depth perception. In this paper, a new method for the depth perception, by using a single camera based on an interpolation, is introduced. In order to find the parameters of the interpolation function, a set of lines with predefined distance from camera is used, and then the distance of each line from the bottom edge of the picture (as the origin line) is calculated. The results of implementation of this method show higher accuracy and less computation complexity with respect to the other methods. Moreover, two famous interpolation functions namely, Lagrange and Divided Difference are compared in terms of their computational complexity and accuracy in depth detection by using a single camera.

Keywords

Depth detection, Camera, Lagrange Interpolation, Divided Difference Interpolation

1. INTRODUCTION

Depth finding by camera and image processing have variant applications, including industry, robots and vehicles navigation and controlling. This issue has been examined from different viewpoints, and a number of researches have conducted some valuable studies in this field. All of the introduced methods can be categorized into six main classes.

The first class includes all methods that are based on using two cameras. These methods origin from the earliest researches in this field that employ the characteristics of human eye functions. In these methods, two separate cameras are stated on a horizontal line with a specified distance from each other and are focused on a particular object. Then the angles between cameras and the horizontal line are measured, and by using triangulation methods, the vertical distance of the object from the line connecting two cameras is calculated. The Main difficulty of these methods is the need to have mechanical moving and the adjustment of the cameras in order to provide proper focusing on the object. Another drawback is the need of the two cameras, which will bring more cost and the system will fail if one of them fails.

The second class emphasize on using a single camera [Con97a]. In these methods, the base of the measurement is the amount of the image resizing in proportion to the camera movement. These methods need to know the main size of the object subjected to distance measurement and the camera's parameters such as the focal length of its lens.

The methods in the third class are used for measuring the distance of the moving targets [Con99a]. In these methods, a camera is mounted on a fixed station. Then the moving object(s) is(are) indicated, based on the four senarios: maximum velocity, small velocity changes, coherent motion, continuous motion. Finally, the distance of the specified target is calculated. The major problem in these methods is the large amount of the necessary calculations.

The fourth class includes the methods which use a sequence of images captured with a single camera for depth perception based on the geometrical model of the object and the camera [Sym00a]. In these methods,

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the results will be approximated. In addition, using these methods for the near field (for the objects near to the camera) is impossible.

The fifth class of algorithms prefer depth finding by using blurred edges in the image [Con88a]. In these cases, the basic framework is as follows: The observed image of an object is modeled as a result of convolving the focused image of the object with a point spread function. This point spread function depends both on the camera parameters and the distance of the object from the camera. The point spread function is considered to be rotationally symmetric (isotropic). The line spread function corresponding to this point spread function is computed from a blurred step-edge. The measure of the spread of the line spread function is estimated from its second central moment. This spread is shown to be related linearly to the inverse of the distance. The constants of this linear relation are determined through a single camera calibration procedure. Having computed the spread, the distance of the object is determined from the linear relation.

In the last class, auxilary devices are used for depth perception. One of such methods uses a laser pointer which three LEDs are placed on its optical axil [Con99b], built in a pen-like device. When a user scans the laser beam over the surface of the object , the camera captures the image of the three spots (one for from the laser, and the others from LEDs), and then the triangulation is carried out using the camera's viewing direction and the optical axil of the laser. The main problem of these methods is the need for the auxilary devices, in addition to the camera, and consequently the raise of the complexity and the cost.

2. PROPOSED METHOD

This new method includes two steps [Con03a]: First, calculating an interpolation function based on the height and the horizontal angle of the camera. Second, using this function to calculate the distance of the object from the camera.

In the first step, named the primitive evaluation phase, the camera is located in a position with a specified height and a horizontal angle. Then from this position, we take a picture from some lines with equal distance from each other. Then, we provide a table in which the first column is the number of pixels counted from each line to the bottom edge of the captured picture (as the origin line), and the second column is the actual distance of that line from the camera position.

Now, by assigning an interpolation method (e.g. Lagrange method) to this table, the related interpolation polynomial is calculated [Mat92a]:

$$f(x) = \sum_{j=0}^{n} f(x_j) L_j(x)$$

$$L_j(x) = \frac{\prod_{i=0, i\neq j}^{n} (x - x_i)}{\prod_{i=0, i\neq j}^{n} (x_j - x_i)} \qquad (1)$$

In this formula, **x** is the distance of the object from the camera, and **n** is the number of considered lines in the evaluation environment in the first step.

In the second step of this method - with the same height and horizontal angle of the camera - the number of the pixels between the bottom edge of the target in the image (the nearest edge of an object in the image to the base of the camera) and the bottom edge of the captured image is counted and considered as **x** values in the interpolation function.

The output of this function will be the real distance between the target in the image and the camera.

This method has some advantages in comparison to the previous methods:

a) Using only a single camera for the depth finding.

b) Having no direct dependency on the camera parameters like focal length and etc.

c) Having uncomplicated calculations.

d) Requiring no auxiliary devices.

d) Having a constant response time, because of having a fixed amount of calculations; so it will be reliable for applications in which the response time is important.

e) The fault of this method for calculating points' distance situated in evaluation domain is too lower.

f) This method can be used for both stationary and moving targets.

However, This method has some limitations such as:

a) The dependency on the camera height and horizontal angle, so that if both or one of them is changed, there will be a need to repeat the first step again.

b) The impracticality of this method for determining the distance of the objects situated out of the evaluation environment (which have been done in the first step).

3. THE RESULT OF EXPERIMENT

In this experiment, some lines are drawn on a uniform surface with 5 cm distance from each other. Then a camera is mounted in a position with 45cm height and 30 degree horizontal angle.

X	34	64	92	114	136	155	173	189	204	218
Y	5	10	15	20	25	30	35	40	45	50
X	232	245	257	268	279	288	297	304	311	319
Y	55	60	65	70	75	80	85	90	95	100

Table1. X is the number of pixels between these lines and the origin line in the captured image and Y is actual distance of lines from camera.

Based on counting the pixels between the image of these lines and the origin line (bottom edge of picture) and considering their actual distance, Table No. 1 has been produced:

Using this table and the Lagrange interpolation formula, a function for distance measurement is defined. Then the distance of some random point is calculated with this function as the following table:

Calculated Distance	36.53	60.78	86.18
Actual Distance	36.5	60.9	85.8
Fault percent	0.8	0.20 %	0.44 %

Table2. Comparison between Actual and Calculated Distance.

As it is realized, this method has more accuracy for measuring the distance of points lay on the primitive environment domain, but out of this domain it is impractical. Considering the properties of this method, it can be used in depth finding systems which have a specified domain, such as the defended systems that react to moving objects in a definite field.

Using this method has no depth limitation provided that the primitive evaluation environment is properly defined. It is needless to say that for increasing the accuracy of the results, the number of lines in the primitive evaluation should be increased.

4. WHY THE LAGRANGE METHOD?

There are two famous interpolation methods: The Lagrange and the Divided difference of Newton [Mat92a]. But for the method proposed above, the Lagrange method has given better results. Because:

1) In the method of the Divided difference of Newton, by adding new points before the first point or after the last point of the table, a few extra operations are needed to correct and adjust the previous interpolation polynomial with the new situation. Whereas, in the Lagrange method, all of the operations must be recommenced.

In our case, this feature is not important. Because, the number of points determined in the evaluation phase and after that time will be constant.

2) Although the fault of both methods is equal, the number of the division operations in the latter method is more than the former.

In the Lagrange method, for n points we need n division operations, but in the Newton method we have n(n-1)/2 of such operations.

As we see, for more than three points (that it will be so) the number of the divisions in Newton case is more than that of the other one. Division causes floating point error as in digital computers, so the faults in the Newton method will be more the faults in the Lagrange method.

3) In Newton method, sometimes useless operations are observed.

The following table can be considered as an example:

x_i	f_i	Δf_i	$\Delta^2 f_i$	$\Delta^3 f_i$	$\Delta^4 f_i$
0	1				
		1			
1	2		2		
		3		0	
2	5		2		0
		5		0	
3	10		2		
		7			
4	17				

Table 3. Useless operations in Newton method

There are five points in this table and it is expected to have a fourth power polynomial as the Newton interpolation function. But really, there is a second power polynomial. So some of the operations will be useless, while in the Lagrange method, the number of operations is fixed and determined.

4) In the Lagrange method, it is possible to have parallel calculations, because the calculation phases are individual. But in the Newton method, each phase needs the result of the previous phase to complete its calculation. Therefore, although the number of operations in the Lagrange interpolation may be, because of parallel processing, more than the Newton one, the total computation time will be less than the second one's.

Reviewing the above reasons, it can be concluded that the Lagrange interpolation method is better than the Newton method in our case.

5. CONCLUSION

The introduced method has some advantages such as simplicity, accuracy, needing no auxiliary devices and no dependency on the camera parameters, compared with the previous methods.

The limitation of this method is the dependency on primitive height and horizontal angle. But the effect of changing these items isn't considerable, and there are some ways to decrease the effect of these faults.

It has also been proved that the Lagrange interpolation method's efficiency is better than the Newton one's in this method.

This method can be used for applications in which more accuracy in a limited domain for depth perception is needed.

6. . REFERENCES

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