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Practical Experience with Distance Measurement Based on Single Visual Camera

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Abstract:

The paper deals with the problem of distance measurement of stationary target by single visual camera in laboratory conditions. The paper describes the practical experiments performed in order to estimate the distance of a target using visual odometry. For the estimation of the distances, we used a camera and a target. For these estimations, photos were taken to obtain the coordinates of reference points on the target surface. The coordinates obtained were used in optical equations to estimate distances of the target in the space. The paper explains the procedures made for the experiment preparation, describes the experiments and finally analyses the results acquired. These practical experiments establish a basis for the implementation of the position algorithm into navigation subsystem of swarm robots.

Keywords:

Single visual camera, distance measurement, error analysis, image analysis, optical properties.

1. Introduction

The reason for using cameras to measure the distance from the target is a creation of a measuring subsystem for autonomous robot which will make odometry more accurate. This functionality will be very helpful especially in robot cooperation. To introduce this intention, a theory has to be defined and tested in applications.

This article follows the time-line described in the paper and published at the IEEE Conference 15th Mechatronika 2012 [1]. In the paper's conclusion, the general experience and conclusions of the experiment are mentioned to enhance experiment results.

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The object of all experiments described in the article was to obtain the highest possible accuracy.

The practical experiments and the first analysis were carried out by cadet De La Bourdonnaye from the French Air Force Academy in Salon de Provence in the context of the Project “Learning Through Research”. It is a French program for second year students of the Master Course. Deeper analyses of the results were carried out by the research team of the Department of Air Defence Systems.

2. Experiment Preparation

2.1. Place of Experiment

The first task was to prepare the conditions for all experiments, followed by an assignment of the laboratory, suitable for the experiment purposes. The laboratory conditions simulated the conditions typical for the rooms in common buildings.

Thirty three points were measured by a theodolite situated on the floor. It is a movable, high accuracy telescope for measuring angles in both horizontal and vertical planes. The guaranteed precision of this geographic method is 1 mm. The obtained grid of the points contains three main lines. The distances between the lines are 2 000 mm. The points on the lines are in minimal distance of 500 mm between two points. The distance between the first and the last point is 6500 mm.

2.2. Model of target

The model of target is a flat board situated on the floor, equipped with consoles with screws that enable its perpendicular positioning. The external dimension of the target is 750 mm x 750 mm. Three reference points – 1, 2 and 3, see Fig. 1 – on the model of target were used for the measurements. The chosen distance (500 mm) used as a reference one, is the distance between the red points 1 and 2. The green point (point 3) in the middle of this distance equals the height of the camera’s optical axis (269 mm from the floor level). The vertical line in the centre of the model of target is positioned on the points on the floor so that the model of target’s accurate position can be set.

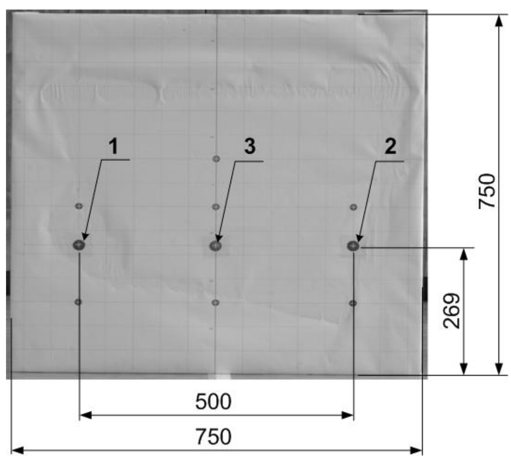

Fig. 1 Reference points and size (in millimetres) of the model of target

2.3. Static support of the camera

The issue to be solved is how to keep an optical axis of the camera in the same position during all measurements and, in addition, perpendicular to the laboratory floor. An experimental device was invented and made by the research team. The camera was joined with the upper plane of the device with a screw. The lower plane was equipped with three reticles positioned as far as possible from the camera centre of gravity of the lower plane. The paper with the millimetre resolution grid was fixed to the laboratory floor to keep the horizontal camera orientation.

To fix the vertical axis, another auxiliary point was created. To make sure that the vertical axis would be alike for all pictures made afterwards, the point had to be in the longest possible distance from the camera. It was in the same height as the reference point 3 of the model of target, and it was located on the laboratory rear wall.

Fig. 2 Experimental static support

2.4. Camera settings

The camera Nikon D70 with lens AF-S Nikkor DX was used for all practical experiments. The main technical characteristics are in Table 1.

Tab. 1 Main technical characteristics of camera Nikon D70

Focal length	18 – 70 mm	Image size	3 008 × 2 000 px
F_{number}	3.5 – 29	Sensitivity	ISO 320
Self-timer	2 s	CCD size	23.7 × 15.6 mm
Image quality	JPEG normal	Focus	Manually set

Important parameters were set up manually while the other ones (i.e. shutter, aperture) were used automatically. A delayed self-timer was applied because when a finger presses the button to shoot, the camera can slightly move and this can lead to measurement errors. With the delay, the camera is stable while the photo is taken. Furthermore, no flash has been utilised because otherwise errors caused by brightness could occur.

In the text F_{number} has been used. Eq. (1) explains it:

$$F_{\mathrm{number}} = \frac{f'}{D}, \tag{1}$$

where *f'* is focal length in image plane and *D* diameter of the camera lens.

The equation (1) can be also replaced by equation (2). It means that F_{number} has direct influence on relative aperture *RA*

$$F_{\mathrm{number}} = \frac{1}{RA}. \tag{2}$$

2.5. Data processing

The software GIMP 2.8.0 was applied to analyse the pictures. Once the photo is taken with the camera, it is opened with GIMP in the computer. Then, the use the zoom of the software accuracy of one pixel is applicable. Coordinates of the three reference points in pixels are obtained from the photo. Standard graphic format jpeg was applied here.

3. Experiment description

This part of the article describes practical experiments which were approved and, in addition, a process of camera model was established.

3.1. Calibration Phase

In order to set the model of camera and to find applicable mathematical relations, a calibration phase was necessary. In the previous experiments (see Fig. 3) the model of camera based on the physical scales of the CCD sensor was used [1]. The model (Eq. (3)) was partially applicable, though it needed certain enhancement, hence a correction by a heuristics constant was carried out

$$\frac{b}{s} = \frac{b'}{f'} = const. \quad \left[\frac{\mathrm{mm}}{\mathrm{mm}}\right], \tag{3}$$

where *b* (*b'*) is a base size in object (image) plane and *s* is a distance of the target.

The camera was at the point C0 on the centre line and stayed there during all experiments. Therefore, six photos were taken in the distance from one to six meters. The centre of the model of target was in front of the camera, in its optical axis. The model of target was perpendicular to the optical axis of camera. The focal length was set up to 35 mm, F_{number} 29 was chosen and hyper-focal distance had to be slightly more than 2 000 mm. The sensitivity ISO 320 guaranteed a good quality of photos. The camera self-timer was set for two seconds to eliminate vibration generated by the press of finger onto the capture. Other camera parameters were set automatically.

The mathematical model of the measurement is represented by the equation:

$$s = 1881.6\frac{1}{b'} \quad [\mathrm{m,px}]. \tag{4}$$

This mathematical equation is valid in the range of distances from 1 to 6 meters.

Another approach to the target distance measurement is to find a relation linking the distance *s* in pixels on CCD to the distance *s* in millimetres in the image. This method is based on the optical scheme in Fig. 3 and the equations presented in the technical report [2]. This is the final equation:

$$\Delta_2 = \frac{b'}{b} \quad \left[\frac{\mathrm{mm}}{\mathrm{px}}\right]. \tag{5}$$

The results of the calculation are in Tab. 2.

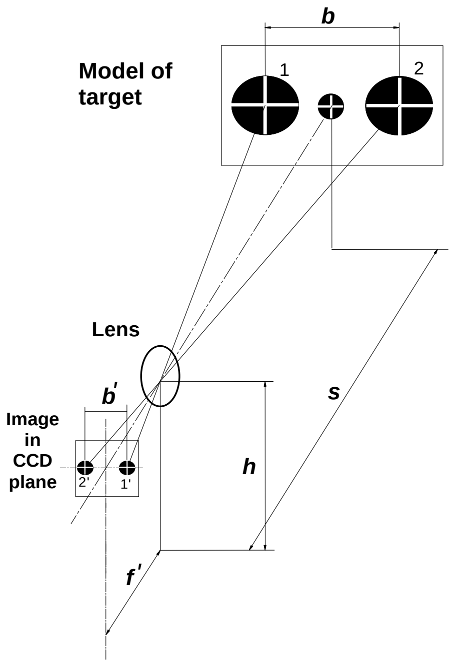

Fig. 3 Spatial arrangement of the experiments

Tab. 2 Table of pixel size on CCD for different distances of model of target

Tested distance l [mm]	Δ_2 [mm/px]
1 002	0.008 029 267
2 003	0.008 022 451
3 004	0.007 993 694
4 002	0.007 952 456
5 003	0.007 885 078
6 004	0.007 679 727

Fig. 4 shows the results of calibration phase after which all six samples were approximated by the curve.

We can state that the second model is valid from the distance of 2 003 mm. If measuring is performed in shorter distances, the camera is not able to give accurate results because of images' distortion. The average value of Δ_2 taken in the distance of minimum 2 003 mm is Δ_2 = 0.007 957 1725 mm/px. In the next part both models are tested.

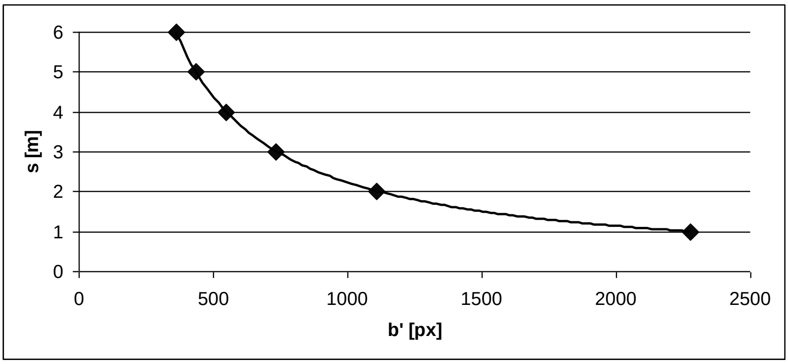

Fig. 4 Results of the calibration phase

3.2. Validation experiment – Distance measurement

The aim of this experiment is to measure the distance between the camera and the model of target using the picture analysis. Therefore, twenty-one pictures were taken in the distance from 1 m to 6 m, every 0.25 m.

Tab. 3 Main parameters of the first experiment

Focal length f' [mm]	35	$s_{\min}$ [mm]	1 000
F_{number}	29	$s_{\max}$ [mm]	6 000
b [mm]	500	Rotation [°]	0

Fig. 5 shows the results of distance measurement. The black lines represent the method which calculates with mathematical model. Their error according to the sign of partial error is –0.30 %. The average error in absolute value is ±0.43 %. Contrary, the grey lines correspond to the model based on CCD size. In the interval between 2 and 5 meters, the error is less than ±1.0 %. In other cases errors are too big.

4. Conclusion

The paper deals with the use of a CCD camera to obtain more accurate indoor navigation data. It should be noted that the distance measurement contains many obstacles. The presented achievements are valid only for an exact type of camera in combination with a particular lens. Nevertheless, the conclusions are generally valid.

Another limitation is caused by the model of target which has to be in optical axes and perpendicular to it. However, the accuracy of distance measurement is less than ±1.0 % for significant samples. Both models are more accurate than the model presented in [1]. In that case the average error could be 6.28 % and maximal error 17.7 %. Hence, a significant progress has been reached.

The method based on mathematical analysis is more accurate than the model using CCD size mainly in low distances. Its disadvantage is that it creates a relative complication for robot embedded computers.

The presented experiments have proved the theory applied, and open the opportunity to define measuring subsystem for odometry support. Even though there were found some limitations, this approach can be applied. The subsystem used in cooperative swarm can improve the measurement accuracy. Furthermore, it is possible to extend its functionality to measure the position in 2D or 3D space.

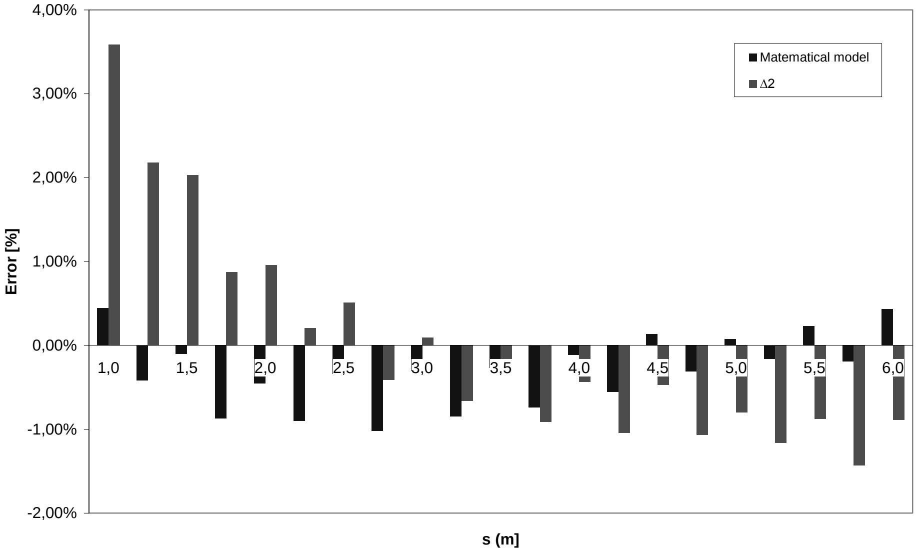

Fig. 5 Error of distance measurement

Although the paper provides some useful algorithms, there are still many problems which have to be solved prior to the measuring swarm robot subsystem implementation.

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