НАВИГАЦИЯ МАЛОРАЗМЕРНЫХ ДРОНОВ С ПОМОЩЬЮ БОРТОВОЙ ВИДЕОКАМЕРЫ

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Представлен алгоритм навигации дрона с помощью бортовой видеокамеры, основанный на сравнении кадров видеопоследовательностей. Алгоритм предназначен для решения задачи возвращения летательного аппарата в начальную точку полета в автономном режиме, без использования сигналов внешних навигационных систем на протяжении всего полета.

Ключевые слова: дрон; автономный полет; навигация; бортовая видеокамера.

NAVIGATION OF SMALL-SIZED DRONES BY ONBOARD VIDEOCAMERA

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The algorithm of autonomous navigation of a drone equipped with one onboard video camera is proposed. It is designed to return the autonomously flying UAV to the starting point of its route without the use of external navigation signals. The algorithm is based on comparative analysis of video frames.

Keywords: drone; autonomous flight; navigation; onboard video camera.

ALGORITHM OF RETURNING SMALL-SIZED DRONES TO STARTING POINT

The implementation of autonomous navigation of small-sized drones are now particular important. These extensively exploited devices have relatively primitive inertial navigation systems that are not able to provide flight along a given trajectory without exploiting signals from satellites or other external systems. They are not able to return home in autonomous mode.

Therefore, the task of autonomous navigation of small-sized drones is currently urgent [1–4].

Below the algorithm to return to the starting point of flight of an autonomously flying drone equipped with an autopilot, an onboard computer and a vertically oriented camcorder mounted on a gyro platform is presented.

It is supposed the drone successfully flew from the starting point along a predetermined route, possibly, by means of external (may be, satellite) navigation signals. During the flight the onboard computer stored in its memory overlapping images of the landscape, shot by the onboard camera. In some instant, the external navigation signals were lost, so the drone navigation system cannot evaluate coordinates of the vehicle with the required accuracy.

The task is to provide the return of the drone to the starting point of its route. The developed algorithm solves this task by matching part of the current image of the landscape, located under the drone, to frames made during machine flight from the starting point along a predetermined path in presence of navigation signals. The proposed approach does not imply the use of any geographical or stationary coordinate systems. It computes the displacement vectors for navigation of the returning drone with help of the found matched. The displacement can be determined, for instance, as the special projective transform of the vector beginning at the point (found by image matching) that corresponds the drone location in some frame, which was shot on device way from the starting point, and ending at the center of this frame. The projective transformation can be calculated explicitly by the focal distance of the camera and the drone altitude.

The correlation and key point algorithms [5, 6] were exploited for image matching.

The applicability of the proposed algorithm has been verified by computer experiments with video sequences shot by the onboard camcorder of the quadcopter DJI Fantom 3, as well as, video sequences made by the USB camera.

In more details. Denote by $\boldsymbol{I}_t$ a sequence of overlapping frames, made by the drone during its flight from the starting point alone its route until navigation signals disappear. Easy calculations show that several gigabyte of computer memory will be enough to store the overlapping frames $\boldsymbol{I}_t$ of landscape image of one hundred kilometers long route. For the sake of simplicity, we will suppose the drone starts the homecoming flight immediately after the loss of the navigation signal. Frames made by the onboard camcorder after the loss of navigation signals will be denoted by $\boldsymbol{F}_t$. Indices t of frames $\boldsymbol{I}_t, \boldsymbol{F}_t$ we will also call by discrete time, believing that the drone had flown along the given route until time $t(0)$, and it started the homecoming flight from discrete time $t(0)+1$.

Our algorithm evaluates the drone coordinates relative to frames $\boldsymbol{I}_t$, shot until time $t(0)$ while the drone had been flown along the given route, by means of matching the central part of the current image $\boldsymbol{F}_t$.

To make the description easier, we suppose that at the beginning of the homecoming route our drone was located over the area of terrain, visible in several frames $\boldsymbol{I}_{t(0)}, \boldsymbol{I}_{t(0)-1}, \dots, \boldsymbol{I}_{t(0)-k}$ (otherwise, before application of the algorithm we should find such area by the special maneuver). We also suppose that at time $t(0)+1$ the drone dropped to the altitude $h_{t(0)+1} = \frac{1}{2} h_{t(0)}$ (or $h_{t(0)+1} = \frac{1}{3} h_{t(0)}$).

The algorithm starts with matching the central part $\boldsymbol{U}_{t(0)+1}$ of the current frame $\boldsymbol{F}_{t(0)+1}$, which contains an image of the landscape located directly under the drone, to regions of previously supplied frames $\boldsymbol{I}_{t(0)}, \boldsymbol{I}_{t(0)-1}, \dots, \boldsymbol{I}_{t(0)-k}$. The found region of the best correspondence will de denoted by $\boldsymbol{C}_{t(0)+1}$ $\left(\boldsymbol{C}_{t(0)+1} \in \boldsymbol{I}_j, t(0)-k \le j \le t(0)\right)$. The local coordinates of the center $\boldsymbol{c}$ of the found region $\boldsymbol{C}_{t(0)+1}$ in coordinate system of the frame $\boldsymbol{I}_j$ are taken as the beginning of the vector $\boldsymbol{v}_{t(0)+1}$, which after will be transformed into the actual drone displacement vector. The end of $\boldsymbol{v}_{t(0)+1}$ is assigned as the center $\boldsymbol{o}$ of the $\boldsymbol{I}_j$. Formally, the vector $\boldsymbol{v}_{t(0)+1} = \overrightarrow{\boldsymbol{co}}$. It means we want the drone to move to the landscape point, which is depicted as the center of $\boldsymbol{I}_j$ (although other preselected parts of $\boldsymbol{I}_j$ can be taken for drone navigation). The vector of the real drone displacement is of the form $\mathbf{d}_{t(0)+1} = f^{-1}\, h_{t(0)+1}\boldsymbol{v}_{t(0)+1}$, where f is the focal distance of the camcorder, and $h_{t(0)+1}$ is its current altitude. Theoretically, after moving the drone by the vector $\mathbf{d}_{t(0)+1}$ we can execute the next step of the algorithm, but practically, due to possible navigation errors the first step has to be repeated until the drone reaches a space point having local x, y-coordinates (in the coordinate system of the frame $\boldsymbol{I}_j$) close to the coordinate of the center $\boldsymbol{o}$ of the frame $\boldsymbol{I}_j$.

Assume that the m-th step of the algorithm ended at time $t(m), (t(m) \geq t(m-1) + +1)$, then $m + 1$-th step of the algorithm, in fact, repeats its first step for the sequence of supplied images $\boldsymbol{I}_{j(t(m))}, \boldsymbol{I}_{j(t(m))-1}, \dots, \boldsymbol{I}_{j(t(m))-k}$, which starts with the frame $\boldsymbol{I}_{j(t(m))}$ consisting the region of the best match with $\boldsymbol{U}_{t(m-1)+1}$.

Fig. 1. Quadcopter Fantom 3 Professional with camcorder mounted on gyro platform

The algorithm has been tested by several video sequences. Part of them were shot by USB camera, the other one were made by onboard camcorder mounted on the quadcopter DJI Fantom 3 that is depicted in fig. 1.

Video sequences were devided into two parts. Their first parts contained pictures of the landscape under drone during its flight from the starting points, the rest frames were made while it was coming back.

Examples of found matches of landscape regions in first and second parts of videos are shown in fig. 2.

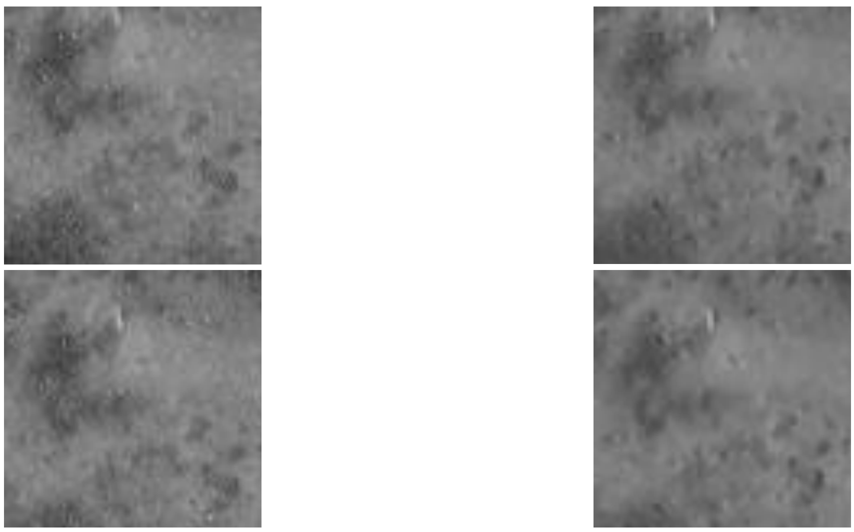

Fig. 2. Examples of found matches of local regions $\boldsymbol{U}_t$ and $\boldsymbol{C}_t$ of frames $\boldsymbol{F}_t$ and $\boldsymbol{I}_{j(t)}$

Experiments with available videos of both types showed applicability of the proposed algorithm. Correlation and key point algorithms were exploited to perform image matching.

The best of them provided matching process with satisfactory accuracy and reliability. Although, in our view, correlation algorithms proved to be more robust. They matched almost 100 % frames correctly. The obtained results allowed to simulate autonomous navigation of drone in order to imitate its return to the starting without use of an external navigation signals and global coordinate systems.

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