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OPTICAL FLOW BASED SYSTEM FOR DETECTION OF DYNAMIC OBJECTS FOR UAVS

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This work presents an optical flow based method for obstacle detection by using a single CCD camera. Computed optical flow is used to detect dynamic obstacles in front of the camera and to adjust rotor's control to avoid them. The proposed system is based on optical flow estimation with weighted image blocks from the streamed video. Hardware simulation is performed to prove the applicability of this system. Methods and algorithms described in this paper are versatile enough and can be implemented for various vehicles with autonomous navigation system. The feasibility of the proposed system for UAVs is discussed

Keywords: UAV, autopilot, optical flow, least squares method, the sum of absolute differences, detection of objects, avoidance of obstacles

Introduction

The widespread use of unmanned aerial systems poses safety problems for their use. An urgent task is to identify the obstacles encountered along the trajectory of UAV motion. Obstacles may be either static or dynamic. Birds, other UAVs and various flying objects in the air are accounted as dynamic obstacles for the UAV. An algorithm is suggested to detect moving dynamic obstacles on the basis of calculation of the field of motion. For a small size of UAV obstacle avoidance system must be light, small, and less power consumption, therefore, special considerations for safety flight must be taken into account in order to apply such system on small vehicles. The proposed algorithm selects the objects whose speed are greater than the velocity of the back-ground field.

Recent developments in surveillance technologies and data processing enable us to solve the problem of automatic object analysis through visual images. There are several limitations of automatic object detection through image analy-sis. First, dimensions of the object are limited by the spatial resolution of the registration system. Second, brightness of the object should be above noise level of the sensor. These problems arise in the detection of moving objects in front of the UAV camera which can lead to lower performance of the collision avoidance system.

The stereoscopic approach accomplishes this using a pair of stereo images by estimating the disparity and using triangulation, where as the monocular approach accomplishes this using sequential images and evaluating the optical flow. The monocular approach additionally requires the knowledge about the egomotion of the camera which can be obtained either by an inertial measurement unit (IMU) [1] or based on optical flow [2, 3]. The structure of optical flow is traditionally regarded as a procedure for rating the brightnessgeometric changes between the present (current) and the previous frame.

Ideally, the optical flow corresponds to the field of motion, under the stipulation that the objects do not change the energy illuminance at the image plane during the motion in the scene and it enables us to assess the relative motion on the basis of image time changes. A popular scheme is the angle criterion [4, 5] which uses the direction of optical flow vectors. When moving purely translational toward the scene, all flow vectors are parallel to the corresponding epipolar lines and point away from the epipole (focus of expansion). This holds true for the entire static scene. If a measured optical flow vector deviate from this expected flow direction (i.e., if the angle between measured and expected direction is not zero), the corresponding point is moving. This angle criterion indirectly exploits the epipolar and the positive depth constraint. To determine the optical flow or motion field, method of matching blocks is the most widely used. This is due to the universality, low computational complexity, high efficiency, and also because of the simplicity of the hardware implementation. There will be also the discussion about the limitation of optical flow, the difficulties in our project, and the solutions.

Problem Statement

Today the majority of UAVs have limits of their sizes and payload weight that can't carry some systems for avoids obstacles such as radar system. Although radar system have a good performance, but still heavy for small size UAV, based on the reasons stated above, it is necessary to develop a low cost, light weight obstacle avoidance system for UAVs to operate in uncertain environment. In this work, the avoidance system base on the optical flow method by employing a signal CCD camera as sensing images. When the camera detect a image, the optical flow method will computes and marks the obstacles, then the flight controller will guides the UAV through out the obstacles. Optical flow is the pattern of apparent motion of objects, surfaces, and edges in a visual scene caused by the relative motion between an observer, such as an eye or a camera, and the scene. It is the distribution of apparent velocities of brightness pattern movement in an image. Optical flow can arise from relative motion of objects and viewer, so it could give important information about the spatial arrangement of the objects viewed and the rate of change of this arrangement [6]. This theory could be used in motion detection, object segmentation, motion compensation, and stereo disparity measurement. Computing the optical flow it only calculates the image intensity variation, and uses this information to estimate the velocity of a moving object.

Alternatively, based on the use of pixel motion, it is possible to analyze the motion of objects in front of the camera. Optical flow is a two-dimensional motion field, which is a perspective projection true of the three-dimensional velocity field onto the sensor plane visible as a relative motion between objects and the sensor field of view [7]. It is necessary to develop a method that works on homogeneous and heterogeneous backgrounds, and separates the moving objects from the background. The optical flow requires only measurements of the electro-optical sensors to evaluate the kinematic behavior of the object (against the background) without navigation system.

Computation of the optical flow is performed by the block method with the weighted image blocks. The main problem of existing discrete and differential approaches for optical flow computation is their high sensitivity to noise. At the same time the block methods require high computational resources.

Determining Optical Flow

The general procedure of the method work is as follows: the current frame is divided into a plurality of disjoint blocks; for each block of the current frame the most similar block in the previous frame is searched; the difference between the positions of the current and previous block is called the motion vector of the current block [8]. The basic approaches for computing block motion detection are: exhaustive search, template methods, method of hierarchical search and methods using vector candidates. Combined method is proposed, based on the method of exhaustive search using a hierarchical search and reduced number of vectors search. If the image intensity is continuous and can be differential, the image intensity at the instant is equal:

$$I(x, y, t) = I(x + \Delta x, y + \Delta y, t + \Delta t), \qquad (1)$$

where function I is the image intensity, x and y are the location in the image, and is the sampling time.

The advantage of the proposed method is reduced number of vectors search, and thus the increased computational efficiency. However, this advantage is leveled in the case of usage of fixed-size blocks and the search area. However, a fixed block size increases the stability of the vectors in flat areas, since the probability of hitting contrast details increases with increase of the block area. This partially allows solving one of the major problems of block motion estimation methods - the problem of finding vectors in smooth and poorly textured areas. For units of such areas the measure of proximity of current and previous frames takes very similar values for the different motion vectors, so that, the use efficiency of its values as the main criterion for choosing the vector is minimized. To increase the probability of a successful finding of motion vector allows the use of larger blocks, but it is effective only in cases where the block size is larger than the smooth areas size.

Optical flow is useful information even in the case of image deformation of the observed surfaces, but in case of camera motion as a rigid body optical flow is strictly defined by this movement. Let us suppose that the camera moves relatively to a stationary environment. In this case, there are several ways of calculating the relative motion of the camera: discrete, differential and the method of least squares. When the discrete approach uses the information from several points of the image, it requires searching the specific points on the images obtained at different times. The shortcoming of the differential approach is the increasing of noise in the measurement of optical flow at the expense differentiation. Least-squares method for calculating the relative motion of the camera uses the entire field of optical flow. This method takes into account the differences in the available data and is robust enough for the numerical solution.

The complexity of using the discrete and differential approaches in real conditions is their high sensitivity for noise in the received video information. But at the same time, use of the least squares method requires large computational resources. For any movement of the camera and any surface we can determine the corresponding optical flow, and we say that the surface and movement generate the optical flow. Combination the techniques of algorithms of different categories within the class block methods, allowed us to construct a universal detection technology having specified properties and easily implemented in hardware.

Solution of the Problem

In this work we propose a novel method for optical flow computation with high computational efficiency. The advantage of the proposed method of is the search of reduced vector number. The optical flow is a local apparent change in the relative brightness of the image that encodes motion of the objects. Prefiltering with a spatiotemporal Gaussian filter, it is possible to extract signal structure of interest and to enhance the signal-to-noise ratio. This attenuates temporal aliasing and quantization effects. Ideally, the optical flow corresponds to the motion field under the condition, that illumination energy of the object should not be changed on the image plane during the motion. This will allow us to estimate the motion in the video sequence through image changes over time.

Each frame of a video sequence with M × N pixels size is divided into multiple nonoverlapping blocks B_{ij} with the size of n × n pixels:

$$B_{ij}(t) = \{I(x_i, y_j, t) : x_k, y_j \in B_{ij}\}, \qquad (2)$$

$$i - \frac{n}{2} < k < i + \frac{n}{2};\; j - \frac{n}{2} < j < j + \frac{n}{2},$$

where *i*, *j* are coordinates of the block center.

The blocks are processed sequentially from the left to the right, and from the top to bottom. Splitting is done so that all the blocks cover the entire frame, i.e. their total area is equal to the one of the frame. Computation of the optical flow is performed on blocks instead of the whole image, thus reducing computation complexity. Therefore, motion vector $(u,v)_{ij}$ is estimated for each block B_{ij} such that:

$$(u,v)_{ij} = \underset{(u,v)_{ij} \in B_{ij}}{\arg\min} \left(SAD\left(t, i, j, (u,v)_{ij}\right)\right), \quad (3)$$

where $SAD\left(t, i, j, (u,v)_{ij}\right)$ - is a function of blocks similarity, i.e. a measure of blocks proximity in the current and the previous frames. SAD function is used to compare the current block and the corresponding area in the subsequent frame by calculating the absolute difference between each pixel. These differences are summed to create a simple similarity metric.

A method for determining and forming an optical flow is used measurement weighting for image blocks. Additional advantage of this method is noise cancelation, as high-frequency noise is usually removed during image reduction. However, along with high-frequency noise, small objects can also be lost, which will lead to incorrect motion detection in areas of objects. Fig. 1 shows an example of the application of the proposed algorithm for determining the motion from a sequence of images.

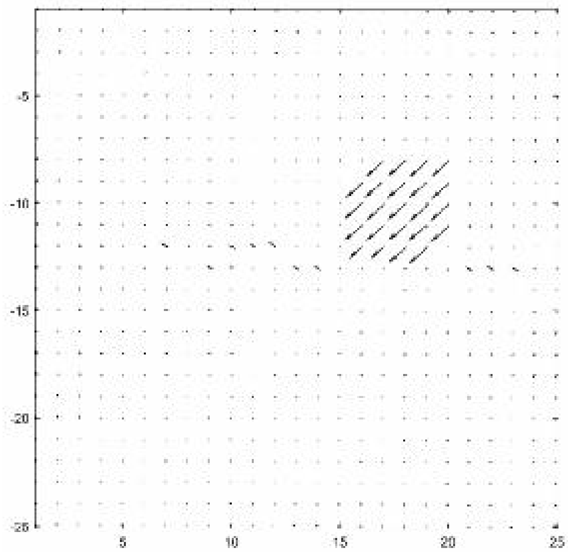

Fig. 1. The field of motion vectors f or the current frame

After estimation of the 2-D motion field, the algorithm separates moving objects from the background by selecting pixels with statistically significant speed. The detection threshold T_V is selected adaptively based on the moving average:

$$T_V = |\mu| \pm K\sigma, \quad (4)$$

where μ is the value of the velocity vector, σ is standard deviation, K is parameter greater than zero.

The next step is the merging of the nearby vectors into a single area. The algorithm calculates coordinates of the center, the average speed and direction of the obstacle motion. The developed algorithm consists of mainly two components: an optical flow estimation, based on the algorithm described above, and a target detector, that selects point objects with a statistically different motion with respect to background. For each pair of adjacent frames, the system computes the global motion, then it extracts potential object pixels, computing their kinematical features. Parameters of the object motion are transmitted to the autopilot input, which analyzes it and makes a decision either to change the flying trajectory (to avoid collision) or to make a full stop. In case of the full stop decision, the UAV will be switched to the hovering mode until obstacle leaves the potential path of the UAV.

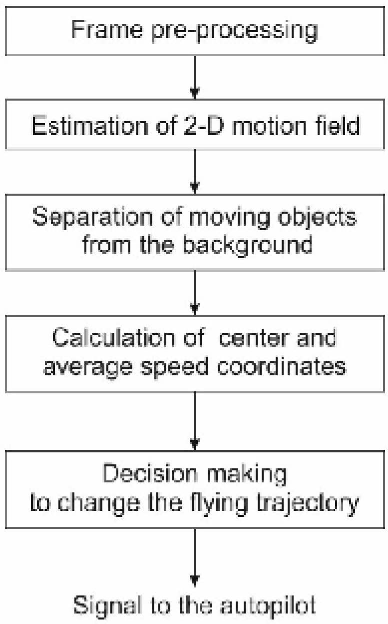

Fig. 2. Algorithm for detection and avoidance of dynamic obstacles

Public computer libraries were used in implementation of the system. One of such libraries is an open source computer vision library (OpenCV), which is designed with C/C++ programming languages and works with popular operating systems (Linux, Windows and Mac OS X). Various existing digital processors, such as NVIDIA's general purpose graphics processing unit (GPGPU), achieve the required computing performance.

Practical Results

Real-time experiment results are presented in this section to validate the performance of UAV during autonomous flight. Obstacle detection was carried out in real time. Autopilot Pixhawk and autopilot producer AVIA KhAI design bureau were used for experiments. As well, the effects of increasing oscillation velocity on the algorithm performances were analyzed. Our system showed correct obstacle detection with a probability of 85% at 25 FPS. Experimental results emphasize the reliability of the algorithm in terms of high detection accuracy and fast processing time.

In order to perform autonomous collision avoidance, as already anticipated an UAV has to be endowed with different capabilities: the capability to develop situational awareness and identify potential threats for flight safety and the capability to perform evasive maneuvers and then recover its nominal trajectory. From an engineering point of view, both capabilities require that ownship dynamics is known in real time: naviga-tion system plays a key role. Then, the autonomous collision avoidance module is connected to the flight control system: in case of predicted collision, it has to ask for trajectory modification and then nominal mission recovery.

Fig. 3.Video fragment of moving object isolation in a sequence of video frames. Red rectangle indicates a moving object; green circles marked the center of object

A multi-sensor configuration, such as the one selected for autonomous collision avoidance, allows for integration of different, complementary measurements and information. The resulting system is intrinsically more reliable with respect to a single sensor configuration: the different sensors derive object signatures from different physical processes, and so they generally do not cause false alarms on the same artifacts. Nevertheless, combining sensors' information in an effective way, and respecting the strict real time requirements of the system, is not an easy task.

Conclusions

On the basis of the data of numerical simulation for the test series and several real images, shows the effectiveness of the proposed methods. An analysis of the errors affecting the reliability of the results of objects detection, shows the efficiency and advantage of the methods used in comparison with existing technologies. The level of the system's reliability is evaluated as the ratio of correct detections to the total number of experiments. The experiments were conducted with different backgrounds during the daytime. In summary, the proposed algorithm exhibited a good reliability level in conditions of nice weather, good illumination, and fixed background. As a result, the database of obstacles was collected.

Conflict of Interest

The authors have no conflict of interest.

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