A Vision System for UAV Position Control

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Abstract—In this paper, we propose a vision-based control system for the localization of an unmanned aerial vehicle (UAV) which equips on-board cameras. [1 2] The proposed approach is combined a visual odometer with inertial measurement from IMU and pressure signal which compensate attitude and altitude, respectively. For the autonomous control of a UAV, we consider only natural landmarks provided by a feature tracking algorithm without the help of visual beacons or landmarks at known positions. The displacement of the UAV is estimated by the homography, the relationship between a pair of points. The experimental results show that it is possible to extract useful position information from the proposed vision system even when the UAV flies high, and the information can be used temporary position control of UAVs during GPS failure.

TABLE OF CONTENTS

1. INTRODUCTION

As the use of an Unmanned Aerial Vehicle (UAV) becomes diverse, the adaptability of the UAV to the operated environment is necessary. For fully autonomous UAV navigation, there are several problems which have to be solved before a UAV is introduced. One of the problems is GPS integrity. General UAV navigation systems rely on GPS and inertial sensors (INS) to reach a predetermined destination, especially for long distance flight. The GPS signal, however, is sometimes unavailable due to radio jamming or multi-path reflection during flight [1]. During GPS failure in few seconds, the INS alone flight may cause fatal drift and unstable state. In order to reduce the drift error, the proposed visual navigation method using vision sensors can give useful means.

Vision sensors are frequently used for the navigation of mobile robots. Compared to other sensors, e.g. laser sensors, video cameras are cheap and spend less power. Also, it is affordable for mounting on UAVs due to light weight. Passive cameras, however, are sensitive to light condition.

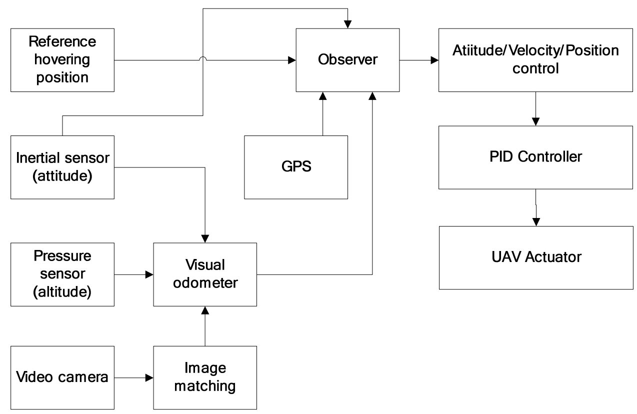

Figure 1 Vision-aided sensor fusion architecture

Vision control has been active field of research in robotics. In the case of UAV, visual odometer was proposed for autonomous flight. [2] and [3] suggest the system employing on board stereo vision for stability and guidance relative to objects of interest in the environment. But the UAV using the stereo vision system for extracting the altitude cannot fly high due to its limited measurement range. In our experiments, the altitude parameter was estimated from a precise pressure sensor. [4] shows a real time computer vision system for tracking a landing target. It presents the design and implementation of a real time vision system for the UAV to estimate its state relative to a known landing target. [5], [6] and [7] use unknown features, i.e. natural landmarks. But their vision system cannot be used in the simple terrain (for example desert or sea) which does not have features.

The proposed system in this paper is an inertial aided visual odometer. Unlike the system using only the image data from on-board camera, the proposed one gets the parameters for perspective projection from a 6 DOF inertial sensor and a pressure sensor. It is effective to reduce the system load, and possible to control the UAV more precisely. The proposed algorithm uses combined information of various sensors, which need high precision synchronization. [8] proposes a solution using quaternion equations.

On board monocular camera provides the consecutive image frames to the navigation system. In our feature based image matching algorithm, KLT feature tracker finds the natural landmarks from two subsequent frames and estimates the

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[2] IEEEAC paper#1233, Version 1, Updated 2011:01:12

Figure 2 Ducted-fan type MAV(TDL40)

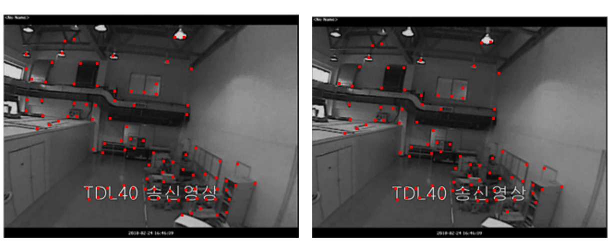
displacements between a pair of features [9]. If any two images share three or more points extracted from the tracking results, we can measure the homography matrices used in 3D projective geometry between each image capturing sequence.

The architecture proposed in Figure 1 shows the vision aided system instead of GPS. The visual odometer finds out the velocity of the UAV and sends the value to position control system using the PID controller

An experimental autonomous UAV platform, a 50cm-diameter ducted-fan type MAV(Micro Air Vehicle) mounted a 26cc gasoline engine, as shown in Figure 2, is used as a test-bed for the development and test of a navigation algorithm during GPS failure.

2. IMAGE MATCHING

The image matching method developed in this work is based on the KLT feature tracker. For estimating the relative displacement, the system tracks the point of corresponding features from two subsequent frames. The points have coordinates (x, y) based on the image plane.



(a) First image (b) Second image

Figure 3 The KLT tracking results when the pair of inp ut images have large displacements

Figure 3 show the feature tracking result. During the time in terval between subsequent frames, 0.1sec, the tracked featur es are matched up to 65%. The disappearing features proble m can then be solved by this periodical registration.

3. VISUAL ODOMETER

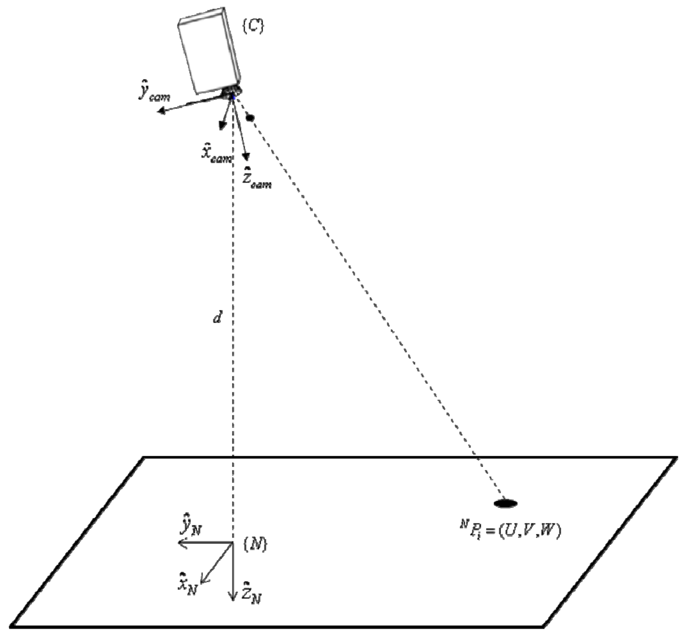


Figure 4 The pinhole camera model

Perspective projection

The pinhole camera model is shown in Figure 4. The origin in the world coordinate system is projected point to ground surface from the camera point. ${}^{N}P_i$ is tracked feature point of the navigation coordinate.

In this application features in the image are tracked up to 100. Once the features are detected in the image frame, they are projected onto the world coordinate using by Equation (1):

$$P_i = \frac{1}{Z} K\,{}^{C}P_i = \frac{1}{Z} K\left({}^{C}_{N}R\,{}^{N}P_i - {}^{C}D\right),$$

$$P_i = \begin{bmatrix} x \\ y \\ 1 \end{bmatrix},\ K \begin{bmatrix} f & 0 & 0 \\ 0 & f & 0 \\ 0 & 0 & f \end{bmatrix},\ {}^{C}P = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix},\ {}^{N}P = \begin{bmatrix} U \\ V \\ W \end{bmatrix} \quad (1)$$

then

$$ {}^{N}P_i = {}^{C}_{N}R\, {}^{N}P_i - {}^{C}D \quad (2) $$

$$ {}^{N}_{C}R \begin{bmatrix} \frac{Zx}{f} \\ \frac{Zy}{f} \\ Z \end{bmatrix} - {}^{N}T = \begin{bmatrix} U \\ V \\ W \end{bmatrix} \quad (3) $$

where K is the cameras' intrinsic parameter matrices that have the focal length of the on board camera and ${}^{N}_{C}R[u, v, w]^T$ is a rotation matrix. The rotation parameter is the relative pose with the world coordination. So we can get the value from inertial sensors. T^N can assume that $[0, 0, -d]^T$ in Figure 3.

$$ \begin{bmatrix} {}^{N}_{C}R_{11}\cdot\frac{Zx}{f} + {}^{N}_{C}R_{12}\cdot\frac{Zy}{f} + {}^{N}_{C}R_{13}\cdot Z \\ {}^{N}_{C}R_{21}\cdot\frac{Zx}{f} + {}^{N}_{C}R_{22}\cdot\frac{Zy}{f} + {}^{N}_{C}R_{23}\cdot Z \\ {}^{N}_{C}R_{31}\cdot\frac{Zx}{f} + {}^{N}_{C}R_{32}\cdot\frac{Zy}{f} + {}^{N}_{C}R_{33}\cdot Z - d \end{bmatrix} = \begin{bmatrix} U \\ V \\ W \end{bmatrix}, \quad W = 0 \quad (4) $$

$$ Z = \frac{d}{R_{31}\cdot\frac{x}{f} + R_{32}\cdot\frac{y}{f} + R_{33}} \quad (5) $$

In Equation (5), Z can be computed. So, we can get (X, Y, Z) is the point as seen from the camera in Equation (1).

Homography method

We have the coordinates, ${}^{a}P_i$ and ${}^{b}P_i$, at two subsequences, a and b, looking for the point P_i. The coordinate transformation matrix, the homography H_{ab}, is

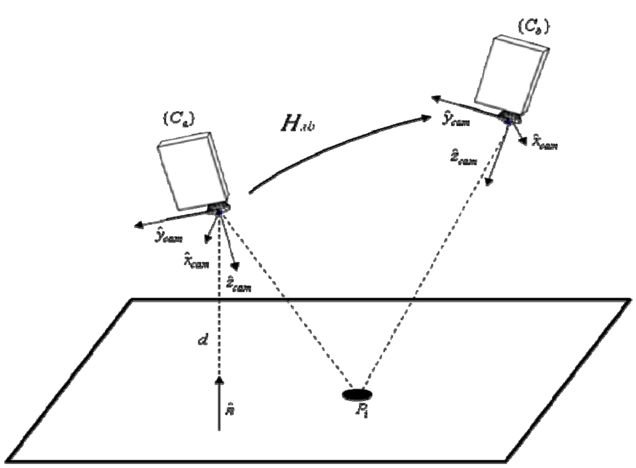


Figure 5 The homography matrix

$$ {}^{b}P_i = {}^{b}_{a}R\cdot{}^{a}P_i - {}^{b}T = H_{ab}\cdot{}^{a}P_i \quad (6) $$

$$ \frac{{}^{b}Tn^T}{d} P_i = {}^{b}T \quad (7) $$

From Figure 5, n^TP is the projection of vector P_i into n^T, and equal to d. The homography matrices are obtained from Equation (6, 7) as

$$ H_{ab} = {}^{b}_{a}R - \frac{{}^{b}Tn^T}{d} \quad (8) $$

The final equation of homography relations is obtained from Equation (6, 8) as

$$ {}^{b}P_i = \left({}^{b}_{a}R - \frac{{}^{b}Tn^T}{d} \right) {}^{a}P_i \quad (9) $$

where ${}^{b}_{a}R$ can be estimated by the difference between a and b of the value of the angle from inertial sensors. Also, n^T and d are estimated by on board sensors. When the Equation (9) summarized with respect to t, we can obtain a vector, ${}^{b}T[X, Y, Z]^T$, between a and b.

$$ X = \frac{\left({}^{b}_{a}R_{11}\cdot{}^{a}X + {}^{b}_{a}R_{12}\cdot{}^{a}Y + {}^{b}_{a}R_{13}\cdot{}^{a}Z - {}^{b}X \right)}{{}^{a}R_{13}\cdot{}^{a}X + {}^{a}R_{23}\cdot{}^{a}Y + {}^{a}R_{33}\cdot{}^{a}Z} d \quad (10) $$

$$ Y = \frac{\left({}^{b}_{a}R_{21}\cdot{}^{a}X + {}^{b}_{a}R_{22}\cdot{}^{a}Y + {}^{b}_{a}R_{23}\cdot{}^{a}Z - {}^{b}Y \right)}{{}^{a}R_{13}\cdot{}^{a}X + {}^{a}R_{23}\cdot{}^{a}Y + {}^{a}R_{33}\cdot{}^{a}Z} d \quad (11) $$

$$ Z = \frac{\left({}^{b}_{a}R_{31}\cdot{}^{a}X + {}^{b}_{a}R_{32}\cdot{}^{a}Y + {}^{b}_{a}R_{33}\cdot{}^{a}Z - {}^{b}Z \right)}{{}^{a}R_{13}\cdot{}^{a}X + {}^{a}R_{23}\cdot{}^{a}Y + {}^{a}R_{33}\cdot{}^{a}Z} d \quad (12) $$

The UAV displacement between two subsequent frames is calculated by RANSAC [10] the displacement of all the features tracked in the image.

Finally, the position at a certain time t is calculated by the o dometer Equation (13).

$$ {}^{N}P(t) = {}^{N}P(t_0) + \sum_t {}^{N}_{b}R(t)\cdot{}^{b}T(t) \quad (13) $$

where ${}^{N}P(t_0)$ is the position at time t_0 when the last useful GPS reading was available. Figure 6 is shown that displacements of the UAV by the tracked natural features.

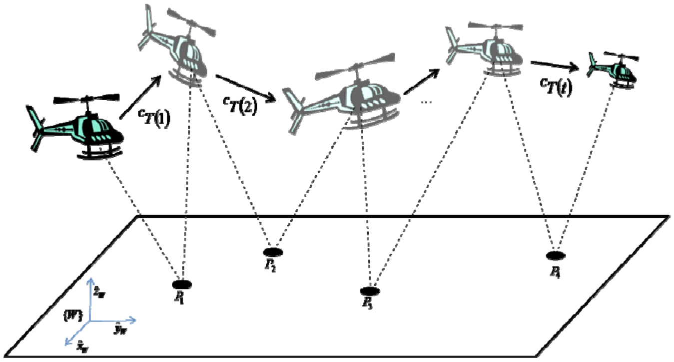


Figure 6 The homography matrix

4. Experimental results

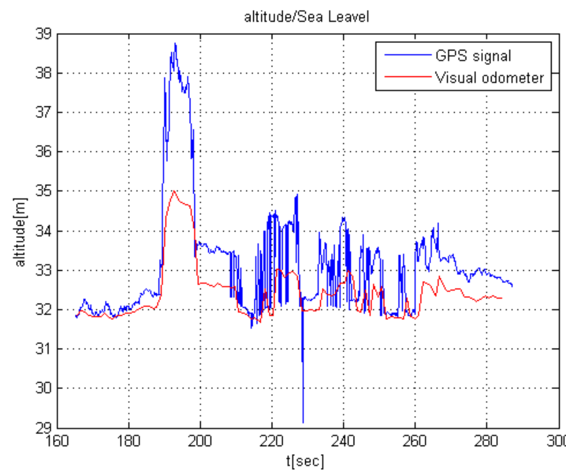
Figure 7 is shown that the matching points and displacements from between two frames at each difference positions of the camera. Good features can be found in places have the texture like trees or road. The feature tracker extracts corresponding point order of accuracy up to 100. But it cannot filter the bouncing value arising from false positive in the tracking KLT algorithm. The critical error could affect the results by feature tracker algorithm will be removed by the RANSAC.

The image source from on board camera and inertial sensor data send to ground station by 5Ghz wireless lan. The captured image data is a resolution for 320x240. The system is able to communicate up to 2km and 300Mbps in the open space. And this matching algorithms to operate 10hz at the ground station.

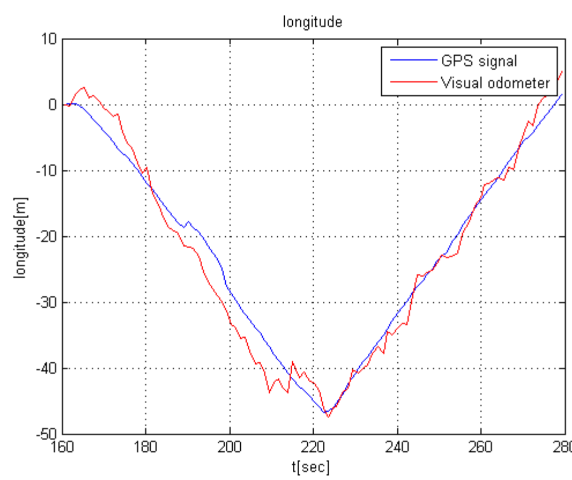
(a) First image

(b) Second image

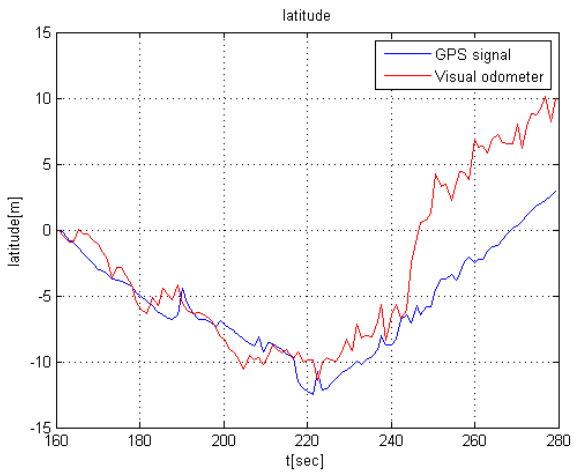
Figure 7 The KLT tracking results when the pair of inp ut images have large displacements



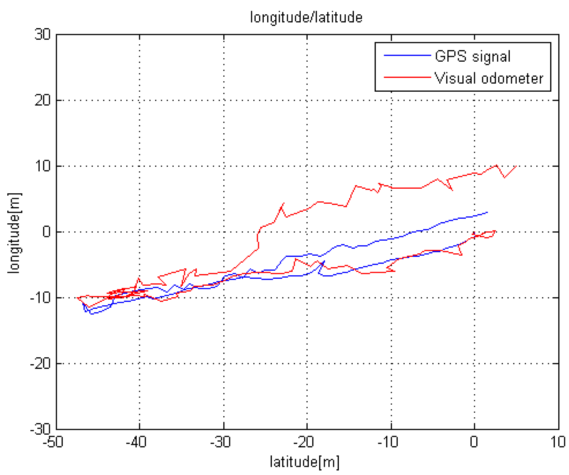
(a) Altitude data



(b) Longitude data



(c) Latitude data



(c) Longitude and Latitude data

Figure 8 The KLT tracking results when the pair of inp ut images have large displacements

Figure 8 is shown that the results of our flight test with the UAV, comparing the output of the vision based state estimation algorithm with the GPS measurements. The errors in the internal and external camera calibration parameters marginally affect some of the estimates. Assuming GPS blockage at 160 sec, translation vector is accumulated every sequence from the first position. So, displacement errors are cumulative over time. Therefore, this system can be used for a few minutes. In our experiment, the draft of the estimated position is causing about 2 minutes later.

The experimental result shows that the vision based system can be used in an autonomous position control and hovering during GPS blockage.

5. Conclusions and Future Work

In this paper, a inertial-aided visual odometry system for safe hovering and position control of Unmanned Aerial Vehicle(UAV) is proposed.

The experimental vision aided UAV positioning system architecture described in this paper has potential to provide a drift-free navigation solution. However, the displacements from the origin during GPS failure can cause drift within a couple of minutes due to error accumulation. So, we need more robust filter to reduce various errors and drift.

Future experiments will be focused on the calibration with r espect to the position vector (absolute value) by matching g eo-
referenced images like the Google maps with captured ones.

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BIOGRAPHY

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