# Distance measuring based on stereoscopic pictures

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*Abstract*— **Stereoscopy is a technique used for recording and representing stereoscopic (3D) images. It can create an illusion of depth using two pictures taken at slightly different positions. There are two possible way of taking stereoscopic pictures: by using special two-lens stereo cameras or systems with two single-lens cameras joined together. Stereoscopic pictures allow us to calculate the distance from the camera(s) to the chosen object within the picture. The distance is calculated from differences between the pictures and additional technical data like focal length and distance between the cameras. The certain object is selected on the left picture, while the same object on the right picture is automatically detected by means of optimisation algorithm which searches for minimum difference between both pictures. The calculation of object's position can be calculated by doing some geometrical derivations. The accuracy of the position depends on picture resolution, optical distortions and distance between the cameras. The results showed that the calculated distance to the subject is relatively accurate.**

## I. Introduction

Methods for measuring the distance to some objects can be divided into active and passive ones. The active methods are measuring the distance by sending some signals to the object [2, 4] (e.g. laser beam, radio signals, ultra-sound, etc.) while passive ones only receive information about object's position (usually by light). Among passive ones, the most popular are those relying on stereoscopic measuring method. The main characteristic of the method is to use two cameras. The object's distance can be calculated from relative difference of object's position on both cameras [6].

The paper shows implementation of such algorithm within program package Matlab and gives results of experiments based on some stereoscopic pictures taken in various locations in space.

## II. Stereoscopic measurement method

Stereoscopy is a technique used for recording and representing stereoscopic (3D) images. It can create an illusion of depth using two pictures taken at slightly different positions. In 1838, British scientist Charles Wheatstone invented stereoscopic pictures and viewing devices [1, 5, 7].

Stereoscopic picture can be taken with a pair of cameras, similarly to our own eyes. The most important restrictions in taking a pair of stereoscopic pictures are the following:

- cameras should be horizontally aligned (see Figure 1), and
- the pictures should be taken at the same instant [3].

Note that the latest requirement is not so important for static pictures (where no object is moving).

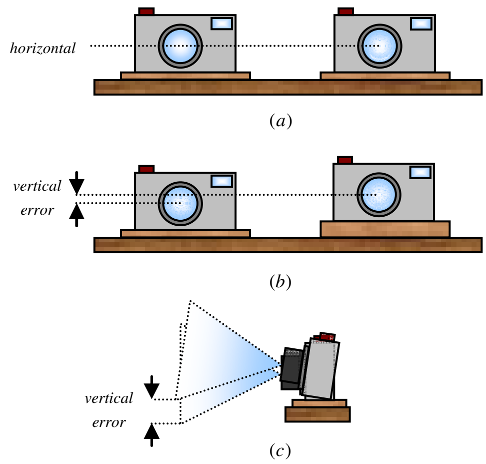


Fig. 1. Proper alignment of the cameras (a) and alignments with vertical errors (b) and (c).

Stereoscopic pictures allow us to calculate the distance between the camera(s) and the chosen object within the picture. Let the right picture be taken in location $S_R$ and the left picture in location $S_L$. B represents the distance between the cameras and $\varphi_0$ is camera's horizontal angle of view (see Figure 2). Object's position (distance D) can be calculated by doing some geometrical derivations.

We can express distance B as a sum of distances $B_1$ and $B_2$:

$$B = B_1 + B_2 = D\tan\varphi_1 + D\tan\varphi_2 , \qquad (1)$$

if optical axes of the cameras are parallel, where $\varphi_1$ and $\varphi_2$ are angles between optical axis of camera lens and the chosen object.

Distance D is as follows:

$$D = \frac{B}{\tan\varphi_1 + \tan\varphi_2} \qquad (2)$$

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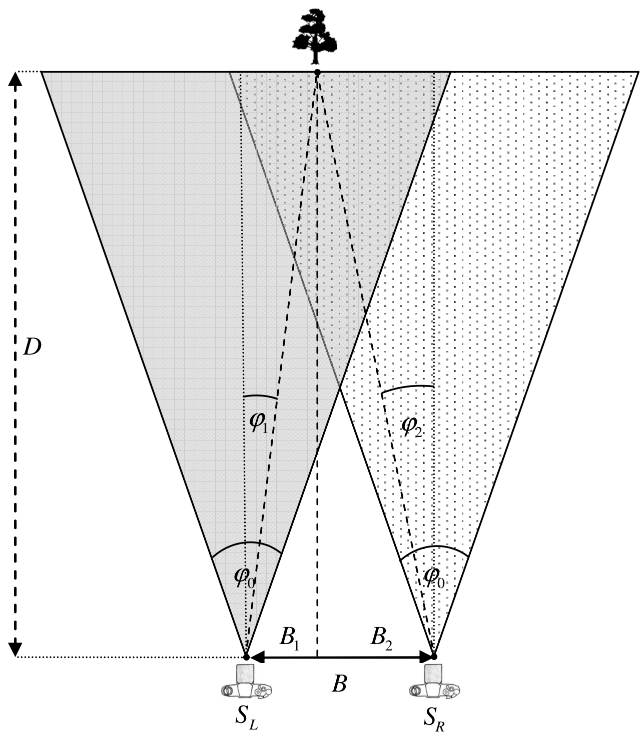


Fig. 2. The picture of the object (tree) taken with two cameras.

Using images 3 and 4 and basic trigonometry, we find:

$$\frac{x_1}{\frac{x_0}{2}} = \frac{\tan\varphi_1}{\tan\left(\frac{\varphi_0}{2}\right)}, \tag{3}$$

$$\frac{-x_2}{\frac{x_0}{2}} = \frac{\tan\varphi_2}{\tan\left(\frac{\varphi_0}{2}\right)}. \tag{4}$$

Distance D can be calculated as follows:

$$D = \frac{Bx_0}{2\tan\left(\frac{\varphi_0}{2}\right)(x_L - x_D)} \tag{5}$$

Therefore, if the distance between the cameras (B), number of horizontal pixels ($x_0$), the viewing angle of the camera ($\varphi_0$) and the horizontal difference between the same object on both pictures ($x_L$-$x_D$) are known, then the distance to the object (D) can be calculated as given in expression (5).

The accuracy of the calculated position (distance D) depends on several variables. Location of the object in the right picture can be found within accuracy of one pixel (see Fig. 5). Each pixel corresponds to the following angle of view

$$\Delta\varphi = \frac{\varphi_0}{x_0}, \tag{6}$$

where $\varphi_0$ is camera's horizontal angle of view and $x_0$ picture resolution (in pixels).

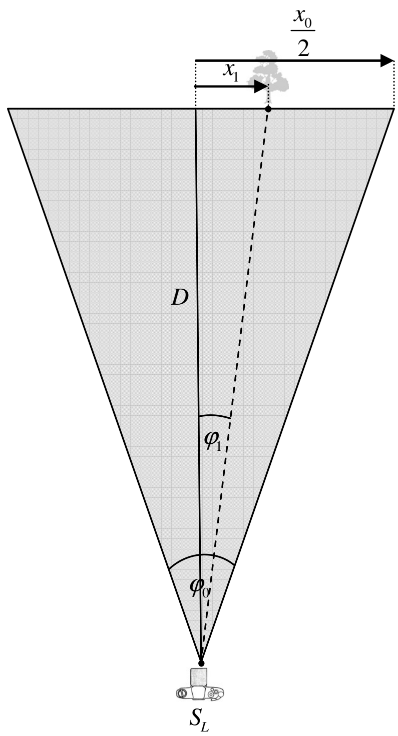


Fig. 3. The picture of the object (tree) taken with left camera.

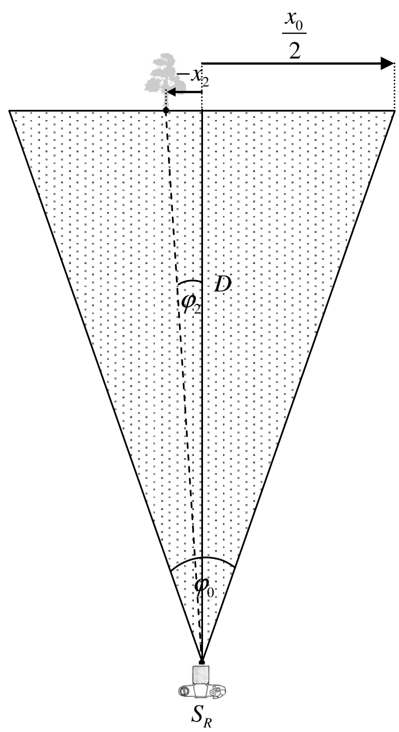


Fig. 4. The picture of the object (tree) taken with right camera.

Image 5 shows one pixel angle of view $\Delta\varphi$ which results in distance error $\Delta D$. In image we find:

$$\frac{\tan\varphi}{\tan(\varphi-\Delta\varphi)}=\frac{\Delta D+D}{D}, \tag{7}$$

Using basic trigonometry identities, the distance error can be expressed as follows:

$$\Delta D=\frac{D^2}{B}\tan(\Delta\varphi). \tag{8}$$

Note that the actual error might be higher due to optical errors (barrel or pincushion distortion, aberration, etc.) [8].

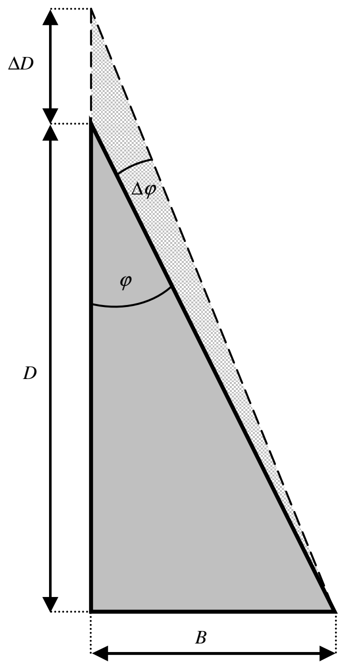


Fig. 5. Distance error caused by 1 pixel positioning error.

## III. OBJECT RECOGNITION

When the certain object is selected on the left picture, the same object on the right picture has to be automatically located. Let the square matrix $I_L$ represent selected object on the left picture (see Figure 6). Knowing the properties of stereoscopic pictures (the objects are horizontally shifted), we can define search area within the right picture – matrix $I_R$. Vertical dimensions of $I_R$ and $I_L$ should be the same, while horizontal dimension of $I_R$ should be higher.

Our next step is to find the location within the search area $I_R$, where the picture best fits matrix $I_L$. We do that by subtracting matrix $I_L$ from all possible submatrixes (in size of matrix $I_L$) within the matrix $I_R$. When size of the matrix $I_L$ is NxN and size of the matrix $I_R$ is MxN, where M>N, M-N+1 submatrixes have to be checked. Image 7 shows the search process.

The result of each subtraction is another matrix $I_i$ which tells us how similar subtracted images are. More similar two subtracted images are, lower is the mean absolute value of matrix $I_i$. Image 6 shows two examples of subtraction. Images in the first example do not match, while in the second example images match almost perfectly.

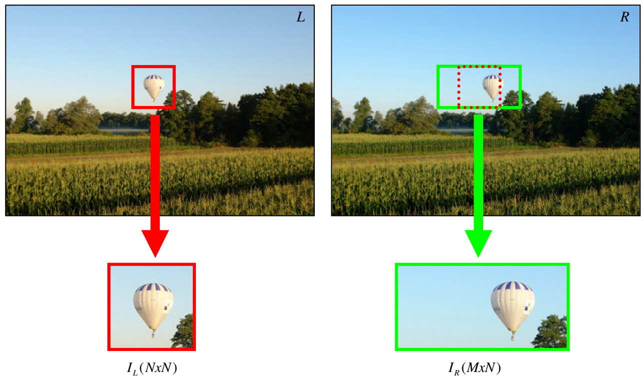


Fig. 6. Selected object on the left picture (red colour) and search area in the right picture (green colour).

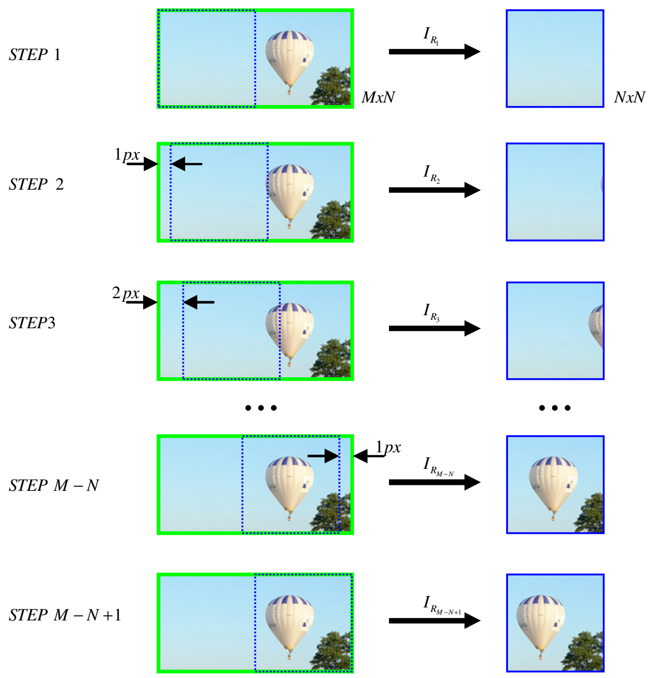


Fig. 7. Finding appropriate submatrix in the right picture.

The matrix $I_k$ with the lowest mean of its elements, represents the location where matrix $I_L$ best fits to matrix $I_R$. This is also the location of the chosen object within the right image. Knowing the location of the object in the left and right image allow us to calculate the distance between the pictures:

$$x_L-x_D=\frac{N}{2}+k-1-\frac{M}{2}. \tag{9}$$

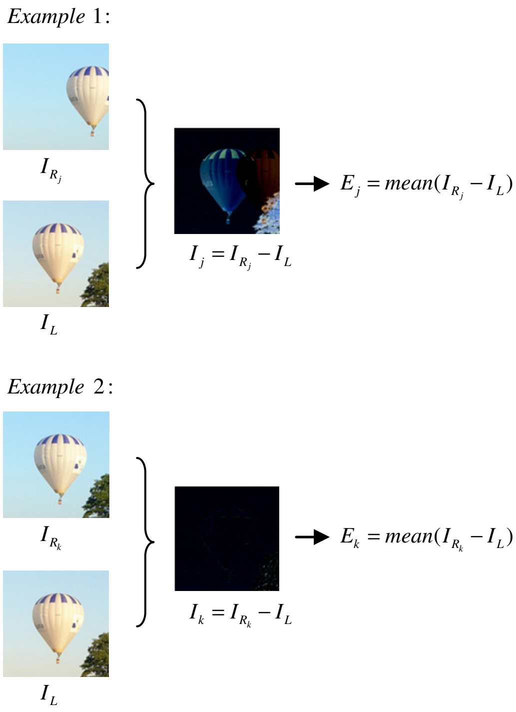


Fig. 8. The difference between selected object in the left picture and submatrix on the right picture.

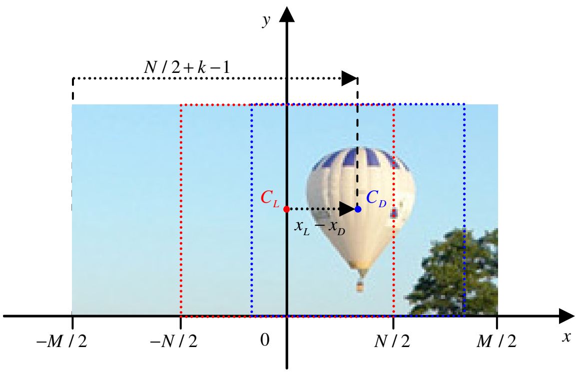


Fig. 9. Calculation of the horizontal distance of the object between left and right picture.

The calculated difference (9) can be used in calculation of object's distance (5).

## IV. EXAMPLES

Four experiments have been conducted in order to test the accuracy of our distance-measuring method. We have used six markers placed at distances 10m, 20m, 30m, 40m, 50m and 60m. Those markers have been placed at various locations in space (nature) and then photographed by two cameras. One of the pictures (with detail view) is shown in Figs. 10 and 11.

Fig. 10. Picture with targets (small white panel boards) located at 10m, 20m, 30m, 40m, 50m and 60m.

Fig. 11. Detailed view of Figure 10 (markers).

After adjusting the cameras to be parallel, the distances were calculated in program package Matlab.

The calculated distances for different locations and different markers (10m, 20m, 30m, 40m, 50m and 60m) are given in Tables 1 to 6.

Table 1. Calculated distance to marker at 10m in various locations

| base [m] | Marker at 10m | | | |
|---|---|---|---|---|
| | location 1 | location 2 | location 3 | location 4 |
| 0,2 | 10,81 | 10,58 | 10,01 | 10,34 |
| 0,3 | 10,63 | 10,40 | 9,77 | 10,47 |
| 0,4 | 10,45 | 10,04 | 10,01 | 10,28 |
| 0,5 | 10,09 | 10,04 | 9,81 | 10,13 |
| 0,6 | 10,18 | 10,03 | 9,90 | 10,18 |
| 0,7 | 10,18 | 9,84 | 9,96 | 10,13 |

Table 2. Calculated distance to marker at 20m in various locations

| base [m] | Marker at 20m | | | |
|---|---|---|---|---|
| | location 1 | location 2 | location 3 | location 4 |
| 0,2 | 21,23 | 21,57 | 21,57 | 20,56 |
| 0,3 | 20,86 | 21,87 | 21,87 | 20,68 |
| 0,4 | 20,81 | 20,49 | 20,49 | 20,33 |
| 0,5 | 20,04 | 20,62 | 20,62 | 20,62 |
| 0,6 | 20,19 | 20,59 | 20,59 | 20,14 |
| 0,7 | 20,44 | 20,41 | 20,41 | 19,86 |

Table 3. Calculated distance to marker at 30m in various locations

| base [m] | Marker at 30m | | | |
|---|---|---|---|---|
| | location 1 | location 2 | location 3 | location 4 |
| 0,2 | 30,80 | 32,47 | 33,02 | 29,57 |
| 0,3 | 31,81 | 31,56 | 27,97 | 31,13 |
| 0,4 | 32,05 | 30,93 | 32,12 | 30,65 |
| 0,5 | 30,25 | 31,55 | 29,22 | 29,77 |
| 0,6 | 30,88 | 31,58 | 30,06 | 30,80 |
| 0,7 | 30,74 | 30,33 | 31,25 | 30,71 |

Table 4. Calculated distance to marker at 40m in various locations

| base [m] | Marker at 40m | | | |
|---|---|---|---|---|
| | location 1 | location 2 | location 3 | location 4 |
| 0,2 | 42,49 | 45,28 | 40,29 | 37,98 |
| 0,3 | 41,67 | 42,72 | 40,76 | 39,78 |
| 0,4 | 42,04 | 40,86 | 38,61 | 40,93 |
| 0,5 | 40,17 | 41,40 | 40,25 | 38,42 |
| 0,6 | 40,69 | 41,34 | 41,08 | 40,42 |
| 0,7 | 41,12 | 40,84 | 39,73 | 40,05 |

Table 5. Calculated distance to marker at 50m in various locations

| base [m] | Marker at 50m | | | |
|---|---|---|---|---|
| | location 1 | location 2 | location 3 | location 4 |
| 0,2 | 50,70 | 57,53 | 47,38 | 46,80 |
| 0,3 | 54,04 | 52,74 | 45,92 | 50,00 |
| 0,4 | 53,10 | 51,16 | 57,50 | 50,15 |
| 0,5 | 51,22 | 52,50 | 49,01 | 48,21 |
| 0,6 | 51,41 | 52,34 | 51,48 | 50,32 |
| 0,7 | 52,30 | 52,05 | 53,85 | 50,07 |

Table 6. Calculated distance to marker at 60m in various locations

| base [m] | Marker at 60m | | | |
|---|---|---|---|---|
| | location 1 | location 2 | location 3 | location 4 |
| 0,2 | 63,36 | 67,69 | 70,67 | 53,26 |
| 0,3 | 63,56 | 64,63 | 59,29 | 64,99 |
| 0,4 | 64,97 | 60,62 | 60,22 | 60,95 |
| 0,5 | 61,95 | 63,97 | 62,01 | 59,42 |
| 0,6 | 62,07 | 63,75 | 62,13 | 61,21 |
| 0,7 | 61,57 | 61,40 | 61,75 | 60,55 |

Figures 12 to 17 show the results graphically. It can be seen that the distance to the subjects is calculated quite well taking into account the camera's resolution, barrel distortion [8] and chosen base. As expected, better accuracy is obtained with wider base between the cameras.

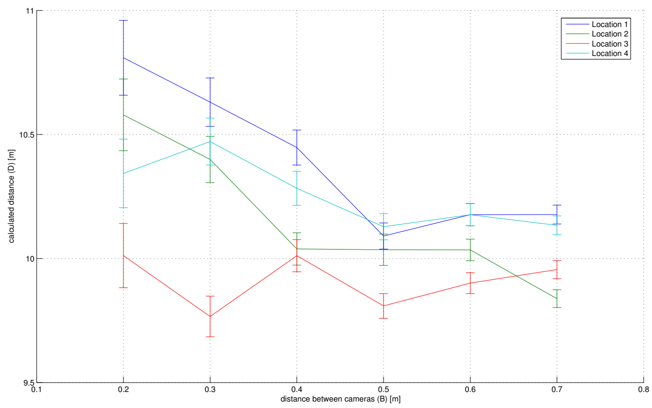


Fig. 12. Calculated distances to marker set at 10m at 4 different locations.

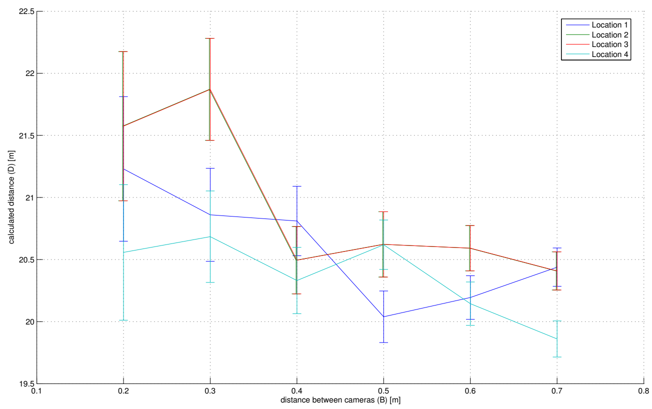


Fig. 13. Calculated distances to marker set at 20m at 4 different locations.

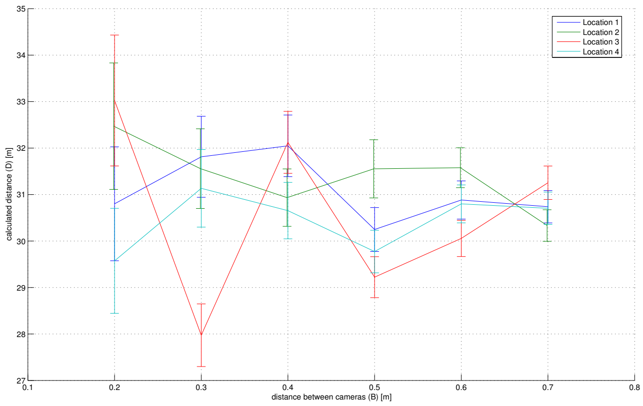


Fig. 14. Calculated distances to marker set at 30m at 4 different locations.

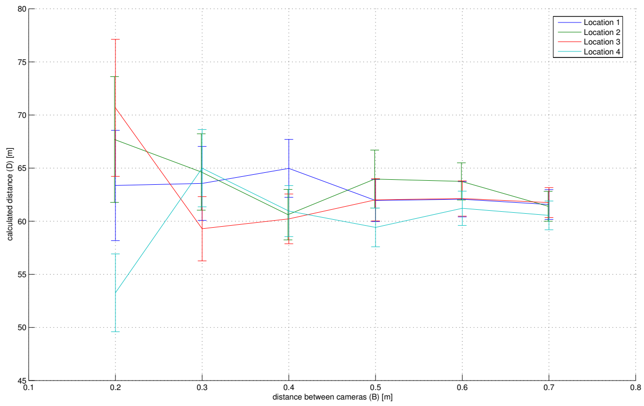


Fig. 176. Calculated distances to marker set at 60m at 4 different locations.

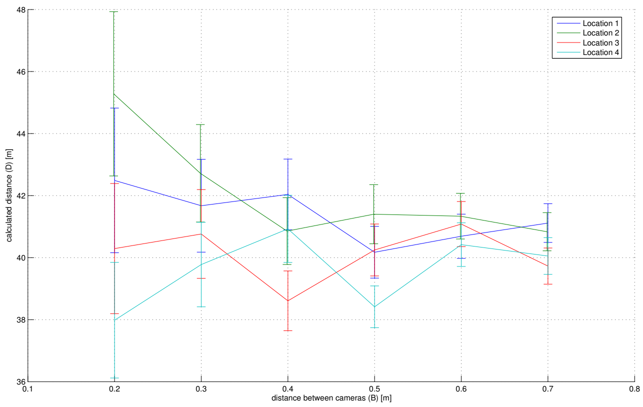


Fig. 15. Calculated distances to marker set at 50m at 4 different locations.

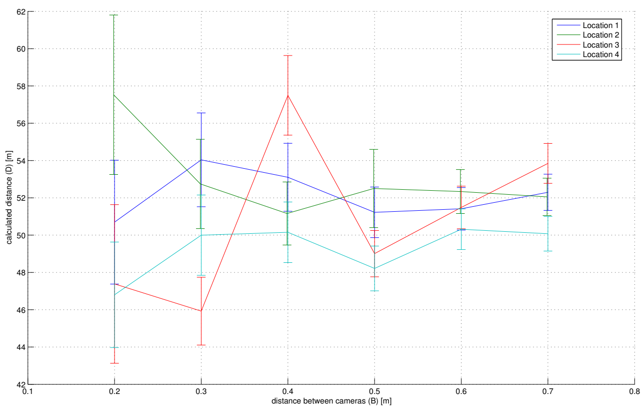


Fig. 165. Calculated distances to marker set at 50m at 4 different locations.

## V. Conclusion

The proposed method for non-invasive distance measurement is based upon the pictures taken from two horizontally displaced cameras. The user should select the object on left camera and the algorithm finds similar object on the right camera. From displacement of the same object on both pictures, the distance to the object can be calculated.

Although the method is based on relatively simple algorithm, the calculated distance is still quite accurate. Better results are obtained with wider base (distance between the cameras). This is all according to theoretical derivations.

In future research, the proposed method will be tested on some other target objects. The influence of lens' barrel distortion on measurement accuracy will be studied as well.

## References

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