PASSIVE RANGING BASED ON USING COMMERCIAL CAMERAS

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Abstract: This paper presents the results of the experiment made with two commercial cameras trying two determine the target range. In the light of limited cameras features only laboratory experiments are considered. The target distance is estimated using nonparallel imaging axis and triangle similarity.

Key words: passive ranging, image processing.

1. INTRODUCTION

Many methods have developed with intention to provide estimate of the target distance. Some of them are based on use of passive sensors, and well known triangulation method [1, 2, 3]. This method is a corner stone of a system, suggested in [4], intended for the range estimation of the ground target during the flight of helicopter at low altitude. In case of the unmanned aerial vehicle the two micro cameras placed at the ends of wings and use of this method in connection with altimeter and inertial sensors are suggested in [5] to provide reliable landing on the platform as it is the aircraft carrier.

Although the theoretically well defined triangulation method in practice suffer from the severe problem, often mentioned in the literature, as the geometric dilution of precision. Bearing in mind that the every measurement consists the appropriate error, over the some distance and also in the directions where the measured angles becomes close, the estimated ranges becomes unacceptable. With the intention to avoid this problem in [2] the use of four cameras placed at the ends of two perpendicular base lines was suggested. In this paper, it has been tried to apply a method based on application of the two cameras and the similarity of the appropriate triangles.

2. PROBLEM FORMULATION

There is a lot of information about the stereovision systems in the literature [6]. The conventional stereo imaging system involves a pair of cameras with mutually parallel optical axes. They are separated by a horizontal distance denoted as the stereo baseline. The optical axes of both cameras are perpendicular to the stereo baseline, and matched in a way that the only difference between the appropriate images exists in the horizontal components. This configuration is known as the parallel axes configuration.

In this paper, the nonparallel imaging geometry is accepted with the intention to avoid the problem in connection with the triangulation method. It is achieved rotating the right camera in the left said at the angle of one degree. As it is shown in the picture 1 the camera optical axes crossing at the distance $r_0$.

![Picture 1. The nonparallel imaging geometry](image)

The distance of the target is estimated comparing the positions of the images in the plane of both cameras. If the left camera is angled so that the image of the target is placed in the middle of its image plane, in case when the target distance is not $r_0$ the right camera is supposed to have the projection of the target displaced relative to the
centre of its image plane. If the target distance is less than \( r_0 \) it will be on the left relative to the centre of the right camera image plane. In case when the target distance is \( r_0 \) both camera will have the target image in the middle of its image plane. Finally, in case when the target distance is further than \( r_0 \) the appropriate image in the right camera image plane will be right relative to the center of its image plane.

Several conditions have to be reached for practical implementation of this idea. First of all, some kind of primary processing of the images has to be realized. Of course, the suitable zoom has to be chosen in accordance with the target distance. Correlation algorithm has to be applied with intention to calculate the coordinates of the target in the image plane of the appropriate camera. If the image coordinates, in case of the distance \( D_i \), are \((x_L, y_L)\) and \((x_R, x_R)\) for left and right camera, respectively, from the triangle similarity it can be written

\[
D_i = \frac{D_j}{d_{x_j}},
\]

where \( d_{x_j} \) is

\[
d_{x_j} = x_L - x_R,
\]

the image position difference along the \( x \) axis of both cameras in case when the target is at the range \( D_i \). Of course, \( D_i \) and \( d_{x_j} \) are the known distance and the appropriate displacement difference, respectively. Obviously, the range of the target relative to the cameras is calculated using equation

\[
r_i = r_0 + D_j \frac{d_{x_j}}{d_{x_j}}.
\]

3. EXPERIMENTAL RESULTS

Several measurements were organized, in laboratory conditions, to check if the idea explained above is really working. As it is shown in the picture 2 two equal commercial cameras were posted at the same platform.

They both were posted as better as it was possible to be in parallel position. However, every time when the picture was taken by the right camera platform was rotated in the left at one degree to make sure the right value of the angle difference. It could be done precisely by the mechanism that posses the resolution of fifty divisions per degree. Of course, it was posted again at initial position after that.

Figure of the sailor was placed on the distances 3, 4, 5 and 6 meters. Both cameras took the pictures with dimension 1200x1600 pixels and with the same zoom value at every distance.

During processing only areas with coordinates from 700 to 899 pixels along horizontal axis, and from 320 to 519 pixels for left and from 370 to 569 pixels for right camera along vertical axis are used. Obviously, there is a difference in coordinates used along vertical axes. The reason is very simple. The elevation angle is not the same for both cameras, and appropriate correction was introduced during processing of the results to simplify and to provide more accurate correlation process.

Gray scale of colors was used to avoid additional problems during calculations. For the sake of simplicity, the values of pixels are summarized in every colon of matrices that are determined by coordinates of the pictures described above. In this way, row vectors are obtained. The shape of the curves presented in Picture 3 show the normalized values of these vectors. Their profile becomes narrower in accordance with the increase of the target distance. Position of the target is determined in the right camera plane finding the maximum value within these vectors. It is not so easy in general case but in laboratory complete process was deliberately simplified choosing white background. Therefore, the appropriate maximum value always originates from the target in any case.

\[
\text{Picture 3. Normalized values of vectors obtained by summation of the values in colons of the appropriate matrices for the targets at 3, 4 and 6 meters; (solid, dotted and dashed line, respectively)}
\]

Using cross-correlation of the appropriate vectors it is possible to determine the coordinates of the target inside the plane of the left cameras. The area with \( x \) coordinates of plus/minus one pixel about the maxim, within the
appropriate vectors of the right camera, is used during this process.

The difference of the target image coordinates represents the displacement that was used in calculations with the intention to check the quality of suggested solution. Picture 4 shows the images of the target in case when its distance is 3 m. The displacement of the target relative to the middle of the appropriate areas, in fact relative to the line of the sight of concrete camera, is increased with the increase of the distance.

**Picture 4.** Target image at the distance of 3 meters

Table 1 shows the differences in coordinates of the target images in the planes of both cameras. Irregular result can be noticed in case of the target distance at range 5m. This was obtained because of the local maximum existence during processing of the appropriate picture. That was the reason why the coordinates of the areas processed during the estimation of the target range were changed, and complete processing was repeated in this case.

**Table 1.** Difference of the target coordinates

<table>
<thead>
<tr>
<th>Range [m]</th>
<th>Difference [pixels]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>61</td>
</tr>
<tr>
<td>4</td>
<td>81</td>
</tr>
<tr>
<td>5</td>
<td>124</td>
</tr>
<tr>
<td>5*</td>
<td>105</td>
</tr>
<tr>
<td>6</td>
<td>123</td>
</tr>
</tbody>
</table>

In contrast to the initially chosen coordinates new processing was done, in case of the target at 5 m, using pixels within area at coordinates in interval 700 to 899 pixels along horizontal axis, and from 280 to 479 pixels for the left and from 320 to 519 pixels for the right camera along vertical axis. In this case the new result, designated as 5* in Table 1, was obtained.

In order to present the quality of suggested method the error defined as the difference of the values obtained as the ratio of the appropriate displacements and real distances is applied in this paper.

$$e_j = \frac{d_j}{d_i} - \frac{D_i}{D_j}, \quad i \leq j$$  \hspace{1cm} (3)

The absolute values of the results are presented in the table 2. The indexes $j=3, 4, 5,$ and 6 are adopted in accordance with the distances 3, 4, 5 and 6 meters.

**Table 2.** The absolute error values defined by Eq. (3)

<table>
<thead>
<tr>
<th>$j$</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e_{3j}$</td>
<td>0,00</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$e_{4j}$</td>
<td>0,31</td>
<td>0,00</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$e_{5j}$</td>
<td>10,81</td>
<td>14,68</td>
<td>0,00</td>
<td>-</td>
</tr>
<tr>
<td>$e_{5j^*}$</td>
<td>1,90</td>
<td>2,85</td>
<td>0,00</td>
<td>-</td>
</tr>
<tr>
<td>$e_{6j}$</td>
<td>0,41</td>
<td>0,81</td>
<td>2,03</td>
<td>0,00</td>
</tr>
</tbody>
</table>

With the intention to confirm the results, designated as $e_{5j^*}$, in the Table 2 two-dimensional cross-correlation of the appropriate pictures was done in the next step. Picture 5 show the combination of the pictures obtained by both cameras in case when the target is at the distance of 5 meters. As it was mentioned above, there is the displacement in the vertical positions of the target that was caused by the difference of camera’s elevation angle.

**Picture 5.** Combination of the pictures obtained by both cameras when the target is at the range of 5 meters.

Bearing in mind the problem about irregular value the two-dimensional correlation was applied during the processing of these pictures. This process takes more calculations but also offer more information. In contrast to the method described above two-dimensional correlation, provide information about displacements in horizontal and vertical direction.

Firstly, the area in the picture taken by the right camera was determined. The chosen area is designated by frame on the picture 6.

**Picture 6.** The area in the picture, taken by the right camera, are chosen to be correlated with the left camera picture elements.
The dimensions of this frame are adopted to be 500x300 pixels. Secondly, this area was correlated with the area determined by the contents of the picture taken by the left camera under the same conditions as it was done by the right one.

The results of the correlation process are presented in the picture 7. Approximately, in the middle of this picture exists the peak that shows the maximum correlation level in concrete case. Considering the coordinates of this peak, it was obtained that the image position differences of the target are 106 and 45 pixels along horizontal and vertical axis, respectively. The value of 106 pixels confirm the similar results, 105 pixels, obtained in case designated with 5* within the table 1.

![Picture 7](image.png)

**Picture 7.** The results of the two-dimensional correlation process.

### 4. CONCLUSION

The results, obtained through the experiments, and appropriate processing are in accordance with the expectations. Laboratory conditions were chosen in a suitable way to avoid additional problems that could be caused by the influence of the background.

It is shown that the system consisting two cameras that are posted at the same platform in a way that their optical axis are mutually unparallel can be successfully applied in the passive ranging systems. In case when their image planes are parallel to the baseline and matched in a way to have the same elevation angles the displacement between the optical centers of the two cameras exist only in horizontal plane (x axes). In this case, the displacement of the target image in the image plane of both cameras and known difference of the fictitious target images at appropriate distance are used for the target range estimation.

In real conditions there is a need to change the zoom in accordance with the position of the target. In any case, it has to be chosen so that the target is viewed by both cameras and is big enough to satisfy the requirements in the light of accuracy. Of course, every change of the zoom has to be followed by the appropriate matching of the values $D$ and $d_x$, known distance and the appropriate displacement difference, respectively.

In addition, whenever the zoom is changed it has to be done in the same way for both cameras. Practical use of the system has to be organized in a way that the target image is positioned in the center of the left camera. At the same time the zoom is supposed to provide suitable resolution. The operator could ensure it.

This system could be used in estimation of the obstacles position around the robot. It could be very useful system considering problems about the range estimation using ultra sound and laser illumination. It is well known that sometimes there is a problem caused by the features of the surface when it is tried to use laser illumination for distance measurement. Also in case of more obstacles, some kind of ambiguity can be caused by existence of more objects in the field of sensors view.

Future papers will be organized in the light of robot guidance and control.

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### References


