CAMERA CALIBRATION FOR VISUAL ODOMETRY SYSTEM

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Abstract: *Estimating it's ego-motion is one of the most important capabilities for an autonomous mobile platform. Besides odometry ,inertial sensors ,DGPS, laser range finders and so on, vision based algorithms can contribute a lot of information. We want to emphasize the fact that stereo odometry is a chain of several single sub processes where each relies on its predecessor's results. In this paper we will present a stereo camera calibration method and with the help of this we will try to find the intrinsic and extrinsic parameters. The method was implemented with succes in OpenCV.*

Keywords: *intrinsic,extrinsic,odometry,stereo,triangulation,calibration,distorsion.*

1. INTRODUCTION

Camera calibration is a necessary step in 3D vision in order to extract metric information from 2D images.[2][8]

A camera is considered to be calibrated when the parameters of the camera are known (i.e. principal distance, lens distorsion, focal length etc.). For this purpose, in the last twenty years, many calibration algorithms have been developed in the computer vision community. This algorithms are generally based on the perspective camera models. Among themost popular is Robert Tsai's calibration algorithm (Horn, 2000), (Tsai, 1987). His algorithm is based on the pinhole model of perspective projection. The model proposed by Tsai assumes that some of the camera's parameters are given by the are manufacturer, in order to reduce the initial guess of estimation. The algoritm requires n feature points (n> 8) per image and solves the calibration problem with a set of n linear equations based on the radial alignment constraint. A second order radial distorsion model is used while no decentering distorsion terms are considered. This method can be used with either a single image or multiple images of a planar or 3D calibration grid.

Another important and very popular calibration method has been developed by Zhenyou Zhang (Zhang, 1998). His method requires a planar checkerboard grid to be placed in front of the camera at different orientations. The algorithm uses the extracted corner points of the checkerboard to calculate a projective transformation between the image points of the different images. The camera's intrinsic and extrinsic parameters are recovered using a closed-form solution. The radial distorsion terms are recovered within a linear least-squares solution.

The final step is the use of a non-linear minimization of the reprojection error that refines all the recovered parameters. Zhang's method is similar to the oneproposed by Triggs (Triggs, 1998). Zhang's algorithm is the basis behind some popular open source implementations of camera calibration (i.e. Intel's OpenCV and Matlab's calibration toolkit).

2. CONTRIBUTION TO SUSTAINABILITY

Stereo Visual Odometry Systems, as part of Active Vision Systems, is an important concept still to be integrated and supported by novel technologies, promising to expand into most of today's domains, including automotive, autonomous driving, robotics and directly aiming for a new concept, driving and navigation systems with no need of satellites connectivity and GPS position data.

A sustainable key feature that our system provides is given by the very low energy consumption compared with the actual GPS systems, which is caused by eliminating the permanent connectivity between the navigation system and satellites. To expand functionality, we propose two features algorithms that properly manage to help the system to have a much better accuracy. The small dimensions of our proposed stereo odometry system along with its developed control system make the device ideal for future autonomous mobiles needs. Our proposed system manages to reduce the main disadvantage of most of the present day navigation systems – the positioning error of the stereo visual odometry system which in our case is significant lower compared with same parameter of the modern navigation systems in the market.

The goal of the presented system, algorithms and tests is to obtain preliminary data for a complete independent navigation and mapping system that we intend to develop.

The proposed system will help future development of already existing domains by opening a path to new ideas and trends for self-sustained and advanced supportive environments. We anticipate that the results presented in this paper will also contribute to autonomous driving evolution, which represent in our view a small step for sustaining future technologies' development.

3. EXPERIMENTAL RESULTS

A. Stereo Visual Odometry System

In automotive and computer vision, visual odometry is the process of determining the position and orientation of a robot by analyzing the associated camera images.

The project was developed in multiple steps, as it follows. First step was to develop the mechanical model necessary for sustaining the servo motors and web cameras and afterwards it was developed the board data acquisition and control servo motors.

The experimental prototype is made of (Fig.1), acquisition and control board consists of:

- Supply via a laptop charger;
- LM7805 voltage regulators;
- MAX 232 Integrated Circuit;
- ATmega8 microcontroller;
- DB-9 connector;
- 2 Futaba S3305 servo motors;
- 2 Logitech Quick Cam Pro webcams 9000;

First step is to detect key points for each captured frame from the cameras system with two different features detection algorithm (ORB, FAST). After that we eliminate outliers points using RANSAC algorithm and performs stereo correlation.The functional block diagram is the following:

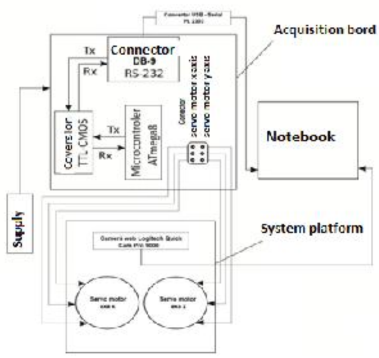

FIG.1. General block diagram of the entire system active vision;

With the remaining points, coordinate transformation is performed from 2D (x,y) to 3D(x,y,z) with the triangulation method (Fig.2).

Having the camera parameters and using the triangulation method, the 3D coordinates of the points are obtained (x_l- coordinate of the feature from the left image, x_r- coordinate of the feature from the left image)[2].

$$Z=bf/(x_l-x_r) \quad (1)$$

The next step is to use the decomposition (SVD method) in order to obtain the values of the rotation matrix (R) and translation (T) of the cameras. To see more easily if the system calculates the correct system trajectory, we introduced additional calculation of the 3 angles of the camera system (roll, pitch, yaw).

To be able to compare the odometry system result, meanwhile the latitude and the longitude of the stereo cameras system are saved for each frame. With those data the system trajectory is created.

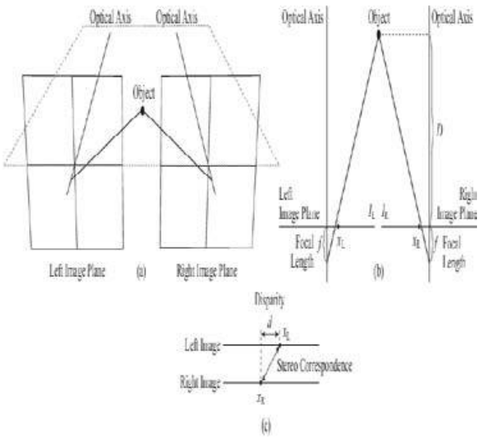

FIG.2. Triangulation method and stereo geometry f- focal length, x_l- coordinate of the feature from the left image, x_r-coordinate of the feature from the right image.

These trajectories are compared in order to determine if the odometry system error is approximately equal to 5% [3].

4. EXPERIMENTAL EVOLUTION

For the experimental evaluation of the above method we have used a wireless CMOS camera. Because the images taken by the camera were very noisy, we needed a filter to remove that noise. The filter used for this purpose was a simple one, the median filter.

The calibration object used for the process consists of two perpendicular planes, in our case we have used two sides of a box. On the two sides we added a calibration pattern consisting of square tiles. The sides of the tiles are 1 cm. Another important step in the calibration process is to choose a convenient world coordinate frame (see Fig.1).[8]

The first step of the calibration process is to set the 3D matrix XYZ, that containts the 3D coordinates of the calibration points. We have chosen those points as follows: as we know the sides of the tiles are 1 cm, so the XYZ coordinates for a point near the origin of the world system are (-1, 0, 1). Then we need to set up the 2D matrix xy, matrix that contains the 2D coordinates of the calibration points. For this purpose we have developed an interactive program that colects the 2D coordinates of these points (see Fig.2).[1][8]

For an accurate calibration process we need between 20 and 30 points. After this step is completed, the estimation of the projection matrix M can be done by applying the method presented early in this work.

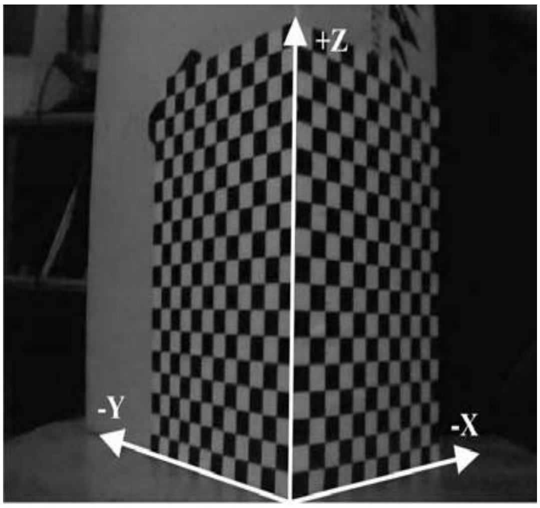

FIG.1. *The calibration object and the chosen world coordinate frame.*

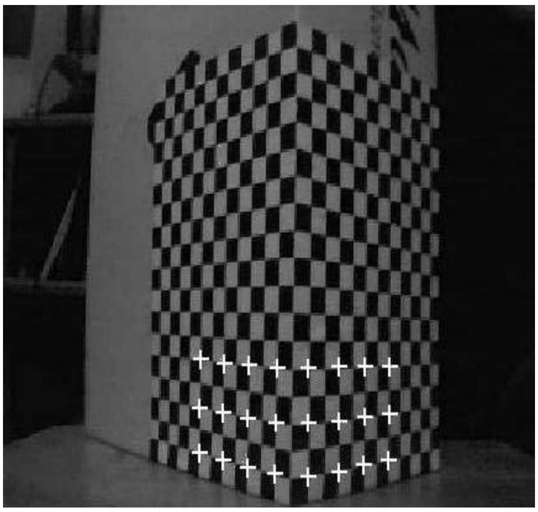

FIG.2. The calibration object and resulting calibration points.

To show that the calibration process was accurate we have considered some cubes with the sides equal to the sides of the tiles and we have put them over the calibration pattern. It can be easily observed the correction of the projection matrix estimation (see Fig.3).

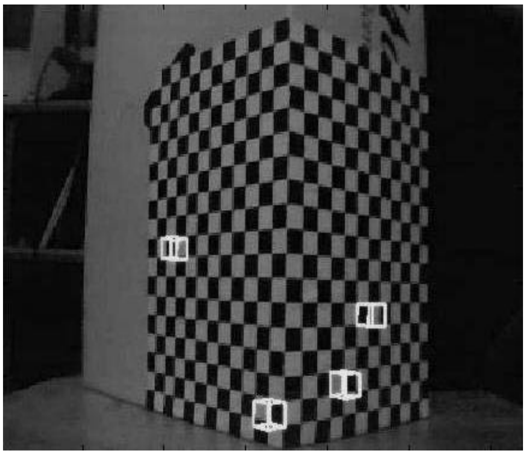

FIG.3. The calibrated camera allows for 3D objects to be drawn in the scene.

In the final step we have computed the estimates for the camera's intrinsic and extrinsic parameters from the projection matrix. The resulting intrinsic parameters are:

$$\begin{aligned} f_x &= 321.0655\,px;\ f_y = 329.5092\,px, \\ o_x &= 156.8256;\ o_y = 164.7667 \end{aligned} \tag{2}$$

And the camera's extrinsic parameters obtained from the calibration process are:

$$R = \begin{pmatrix} 0.0192 & -0.0070 & 0.9998 \\ 0.7375 & -0.6751 & -0.0189 \\ -0.6750 & -0.7377 & 0.0078 \end{pmatrix}$$

$$T = \begin{pmatrix} -6.2695 \\ -0.6508 \\ 23.9378 \end{pmatrix} \tag{3}$$

The entire calibration process has been implemented in the programming and simulation environment from Intel OpenCV.

CONCLUSION AND FUTURE WORK

The method presented here is a simple calibration method that gets the job done. The precision of the calibration depends on how accurately the image and world reference points are located. The errors on the parameter estimates propagate to the result of the application. The calibration process ultimately depends on the accuracy requirements of the target application. For example, in industry accuracies of submillimeter are required. In other application are accepted even errors of centimeters.

Stereo visual odometry systems remain one of the major research issues for the Autonomus driving and navigation. Creating a totally independent system for the user like an alternative for the standard navigation systems is an important goal to be reached.

As a future development direction we intend to apply a fuzzy logic control algorithm in order to improve the system accuracy. Also we intend to implement a new algorithm with a better accuracy to convert the points from 2D to 3D. Our intention is to research and develop a complete stereo odometry system with application in actual and future areas of interest.

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