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ACCURACY EVALUATION OF OBJECT POSITION DETERMINATION IN THE WORKING AREA OF STERIO RANGE FINDER

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The solution of problem on position determination of moving objects system in operating TV stereo range finder has been shown. The technique of accuracy evaluation in determining their position is described. The results of the method application on the TV stereo range finder model are presented.

Introduction

Range finders are used to determine the distance to the objects [1]. There often appears the problem of applying computer-aided measuring complexes capable of observing area of large size and defining the coordinates of all objects on it. Moreover, objects can move, i. e. their coordinates can change in time. Identification of objects by definite features is also required. Most range finders (laser, optical) need target destination (direction) to the object and allow for simultaneous determination of distance only to one object or a group of objects at a small distance from each other. Besides, they fail to describe the observed object by definite features. Thus, in production of computer-aided measuring complexes for solution of similar problems application of standard range finders appears to be unpractical.

In the complex the problem of defining the coordinates of objects located on the large territory and their identification can be solved on the basis of optical TV stereo range finder operating on the model of human eyes. That is, moving off object from the system consisting of two space-apart TV cameras operating synchronously is defined by the value of object displacement on both images. Accuracy in determination of object coordinates is different for different parts of stereo zone and its value depends on a number of system parameters and object remoteness. Hence, the problem of calculating the error in object coordinate determination in stereo zone and the problem of finding out the boundaries of stereo range finder operation zone with specified accuracy is posed.

Method of object coordinates calculation

Let us consider geometrical model of the system shown in Fig. 1, consisting of intersections of central optical planes of both cameras lenses. In Figure the main parameters of the system described are indicated, where L is the base, i. e. the distance between optical centres of two cameras lenses, H is the distance between the base line and the crosspoint of optical axes of video camera lenses, Au is the pickup angle of camera lenses. The pickup angle of camera lens Au consists of n elementary angles corresponding to pickup angle of each pixel of the accepted image. To make it visual, in the Figure the pickup angle of the lens Au is divided into just three elementary angles, which for processed image correspond to resolution across the width of three pixels. It is seen in the model that at some optical axes convergence of camera lenses to each other the elementary pickup angles of camera lenses intersects forming a common visual zone (stereo zone), like convergence of visual axes of human eyes. The result of intersection of each elementary angle is a quadrilateral and in Figure (Fig. 1) has its shading. In general the whole stereo zone is divided into elementary quadrilaterals.

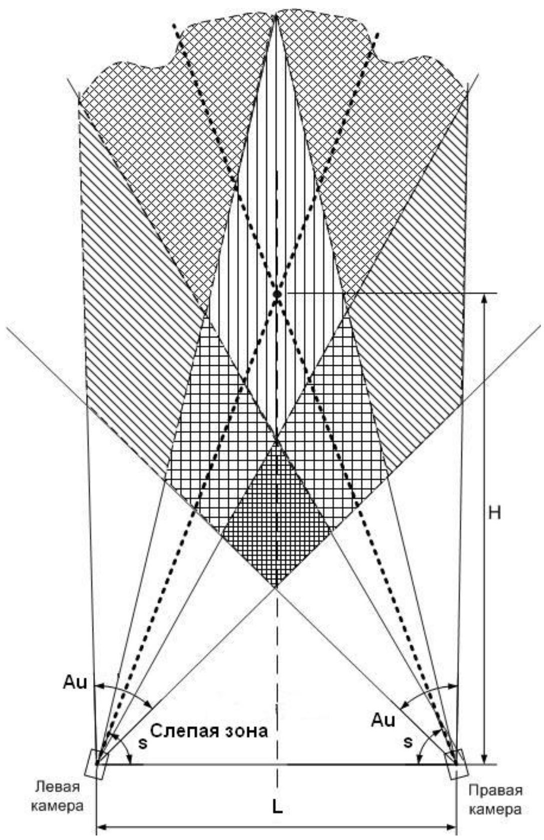

Fig. 1. *Simplified geometrical model of the system*

Besides, in calculations the following significant system parameters are taken into account: Res is the number of image pixels in width; $Nc1$, $Nc2$ are the numbers of image pixels along the axis X defining the position of the sought for object. Real TV cameras have width resolution equal to 640 pixels. Consequently, in fact, the pickup angle of the lens for each TV camera is divided into 640 elementary angles, but magnitudes of $Nc1$, $Nc2$ can take the values from 1 to 640. We can conclude that if the observed object is in stereo zone, it is in the images obtained from both cameras and its coordinates are localised in one or several neighbourhood elementary quadrilaterals. Geometrical sizes of the concrete quadrilateral limit the accuracy of object coordinate determination by TV stereo range finder. In other words, distance to the object can be defined if the basic geometrical parameters of the system and the numbers of pixels, which contain the image of the object, are known. Since the elementary quadrilateral is perceived by the camera as one image pixel, the coordinate of the object in stereo zone are equal to those of the centre of the elementary quadrilateral, but the error of coordinate measurement will be in the range of projection half-length of this quadrilateral on the axis X (displacement) and the axis Y (distance).

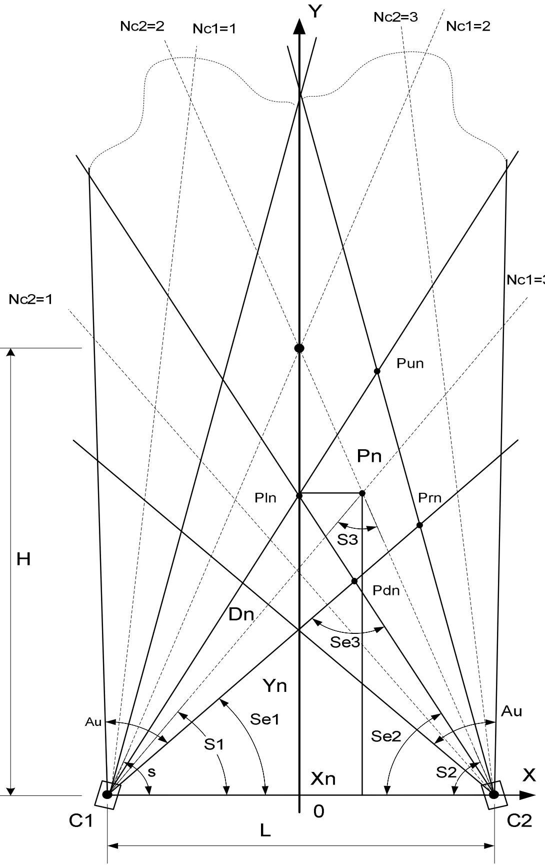

Fig. 2. *Geometrical model for the solution of the problem on determination of object coordinates in the zone of stereo range finder operation*

In Fig. 2 the model for solution of the posed geometrical problem is presented. The following parameters: L, H, Au, Res, $Nc1$, $Nc2$ are known (Fig. 2). It is necessary to find the projection values Xn and Yn of the point Pn on the axes X and Y. We obtain the following basic relationship:

a) $S1$ and $S2$ are the angles between the base line and the line from camera 1 and 2 to the point Pn, defined by the expression:

$$S1(Nc1) = \left(\mathrm{arctg}\left(\frac{2 \cdot H}{L} \right) - \frac{Au}{2} \right) + \\ + \frac{Au}{2 \cdot Res} + \frac{Au}{Res} \cdot (Res - Nc1); \quad (1)$$

$$S2(Nc2) = \left(\mathrm{arctg}\left(\frac{2 \cdot H}{L} \right) - \frac{Au}{2} \right) + \\ + \frac{Au}{2 \cdot Res} + \frac{Au}{Res} \cdot (Nc2 - 1); \quad (2)$$

b) $S3$ is the triangle angle with the vertexes in the points $C1$, Pn, $C2$:

$$S3(Nc1, Nc2) = \pi - (S1(Nc1) + S2(Nc2)). \quad (3)$$

From the expressions (1–3) the formula of distance calculation Dn from camera 1 to the sought-for point Pn:

$$Dn(Nc1, Nc2) = \\ = \begin{cases} L \cdot \dfrac{\sin(S2(Nc2))}{\sin(S3(Nc1, Nc2))} & \text{if } S3(Nc1, Nc2) > 0 \\ 0 & \text{if } S3(Nc1, Nc2) \le 0 \end{cases}. \quad (4)$$

Then, from the expressions (1, 3, 4) the sought-for coordinates Xn, Yn are defined:

$$Xn(Nc1, Nc2) = \cos(S1(Nc1)) \cdot Dn(Nc1, Nc2) - \frac{L}{2}, \quad (5)$$

$$Yn(Nc1, Nc2) = \sin(S1(Nc1)) \cdot Dn(Nc1, Nc2). \quad (6)$$

Method of error calculation in object coordinates determination

Using the given method of coordinate determination let us define the formulas of coordinate calculation of the points Pun, Prn, Pdn and Pln, forming a quadrilateral, the projection half size of which gives the error value of object coordinate determination in operating stereo range finder zone. As it was mentioned above the error in determination of object coordinates along the axis X is formed by half of the project distance on the axis X of the segment $PrnPln$, but the error in coordinate Y – by half of the project distance on the axis Y of the segment $PunPdn$. Let us give the expressions for determination of vertex coordinates of elementary quadrilateral for both axes (see Fig. 2):

$$Se1(Nc1) = \\ = \left(\mathrm{arctg}\left(\frac{2 \cdot H}{L} \right) - \frac{Au}{2} \right) + \frac{Au}{Res} \cdot (Res - Nc1), \quad (7)$$

$$Se2(Nc2) = \left(\mathrm{arctg}\left(\frac{2 \cdot H}{L} \right) - \frac{Au}{2} \right) + \frac{Au}{\mathrm{Re}s} \cdot (Nc2 - 1), \quad (8)$$

$$Se3(Nc1, Nc2) = \pi - (Se1(Nc1) + Se2(Nc2)), \quad (9)$$

$$Den(Nc1, Nc2) = \\ = \begin{cases} L \cdot \dfrac{\sin(Se2(Nc2))}{\sin(Se3(Nc1, Nc2))} & \text{если } Se3(Nc1, Nc2) > 0 \\ 0 & \text{если } Se3(Nc1, Nc2) \le 0 \end{cases}, \quad (10)$$

$$Xen(Nc1, Nc2) = \\ = \cos(Se1(Nc1)) \cdot Den(Nc1, Nc2) - \frac{L}{2}, \quad (11)$$

$$Yen(Nc1, Nc2) = \sin(Se1(Nc1)) \cdot Den(Nc1, Nc2). \quad (12)$$

From the expressions (7–12) the coordinates of the points *Pun*, *Prn*, *Pdn* and *Pln* are expressed. As a result we obtain the formulas for error calculation of coordinate determination in the specified quadrilateral:

$$\mathrm{Er}\, xn(Nc1, Nc2) = \left| \frac{Xen(Nc1+1, Nc2) - Xen(Nc1, Nc2+1)}{2} \right|, \quad (13)$$

$$\mathrm{Er}\, yn(Nc1, Nc2) = \left| \frac{Yen(Nc1, Nc2) - Yen(Nc1+1, Nc2+1)}{2} \right|. \quad (14)$$

Determination of stereo zone boundary by maximum value of error

From the expressions (13, 14) the problem of determination of stereo zone boundary is solved for the specified error value of object coordinate determination. In this article the deduction of solution algorithm for this problem is omitted. The final result of calculation is presented. In Fig. 3 the example of stereo zone boundary calculation is shown for four different error values of object coordinate determination: 0,1, 0,2, 0,5, 1,0 m for the following parameters of the system: L=1,8 m, H=49 m, Au=29,8° Res=640. The given parameters fully correspond to those of really operating stereo range finder breadboard. As it is seen in the Figure, the error in object coordinate determination increases as object moving away from the system.

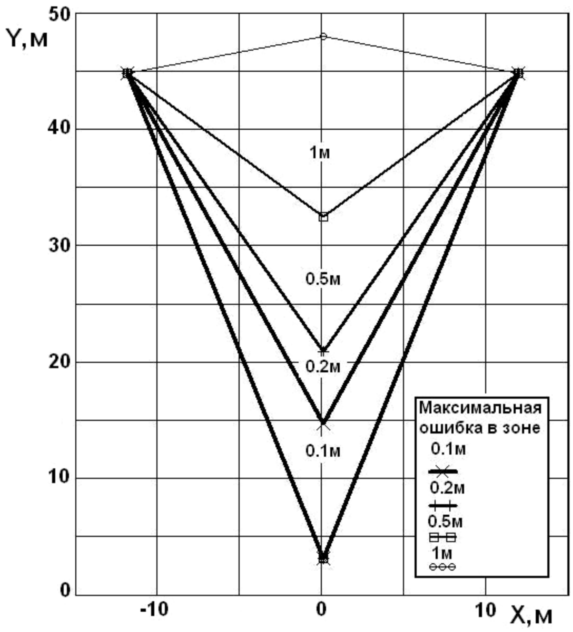

Fig. 3. View and boundaries of four stereo zones for specified errors of coordinate determination. Stereo system is in the point with coordinates (0,0)

Application

The foregoing calculations have been checked in the course of testing the operating breadboard of TV measuring stereo system, Fig. 4. The complete technique of system optical part adjustment can be read in the works [2, 3].

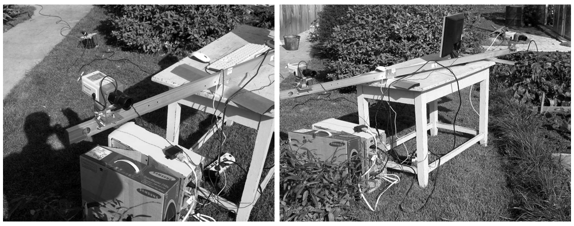

Fig. 4. Breadboard of TV stereo range finder

In Fig. 5 experimental results of operation of stereo measuring system breadboard are shown.

Fig. 5. Example of TV stereo range finder operation

In Figure one can see two measured objects (pegs) singled out by white quadrilaterals. The distances from the system to each object as well as the distance between the objects are measured by hand tape. It is seen from the given Figure that positions of the objects in the images of two cameras are different, which corresponds to the foregoing theory of TV stereo range finder operation. In the Table the results of hand measuring the distances to the objects and distances measured by the breadboard of TV stereo range finder in terms of calculation relationships (5, 6). Besides, other characteristics of system operation are presented.

Table. *Results of stereo range finder breadboard tests.*

Magnitudes	Object 1	Object 2
Distance measured by the tape, m	19,00	18,60
Number of pixel of left/right camera	222/152	454/381
Distance measured by stereo range finder, m	18,95	18,69
Coordinate of object displacement along the axis X/Y, m	–2,1/18,92	1,48/18,54
Theoretical/real error of distance measurement, m	0,16/0,05	0,16/0,09

It is seen from the Table that the obtained result lies in the range of calculated values. Since the foregoing method of calculation is of discrete character explained by the way of breaking the space into the number of pixels, the values of theoretical errors are of discrete character. Hence, the obtained value of experimental error is less than theoretical error, but it is not surprising, as the procedure of distance measurement with the tape is not discrete.

Conclusion

1. The operational principle of TV optical stereo range finder has been described for simultaneous determination of coordinates for a set of objects including moving ones. It is possible to construct the system capable of making the picture of object moving in the territory and to solve the problem of three-dimensional relief reconstruction of the surface.
2. The method of object coordinates calculation being in the stereo zone realised on the system breadboard has been suggested.
3. The technique of error calculation in object coordinate determination in the specified point has been suggested. The results of applying the method of error determination in object coordinates are supported by full-scale tests of the system breadboard.

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RECONSTRUCTION ALGORITHM OF SPERICAL IMAGE OBTAINED AT OPERATING WIDE-ANGLE OPTICS

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Reconstruction problem of spherical image obtained at operation of wide-angle optics is considered. Rapid algorithm of pixel-by-pixel reconstruction is suggested. The relations connecting pixels of spherical and reconstructed images have been obtained. The results of the algorithm operation are presented.

Introduction

When using optical cameras, for example, TV ones the parameters of applied optical system are known to be important characteristics [1]. Among the existing standard optical lenses the ultra-wide angle lenses or with so-called fisheye lenses are of particular interest. As a rule, lenses of this type have an observation angle (opening angle) 120...180°. Images produced by such lenses look similar to those of mirror ball or sphere reflection. The example of such an image is shown in Fig. 1.

It is seen from the Figure that when directing ultra-wide angle lenses camera vertically to the earth («from the top down») it is possible to «hold» circularly all surrounding territory 360° along the skyline. In this case the skyline is along the whole external part of the circle in the picture. Below in the paper such images are called «spherical».

Spherical images produced by ultra-wide angle lenses can be used in the problems connected with the requirements for wide-angle observation, for example, monitoring of different earth or technical surfaces, video surveillance system, automatic follow-up and navigation system etc. However, there are some difficulties in using spherical images owing to the fact that spherical images contain significant geometric distortions of the information obtained. When operating at spherical images it becomes difficult to estimate all received information and compare it with real objects. Therefore, video systems with conventional lenses are often used. They are fitted with extra position control system which is less efficient and expensive. Hence, there appears the problem of spherical image reconstruction (transformation) to the view suitable for subsequent processing.

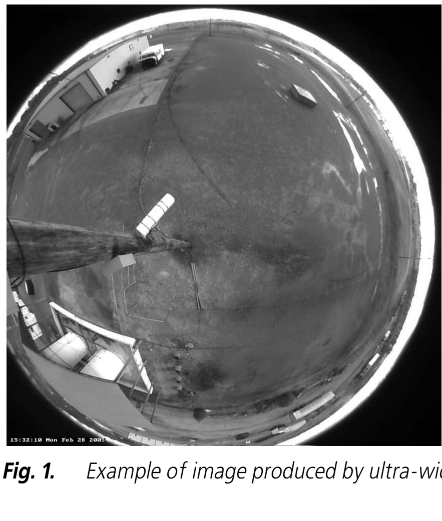

Fig. 1. Example of image produced by ultra-wide angle lenses