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Physics Procedia 24 (2012) 1701 – 1706

Physics Procedia

2012 International Conference on Applied Physics and Industrial Engineering

Natural-Landmark Scene Matching Vision Navigation based on Dynamic Key-frame

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Abstract

To study a backup navigation scheme for allowing temporally GPS faults or degradations, this paper proposes a dynamic key-frame-based natural-landmark scene matching visual navigation method for UAV. Firstly, this method could autonomously describe and check featured natural landmarks by analyzing image sequence from on-board camera. After abstraction of key-frames including featured natural landmark, UAV will be located by the means of NLSM (Natural-Landmark Scene Matching) which based on dynamic key-frame. Additionally, this navigation scheme adopt inter-frame scene matching algorithm in order to improving the navigation performance of accuracy, reliability and runtime. Experiments show that the vision based backup navigation scheme proposed fitted the requirements of navigation in complex and unknown environment for UAV.

Keywords:dynamic keyframe, natural landmark, interframe scene matching, vision navigation, UAV

1.Introduction

High precision positioning [1] and autonomous navigation technologies [2, 3] for UAV, as well as terminal guidance technology, become currently international focus research. Advanced navigation system in the UAV system plays an important role, which determines whether UAV could accomplish a combat mission successfully.

Currently, UAVs perform a variety of different tasks in complex environment, such as detection, surveillance, identification, tracking, attack, etc., which require a more reliable and precision navigation system than ground navigation station. In the past twenty years, navigation system based on vision for UAV is hard to apply in the unstructured natural environment. Spatially entry an unknown environment remains a tremendous challenge.

In most cases, UAVs use the global position system (GPS) to determine their position. As pointed out in the Volpe Report [4], the accuracy of this estimation directly depends on the number of satellites used to compute the position and the quality of the signals received by the device; radio effects like multi-path propagation could cause the degradation in the estimation. In addition, radio frequency interferences with coexisting devices or jamming could make the position estimation unfeasible.

 doi:10.1016/j.phpro.2012.02.251

Integrated navigation system was developed with high fault tolerance in complex environments for UAV [5]. Scene matching vision-based navigation is commonly used in assisted navigation systems. This method can be a reliable backup system and prevent the UAV lost as GPS failure. Especially, Scene matching navigation system based on natural landmarks can be assisted to localizing and positioning for UAV when GPS blocked. For medium and small size UAVs, maximum payload is often limited. Variety of multi-mode sensors such as 3D or 2D laser scanners are too heavy to be carried on, while the EO / IR vision sensors with light weight, small power, long detection distance, high resolution, are suitable for medium or small UAVs to equip.

In this paper, a new navigation system based on dynamic key-frame natural landmarks scene matching (NLSM) algorithm was proposed. By extracting image feature of real-time image sequences that contains natural landmarks, NLSM finds a series of key-frames. Image mosaic technology [6] was applied to register images sequences with inter-frames. Abandon the "absolute" Scene Matching (register real-time image to base map) , NLSM adopted a "relative" scene matching by registering real-time map to the dynamic key-frame). This strategy is able to deduce big register error in the non-suitable areas with rare characteristics. In addition, in order to eliminate the accumulated error since image sequence registration this paper presents a dynamic key-frame [7] management mechanisms, based on extended Kalman filtering (EKF) technique, location and position of UAV can be updated, as well as reduces the accumulated error of inter-frame scene matching.

2.NLSM Algorithm Principle

Traditional visual navigation technology often requires prior knowledge of the starting coordinates of UAV, as well as the precise coordinates of ground control points. These priori information can improve the accuracy and reliability of visual navigation system, however, in practice, UAV should entry or explore complex or unknown environment for detecting, monitoring, tracking, even attacking, before which it is impossible to pre-set any ground control points. Therefore, it is significant for UAV to study a vision-based natural landmarks scene matching navigation system without bound by prior information.

By analyzing the on-board camera captured image sequence (called "Real-time image sequence" in this paper), NLSM autonomously retrieve the image frame that contains distinct natural landmarks (such image frame called "key-frame" in this paper) and then the key-frame to satellite digital map (called "base map" in this paper) to calculate the geodetic coordinates for UAV.

2.1.Natural Landmark Keyframe

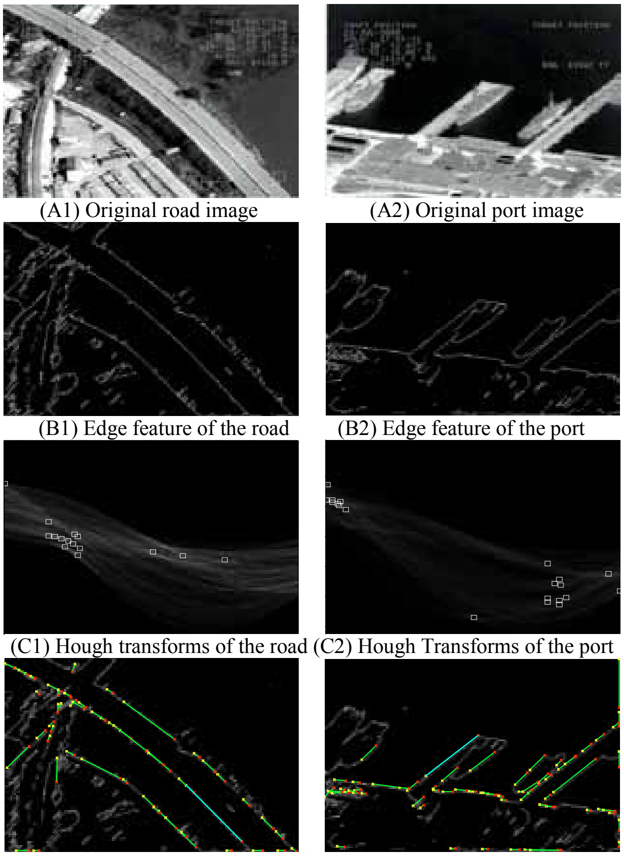
Key-frame retrieve technology [8, 9] was widely used in the field of video analysis and frame extraction technology, which can reduce the redundancy of video data stream. Similarly, the retrieved key frame from real-time image frame sequence, contains distinct natural landmarks, is characterized by obvious features such as rich textures, corner points etc. Key-frame in NLSM algorithm is a special frame with higher matching probability. Simultaneously, since key-frame and real-time image frame sequences are imaging from the same EO/IR sensor, and under the same imaging conditions, and at the same time period to obtain images, which make the inter-frame register to each other based on key-frame uniquely and have the following advantages mainly below:

- There are almost same noise distribution between real-time images and key-frames;
- There are almost none different imaging errors between real-time image and key-frames.

2.2.Selection of Keyframe

Landmark key-frame is characterized by edge features and corner points and amount of continuous geometric curves. The more features the key-frame contained, the higher accuracy of NLSM becomes. Rivers, bridges, ports, roads, airports, and landmark buildings etc., are usually presenting more stable point and edge features, which can be identified as natural landmarks. In this paper, firstly, the original real-time image will be pre-processed through de-noise, enhancement, geometric correction. Then, the edge feature will be extracted for constructing feature space vectors. After random sample consensus computed, the key-frame will be transformed with Hough transform to extract a series of continuous geometric curves. Lastly, based on the threshold preset to judge whether the current real-time image is key-frame or not.

If real-time image contains at least one natural landmark, the real-time image frame can be selected as a "key frame", the frame near the key-frame will be registered to it so called relative registration, that is to say, NLSM navigation for UAVs is based on the inter-frames registered the key-frames and filtered by extended Kalman filter to update locations. Fig.1 shows the Procession of key-frame selection. Experiment parameters here as follows: point threshold more than 20 points and continuous corves more than 15 items.



(A1) Original road image (A2) Original port image

(B1) Edge feature of the road (B2) Edge feature of the port

(C1) Hough transforms of the road (C2) Hough Transforms of the port

(D1) Segmented curves of the road (D2) Segmented curves of the port

Figure 1. Procession of keyframe selection

2.3.Dynamic Keyframe Strategy

Supposed the selected key-frame number is 1…m1, m2…Here we represent $H_{i,j}$ as the local mapping relationships between with the real-time image frame j and its perversions key-frame i. obviously, the value of i is less than j. As the value of i and j increasing, the key-frame label constant updates, the contents of key-frame also change, this procession called "dynamic key-frame" in this paper, as shown in Fig. 2. By using dynamic key-frame strategy, the mapping relationship between the key-frame and real-time images from the first key-frame as follows:

$$\begin{aligned} &M(k) \\ &= M(m^s)\cdot H_{m^s,k} \\ &= M(m^{s-1})\cdot H_{m^{s-1},m^s}\cdot H_{m^s,k} \\ &= H_{1,m^1} H_{m^1,m^2}\cdots H_{m^s,k} \end{aligned} \tag{1}$$

Which m^i said the key-frame labels: $1 < m^i < k, i = 1,\ldots,s$.

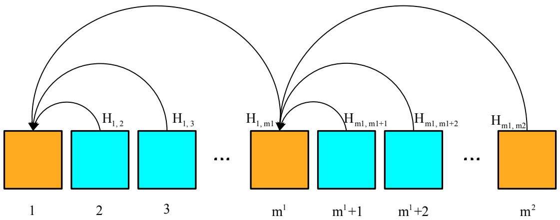


Figure 2. Transform relationship between current frame and keyframe

2.4.Inter-frame Scene Matching

Dynamic key-frame continuously updated with the coming real-time image frames, grouping and circular relationship between key-frames and real-time image frame were shown in Fig.3. Symbol H represents the local mapping model internal

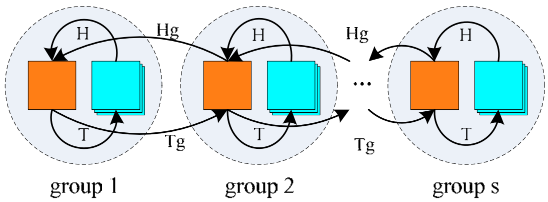


Figure 3. Procedure of inter-frame scene matching

group relationships between key-frame and real-time image frames. Symbol Hg represents the local mapping model external relationships among key-frames. While symbol T represents internal group coordinate transformation between key-frame and real-time image frames. Symbol Hg represents external group coordinate transformation among key-frames.

Suppose $P(X,Y)$ is a dynamic key-frame registered to the base map and its center coordinates is $P_0(X_0,Y_0)$. If the center coordinates $P_m(X_m,Y_m)$ of current real-time image frame m (supposed its index as m) was located on the dynamic key-frame with the "relative" location stratagem of NLSM. Here we can easily compute the coordinates offset: $\Delta p_m(\Delta x_m, \Delta y_m)$, which computed formula is below

$$\begin{cases} \Delta x_m = X_0 - X_m \\ \Delta y_m = Y_0 - Y_m \end{cases} \tag{2}$$

Thus, the current real-time image frame m was ultimately located at $P_m^{'}(X_m^{'},Y_m^{'})$ on the base map. Relative compute formula is below

$$\begin{cases} X_m' = X_0 + \Delta x_m \\ Y_m' = Y_0 + \Delta y_m \end{cases} \qquad (3)$$

In this paper, weighted Hausdorff distance- similarity measure was adopted in NLSM algorithm, which is based on edge feature and can be tolerant to translation, rotation, scale change and illumination variations [9]. Therefore, NLSM algorithm could group the real-time image sequence into dynamic key-frame and real-time image frame, and then continuous registering those frames to the base map.

TABLE 1. EXPERIMENTS OF LOCATING ON THE BASE MAP OF RUN-TIME IMAGE SEQUENCES OF CCD /PIXEL

Natural Landmark	*Frame Type*	*Frame No.*	*Matched coordinates*	*Matched Time / s*	*True shift*	*Computed shift*	*Matched error*
Group 1 (Airport)	Key-frame	380#	(60, 80)				
	Current frame	384#	(62, 80)	1.655794	(2, 0)	(2, 0)	(0, 0)
		388#	(64, 80)	1.648232	(4, 1)	(4, 2)	(0, 1)
		392#	(66, 80)	1.611532	(4, 0)	(4, 0)	(0, 0)
		396#	(68, 82)	1.637638	(8, 0)	(8, 0)	(0, 0)
		…...					
Group 2 (Road)	Key-frame	1200#	(60, 80)				
	Current frame	1204#	(62, 80)	1.713708	(2, 0)	(2, 0)	(0, 0)
		1208#	(64, 80)	1.631098	(4, 0)	(4, 0)	(0, 0)
		1212#	(66, 80)	1.629116	(6, 0)	(6, 0)	(0, 0)
		1216#	(68, 80)	1.629385	(8, 0)	(8, 0)	(0, 0)
		…...					
Group3 (River)	Key-frame	3120#	(60, 80)				
	Current frame	3124#	(62, 80)	1.673201	(2, 0)	(2, 0)	(0, 0)
		3128#	(64, 80)	1.621191	(4, 0)	(4, 0)	(0, 0)
		3132#	(66, 80)	1.624186	(6, 2)	(6, 1)	(0, 1)
		3136#	(68, 80)	1.646319	(8, 0)	(8, 0)	(0, 0)
		…...					
Group 4 (Bridges)	Key-frame	4040#	(60, 80)				
	Current frame	4044#	(62, 80)	1.683208	(2, 0)	(2, 0)	(0, 0)
		4048#	(64, 80)	1.651192	(4, 0)	(4, 0)	(0, 0)
		4052#	(66, 80)	1.684488	(6, 0)	(6, 0)	(0, 0)
		4056#	(68, 80)	1.646354	(8, 0)	(8, 0)	(0, 0)
		…...					
Group 5 (Road)	Key-frame	7660#	(60, 80)				
	Current frame	7664#	(62, 80)	1.703206	(2, 0)	(2, 0)	(0, 0)
		7668#	(64, 80)	1.681192	(4, 0)	(4, 0)	(0, 0)
		7672#	(66, 80)	1.664383	(6, 0)	(6, 0)	(0, 0)
		7676#	(68, 80)	1.637519	(8, 0)	(8, 0)	(0, 0)
		…...					

3.Experimental results and analysis

Experiment Environment: Windows XP, CPU 1.86GHZ, 1G memory, based on MATLAB simulation platform, the image size of real-time sequences are 320 × 240 (pixels), frame rate is 25 frames / sec. CCD data source: the base map was made from Google Earth, Real-time image sequences were made from videotape records of UAV flight tests. Experimental statistic data results of locating on the base map of run-time image sequences of CCD shown in Tab.1.

As can be seen from Table 1, based on natural landmark, NLSM algorithm procession was derived into two models: relative localizing and inter-frame register, linking with dynamic key-frame. Matched errors were reduced to less than 2 pixels. Simultaneously, matched time is cut to the bone because of the same small size of real-time images and key-frames, which will significantly shorten the engineering process of NLSM algorithm.

4.Conclusion

For fault or failure of GPS, a vision-based scene matching navigation algorithm was proposed with precision and reliability, based on natural landmarks dynamic key-frames. Through extracting features from the real-time images, to accomplish selecting key-frame this contains distinct natural landmarks. After registering key-frame to base maps and inter-frame scene matching, the geodetic coordinates of UAV will be computed accurately and filtered by extended Kalman filter and continuously updated. At the same time, by computing the correlation between real-time image frames and key-frames, relative register was applied between inter-frames, and then transform the relative register coordinates to absolute register coordinate by registering dynamic key-frames to base map, so as to realize every real-time image frame register to the base map precisely. Dynamic key-frame mechanism was used to manage key-frames without increasing the computation, contrary greatly reduces the inter-frame cumulative error. Experimental results show that NLSM algorithm greatly meet the requirements of UAV in actual working environment such as real time, accuracy, robustness. NLSM could serve as an optimal backup navigation technology when GPS got malfunction or failure.

Acknowledgment

This work was supported by Major Program of National Natural Science Foundation of China (60634030), by National Natural Science Foundation of China (60702066), by Program for New Century Excellent Talents in University (NCET-06-0878), by Aviation Science Foundation of China (20090853013), Northwestern Polytechnical University Soar Star Program.

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