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Mapping of Real-Time 3D object movement

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Abstract

Tracking of an object in 3D space performed in real-time is a significant task in different domains from autonomous robots to smart vehicles. In traditional methods, specific data acquisition equipments such as radars, lasers etc, are used. Contemporary computer technology development accelerates image processing, and it results in three-dimensional stereo vision to be used for localizing and object tracking in space. This paper describes a system for tracking three dimensional motion of an object using color information in real time. We create stereo images using pair of a simple web camera, raw data of an object positions are collected under realistic noisy conditions .The system has been tested using OpenCV and Matlab and the results of the experiments are presented here.

Keywords: *HSV, stereo image rectification, stereo image correspondence, camera pixels, focal length, Kalman filter*

1. Introduction

Detecting and following an object is a useful capability in many applications.. Nowadays, lot of research works have done in area of unmanned vehicle and robotics. One of the important goals is to achieve a fast and reliable, in other words real time, detection of moving objects in 3D space. Object detecting, tracking and elimination technologies are very applicable in military request. In entertainment, like sports such as football, basketball, tennis tournament etc., determining position of the ball is important case to avoid false identifications of the ball. The main research objectives of the 3D space data is improving accuracy of results as well as achieving real-time high performance in obtaining those results[2, 3, 4, 5]. The methods use two cameras and distance of an object from camera and size can be calculated from relative difference of object's position on both cameras.

In stereo image processing, there are several challenges: since two cameras take a picture using different angles, visible object in one image may not appear in the other image; correspondences between two points cannot appear, depending on the brightness of ambivalent light, object color etc.

In this experimental research work we tested object tracking system based on color information. The object in three-dimensional space can be represented by X, Y, and Z coordinates. However image representation is defined on2-dimensional plane by X and Y and one dimension is lost due to projection. So,

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in Computer Vision the main goal for three-dimensional imaging is restoring the lost dimension. In stereo vision system, there are several known ways of estimating the depth like motion, shading, texture and stereo[10,11]. The first step for us was becoming familiar with camera model. In our previous article we reviewed camera model [12,13].

2. Moving object detection based on color information

In this article we offer a way of detecting and mapping of a moving object in real-time using the color characteristics. The five tracking problems are camera calibration, image rectification, feature extraction, correspondence and3D triangulation.

2.1 Stereo Image System

Stereo vision system can be divided into two parts: the preparation stage and the measuring stage. The preparation stage of the system includes camera calibration and calculation of transformation matrices for epipolar rectification and a series of calibration patterns must be taken for this stage. In stereo camera calibration it needs to calculate following two matrices.

Essential matrix contains information about the translation and rotation that relate two cameras in physical space

$$P_r^T E P_l = 0 \quad (1)$$

$$E = RS \quad (2)$$

Here, P_l, P_r which are the locations of the point P located on epipolar plan, S is vector multiplication, R is rotation matrix and E is an essential matrix.

Fundamental matrix contains the same information as E in addition to information about the intrinsic parameters of both cameras.

$$x_r^T (M_r^{-T} E M_l^{-1}) x_l = 0 \quad (3)$$

$$x_r^T F x_l = 0 \quad (4)$$

Here x_l, x_r are the coordinates on the image plane of the P point, M_r and M_l are camera matrices and F is a fundamental matrix.

According to the Fundamental matrix the lens distortion parameters estimated. Here we describe two main lens distortions which are radial and tangential distortions. Radial distortion described following set of equations.

$$x_d = x_u(1 + K_1 r^2 + K_2 r^4 + K_3 r^6) \quad (5)$$

$$y_d = y_u(1 + K_1 r^2 + K_2 r^4 + K_3 r^6) \quad (6)$$

$$r = \sqrt{(x_u - x_c)^2 + (y_u - y_c)^2} \quad (7)$$

Here, (x_d, y_d) –is the new location as a result of the correction, (x_u, y_u) –is the original location of the distorted point, (x_c, y_c) –is principal point, K_n-is distortion coefficient and r- is pixel radius.

The second major distortion is tangential.

$$x_d = x_u + [2p_1 y + p_2(r^2 + 2x^2)] \quad (8)$$

$$y_d = y_u + [p_1(r^2 + 2y^2) + 2p_2 x] \quad (9)$$

Thisp_1 and $p_2$are tangential distortion coefficients. There are many other types of lens distortions [11].

We are using a simple two web cameras to create stereo camera since the two cameras almost never have exactly coplanar, row-aligned imaging planes and it's generate horizontal and vertical axis errors. The axis errors correction improved by image rectification method. Epipolar geometry is one of the basic facilities of the stereo image processing. Image rectification is a transformation process used to project two-or-more images onto a common image plane. This method increases the processing speed to find corresponding points [9, 10,11].

2.2 Object Detection

In Computer vision one of the research direction is to track a moving object in real-time. There are many ways to track the object in real-time and is to track the object based on its color characteristics[14,15,16]. The color identification method has some advantages which are high processing speed, simple to use, not influence in geometry changes like turn, dimensions change. But this method has disadvantages for the lighting changes, shadows, glare and reflections.

We use HSV(hue-saturation-value)color model for tracking the object and convert initial RGB image to HSV image. After color conversion to filter out tracking object have been used threshold, erode, dilate functions in OpenCV.

The threshold:

$$g(x,y) = \begin{cases} 1 \text{ if} f(x,y) \geq T \\ 0 \end{cases}$$

Erosion:

The main purpose of the erosion function is to eliminate the points out of object border

$$E = I \ominus S \tag{10}$$

$$E(x) = \begin{cases} 1 \text{ if} S \text{ fits } I \text{ at } x \\ 0 \end{cases}$$

Dilation:

The main purpose of the dilation function is to expand the borders of the object.

$$D = I \oplus S \tag{11}$$

$$E(x) = \begin{cases} 1 \text{ if} S \text{ hits } I \text{ at} x \\ 0 \end{cases}$$

The object appears to be tracked in the image plane, after applying above functions. The tennis ball is the object for our experiment. The center of the ball in both images is found by filtering and the process is similar to finding corresponding points between two images. Using center of the object we calculate disparity value (12).

$$d = x_l - x_r \tag{12}$$

Here, x_l and x_r are center of the ball in the left and right images correspondingly and*d* is disparity.

3. Results of experiments

This section describes practical measurement results of moving ball experiments in real time and 3D mapping of the experiments.

3.1 Calculating matrices

We use two ordinary web cameras to create a stereo camera and using the hardware we obtain pairs of images to produce stereo images. In order to get correct stereo images, certain parameters should be calculated, for each camera, such as internal parameter matrices M1and M2, lens distortion parameter matrices D1 and D2, rotation matrix R for the relationship between the cameras, and translation matrix T. The calculated values are following.

$M1 = [\,1031.186, 0., 278.083, 0., 1031.186, 210.942, 0., 0., 1.\,]$
$D1 = [\,-0.094, 2.631, 0., 0., 0., 0., 0., 14.956\,]$
$R = [\,0.999, 0.006, 0.039, -0.006, 0.999, 0.003, -0.039, -0.003, 0.999]$

$M2 = [\,1031.186, 0., 296.788, 0., 1031.186, 202.531, 0., 0., 1.\,]$
$D2 = [\,-0.094, 0.349, 0., 0., 0., 0., 0., -6.884\,]$
$T = [\,-6.776, -0.0316, -0.402]$

The determination of above parameters for the stereo camera gives us to make correct for stereo image rectification. One can make next step as determining correspondence of points for the stereo pairs. Although image is 2D dimensional quantity the results of rectification allow us to find correspondence of pairs of points in stereo images in 1D dimension. As a result, the processing steps repair the deviation errors.

After determining the correspondence of points, we moved the ball slowly away from the camera to determine relationship between disparity and distance, and the results of measured distance and disparity is in Table 1.

Table 1. Distance and disparity relationship dependence

Disparity(pixel)	570	415	304	232	184	152	124
Distance(cm)	10	15	20	25	30	35	40

Figure 1 shows the dependence of disparity and distance. As seen from the graph, the dependence of disparity and distance from the camera is in inverse relation to each other.

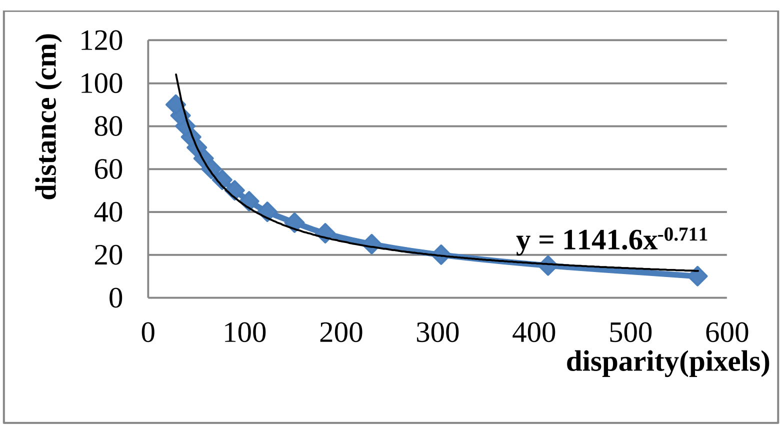

Figure 1. Graph of disparity and distance dependence

After completion of the preparatory phase, we implemented object identification which consists of converting RGB color from stereo camera to HSV format (Figure 2a). The Color thresholding (Figure 2b), removes unwanted distortions, appearing due to uneven lighting and similar colors, while erosion method (Figure 2c) and restoring partially destroyed shape of the ball using method of dilation. Lastly, it is able to track moving orange ball (Figure 2d).

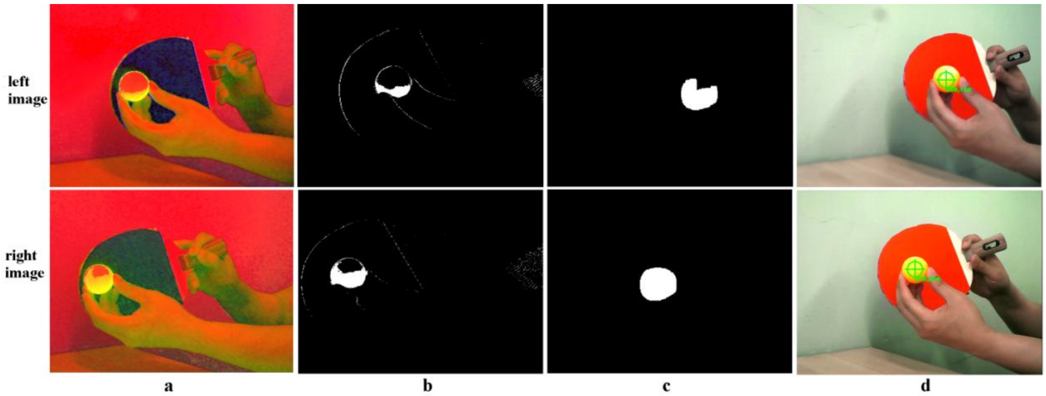

Figure2. a. RGB to HSV image from stereo camera, b. Color thresholding, c. Removing unwanted distortions, d. Restored stereo image

3.2 Collecting data

Using the method described above we collected tracking data in real time and simultaneously stored it in a file. The ball movement was created in such a way that, starting near the camera and moving the ball in a spiral away from the camera gradually increasing the radius of the trajectory for one minute.

The experiments were repeated several times and using the raw data stored in the file the trajectory has been recreated in 3D graph shown in Figure3,where the direction of ball movement is marked with the red arrow.3D coordinates of the ball calculated by following equations.

$$Z = \frac{B*f}{d} \tag{13}$$

$$\begin{bmatrix} X \\ Y \end{bmatrix} = \begin{bmatrix} x_l \\ x_r \end{bmatrix} \times \frac{Z}{f} \tag{14}$$

Here, *B* is base line between two cameras, *f* is focus length of camera.

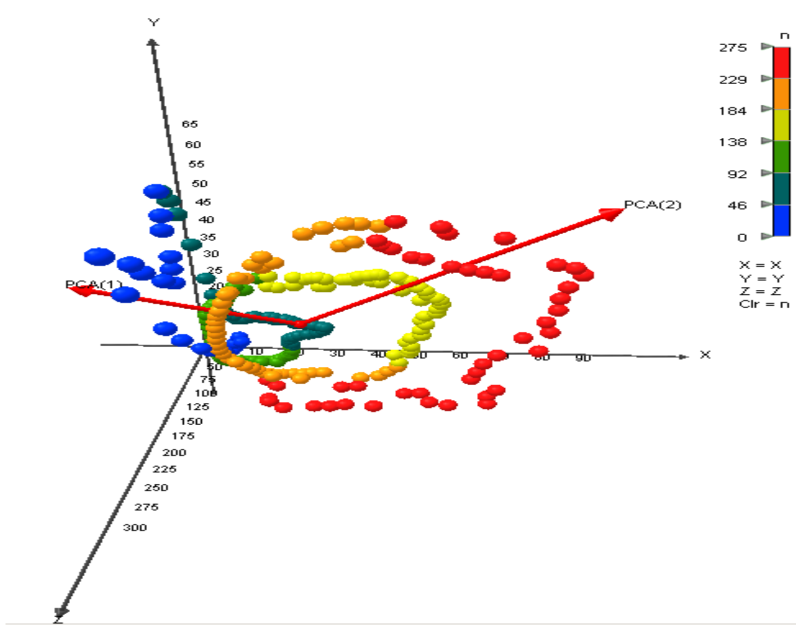

Figure3. Direction of Ball movement.

3.3 Filtering

Figure 4 shows the three-dimensional graphical representation of the movement. The numerical values of the data is highly unstable and it has to be filtered from noise. One of modern approach for filtering sensor data from noise is Kalman filter based on probability estimation [17]. When process model is unknown or when one has only noisy output signals from sensors the state space equations of discrete Kalman filter become as (15) and in this case 3×3 dimensional A, B, C matrices equal to identity matrix.

$$\begin{gathered} \hat{x}_{n+1}^{-} = \hat{x}_n \\ \hat{y}_n = \hat{x}_n \\ P_{n+1}^{-} = P_n + Q \\ K_n = P_n^{-} * (P_n^{-} + R)^{-1} \\ \hat{x}_n = \hat{x}_n^{-} + K_n(y_n - \hat{y}_n) \\ P_n = (I - K)P_n^{-} \end{gathered} \tag{15}$$

Where $\hat{x}_n^{-}, \hat{x}_n$ are priori and current states, P_n^{-}, P_n are priori and current predictions of mean, $y_n, \hat{y}_n$ are outputs of the sensor and the filter, K_n is Kalman gain of *n-th* step and A, B, C are discrete time state matrix, input matrix and measurement matrix correspondingly. Also it was assumed that for the filter, when programming in MATLAB, the process noise covariance $Q = 0.001$ and measurement noise covariance $R = 1$. Results before (left) and after (right) filtering are presented in Figure 4. It is seen that the first picture shows randomly scattered noisy data so it is not so clear the trajectory of the ball but in the second picture the ball movement trajectory is very clear.

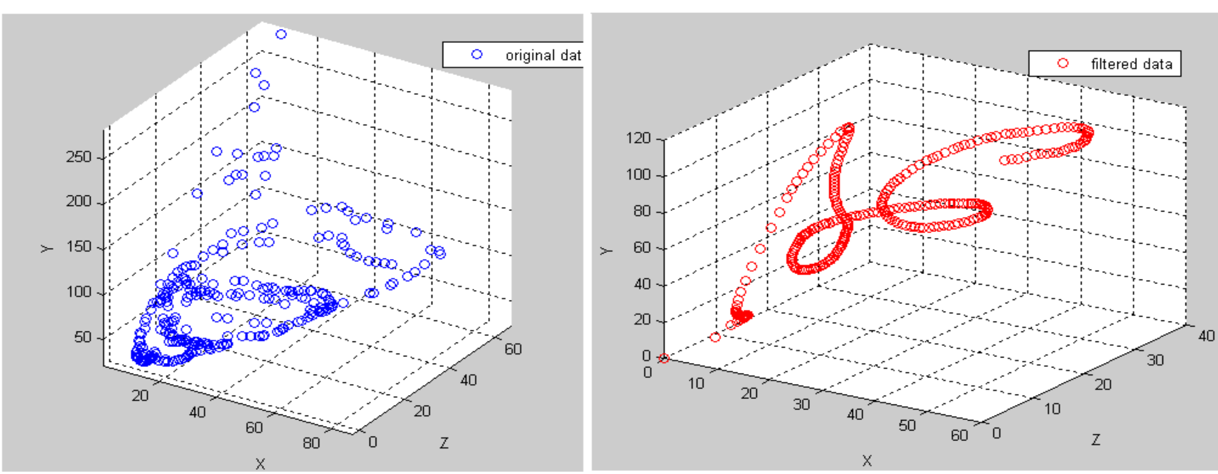

Figure 4. 3D raw data (left) plot and filtered 3D data (right)

4. Conclusion

This article introduced object detection method based on color contrast information and tracking of an object in 3D space in real time. Two simple web camera based stereo camera pair is set up. Using the camera rig rectification, internal and external parameter corrections, angle error calculation and correction of stereo pair of images are done in the experiment. Using this method a moving object can be tracked in 3D space regardless of its geometric shape, degree of dimensional change and different color in real time. However, it was found some difficulties due to uneven lighting in identification of the object.

Stereo image rectification processing and editing methods using a stereo pair of images depend on geometry makeup points. With the above steps we are able to determine the exact distance between the object and the camera.

Further, it is clear that in identification of an object can be used combination of color and shape of the object and this combined method could minimize errors due to lighting changes. Moreover, by knowing the changes of incoming frames we might become able to calculate speed and acceleration, predict future position of the moving object. Also, what we have reached is for one object, it is possible to follow in real-time 3D space more than one object.

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