Determining the orientation of the observed object in three-dimensional space using stereo vision methods

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Abstract. The task of matching an object with its template is central for many optoelectronic systems. Solution of the matching problem in three-dimensional space in contrast to the structural alignment in the image plane allows using a larger amount of information about the object for determining its orientation, which may increase the probability of correct matching. In the case of stereo vision methods for constructing a three-dimensional image of the object, it becomes possible to achieve invariance w.r.t. background and distance to the observed object. Only three of the orientation angle of the object relative to the camera are uncertain and require measurements. This paper proposes a method for determining the orientation angles of the observed object in three-dimensional space, which is based on the processing of stereo image sequences. Disparity map segmentation method that allows one to ensure the invariance of the background is presented. Quantitative estimates of the effectiveness of the proposed method are presented and discussed.

1. Introduction

The fundamental problem arising in the process of matching is the problem of prior uncertainty due to the variability of object and shooting conditions (angle and lighting), as well as a lack of information about the properties of object. There are two basic approaches to the determination of the angle of observation or combination of reference and current visual information that can be divided by the fact whether there is alignment in the image plane or in three-dimensional space. In the first case, the current image should be aligned with the template image formed for the corresponding angle, distance, lighting conditions and background [1]. In this approach, the number of templates for each object can be quite large, and the process of aligning with each of them to establish the angle could become resource consuming.

In the second case, the alignment should be made for the reconstructed disparity map and three-dimensional model of the object [2]. Data on the three-dimensional shape of an object is initially presented in a form invariant to lighting conditions. Invariance w.r.t. background is also easily reached by depth map segmentation as a background has zero disparity. Furthermore, invariance w.r.t. distance to the object which is extracted by stereovision methods is automatically achieved. These features of the second approach can provide a higher probability of correct matching. To determine the relative orientation of the observed object in the processing sequence of stereoscopic images one can use the methods of alignment the three-dimensional model of the object reconstructed on the basis of dense depth maps for images from a sequence of stereo pairs. In this paper, we propose a method that uses the approach described above to determine the orientation angles of the object in three-dimensional space.
2. Modeling and obtaining baseline data

In the course of this work orbital space flight simulator Orbiter 2010 [3] was used as a basis for the modeling system. Software that uses a graphical module OGLA, which allows visualization of the processes of change the relative position of the observer and the investigated object, was developed. This program implements emulation for a stereo imaging of observed scene with the automatic change of camera parameters that allows the study of algorithms in various stereovision conditions.

At the second stage additive white Gaussian noise with the specified signal/noise ratio is superimposed on the obtained images of stereo pair. The resulting disparity maps were generated using Semi-Global Stereo Matching algorithm (SGM) [4]. This algorithm is showed its effectiveness at the stage of preliminary studies, because firstly, it was comparable in speed with local algorithms, and secondly, as compared with Graph cuts and Belief Propagation, it provides a better smoothness for various disparity values.

3. Disparity map segmentation algorithm

Due to the fact that even at the signal / noise ratio of 21, there is considerable distortion in the background region of the resulting disparity map, an important part of the work was to develop a method of disparity maps filtration in order to separate the observed object and background. Suggested algorithm consists of combination of SURF for key points detection and binarization with the addition of morphological operations. It can be represented as the following steps, as shown in Figure 1.

![Figure 1. Steps of filtering disparity maps: smoothed disparity map with highlighted key point (a), application of thresholding (b), application of opening (c), median filtering and selection of the largest contour (d), disparity map after filtering and segmentation (e).](image)

4. Algorithm for determining the orientation angles of the observed object

4.1. Peculiarities of the algorithm. The input data of the developed algorithm is a pair of segmented disparity maps. At the first stage with the knowing of the virtual camera of the simulation system internal parameters the reconstruction of point clouds in three-dimensional space is carried out. Then in the case of temporary delays or low frequency mode rough alignment on the 4 corresponding points is performed using previously obtained key points (SURF). To obtain more accurate values of displacements iterative optimization is performed using the ICP method [5].

The result of ICP algorithm is a rigid transformation of initial point clouds, which may be represented by the transformation matrix. Knowing the transformation matrix the Euler angles can be restored. Excluding shift angles it can be expressed for the three axes of rotation of the elements of the transformation matrix as follows:

\[ \theta_x = \arctan(2a_{32}, a_{33}) \]  
\[ \theta_y = \arctan(2(-a_{31}, \sqrt{a_{32}^2 + a_{33}^2})) \]  
\[ \theta_z = \arctan(2(a_{21}, a_{11})) \]
4.2. Experimental results. The proposed algorithm has been tested for the following situations:
1. Object of simple shape «Pioneer-1», turn on the Y axis by 10 degrees.
2. Object of simple shape «Carina», turning on the X axis by 15 degrees and the Y-axis by 10 degrees.
3. Object of complex shape «Dragonfly», turning on the Y-axis by 20 degrees.

Table 1. Quantitative evaluation of the effectiveness of the algorithm.

| Situation | Axis | Initial angles, degrees | Obtained angles, degrees | Error of the algorithm, degrees |
|-----------|------|-------------------------|--------------------------|---------------------------------|
| 1         | OX   | 0                       | -0.43                    | 0.43                            |
|           | OY   | 10                      | 7.87                     | 2.13                            |
|           | OZ   | 0                       | 0.45                     | 0.45                            |
| 2         | OX   | 0                       | 1.82                     | 1.82                            |
|           | OY   | 10                      | 6.33                     | 3.67                            |
|           | OZ   | 15                      | 13.25                    | 1.75                            |
| 3         | OX   | 0                       | 0.16                     | 0.16                            |
|           | OY   | 20                      | 15.16                    | 4.84                            |
|           | OZ   | 0                       | 2.73                     | 2.73                            |

5. Conclusion
Analysis of the experimental results of this algorithm allows saying that there is a relationship between the magnitude of the error in determining an object's orientation and the direction of change in orientation. The rotation along the OY axis significantly increases the error in the determination of the angle, which can be explained by a small change of the resulting maps range due to the symmetrical shape of the observed objects. At the same time, rotations in other directions determined with higher precision, the value of the error amounted to 1-2 degrees. The developed algorithm allowed demonstrating the principal possibility of determining orientation of the observed object using stereo vision methods, but for more detailed qualitative and quantitative evaluation of the algorithm one should develop more detailed standards of the object.

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