2012 4th International Conference on Signal Processing Systems (ICSPS 2012)
IPCSIT vol. 58 (2012) © (2012) IACSIT Press, Singapore
DOI: 10.7763/IPCSIT.2012.V58.17

Research on Distance Estimation from a Target to the camera Based on Line Segment Feature

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Abstract. It invested into the passive ranging method based on the imaged features from a monocular imaging system to a non-cooperate target. With a general passive ranging model settled, the principle of the algorithm was introduced. In our method, a three point matching between two adjacent frames in images sequence should be done. Based on these three points, a virtual circle is settled for extracting line segment feature Ln or Ln+1, and then we could get the ratio of the distance between two sampling time, named ρ, with azimuth α_n, pitching β_n, and the coordinates of the observer, we could determine the distance by solving a quadratic equation. We give a comparison between the Scale Invariant Feature Transform (SIFT) Key points matching and the Harris corns matching in the matching algorithm. It implied by our experiment that either the SIFT or the Harris algorithm can achieve a good ranging results, but the error is a bit of big while the real time realization performance is better for Harris. This method is valid a moving imaging tracking system.

Keywords: passive ranging, monocular, experiment, ine segment feature, image matching

1. Introduction

To some extent, it is not an easy work to estimate the distance from an imaged target to the camera. Because of the theoretical significance and practical value, much works having been doing on this research. It has been proved that to a cooperative target, such as with the initial distance [1], or with the characteristic lines known [2~4], we could get satisfied results. But to a non-cooperative target, the problem still exists. The authors have noticed that among the literature 2 to 4, line segment feature in FU's work does not depend the target itself very much. It is a good beginning for further research. WANG [5] have developed a line segment feature which has been successfully used in passive ranging, it is a string from the circumcircle determined by matched points more than three. The line segment feature is long than any other line feature before, so it has less location error under the same image procession accuracy.

Supported by a grant from the National Natural Science Foundation of China (No. 60872136), we have done a continued research on non-cooperative imaged target passive ranging, which include the theory and engineering realization. In this paper, we instructed the ranging principle, the line segment feature define and extract, and along with a reduced model experiment.

2. Ranging Principle and Line Segment Extration

2.1. Ranging principle

In this paper, we take the geography coordinates o-xyz as the host coordinates, the north, the west and the upper direction works as the positive direction for *x, y,* and z axis respectively. It is a reasonable

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assumption that the state of our measurement-platform on which the camera fixed are known from other detection system at mean time, say the GPS and the inboard sensors, these information includes the azimuth, pitching, radial distance to point o, velocity, acceleration, and the attitude.

The platform itself also constitutes a coordinates O-XYZ, i.e. the platform coordinates. If we take an aircraft as the platform, then the nose head, right wing, and engine-room top is the positive Y, X, and Z axis respectively, they are also in a right-hand coordinates. The airborne measurement-platform in the geography coordinate is showed in Fig. 1.

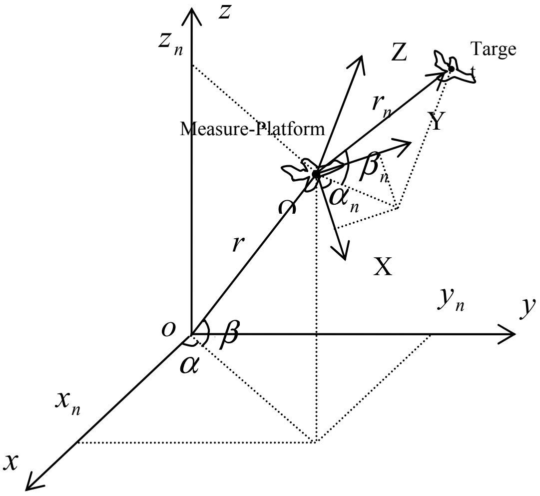

Fig. 1: The airborne measurement-platform in geography coordinates.

At the n-th sampling time, the point O in o-xyz coordinates is $O(x_n, y_n, z_n)$, supposed the moving target in the measurement-platform coordinates is expressed as (r_n, α_n, β_n) in a spherical form. Here, α_n, β_n is the azimuth, pitching from camera to the target, and the sightline of camera to the target $\overrightarrow{OT}$ in the geography coordinates could be expressed as the direction vector (l_n, m_n, n_n) as below

$$\begin{pmatrix} l_n \\ m_n \\ n_n \end{pmatrix} = \begin{pmatrix} t_{11}^n & t_{12}^n & t_{13}^n \\ t_{21}^n & t_{22}^n & t_{23}^n \\ t_{31}^n & t_{32}^n & t_{33}^n \end{pmatrix} \begin{pmatrix} \cos\alpha_n \cos\beta_n \\ \sin\alpha_n \cos\beta_n \\ \sin\beta_n \end{pmatrix} \tag{1}$$

Here, $\begin{pmatrix} t_{11}^n & t_{12}^n & t_{13}^n \\ t_{21}^n & t_{22}^n & t_{23}^n \\ t_{31}^n & t_{32}^n & t_{33}^n \end{pmatrix}$ is the transposed matrix of the direction vector for X, Y, and Z-axis in o-xyz coordinates.

Suppose that there exists a one-dimension scale x_0 in the target, which is invariable to the rotation of the camera in two adjacent sampling times; this scale's projection on the camera focus plane is called the target's line segment feature. Now, let's take into account the normal condition in which both the target and the measurement-platform are moving. Fig. 2 illustrated the line segment feature on which a recursive ranging mode was build [6].

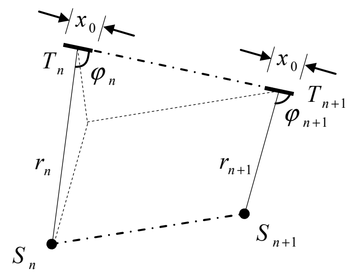

Fig. 2: The recursive ranging mode based on line segment feature.

In Fig. 2, T and S is the Target and Surveyor (camera) individually, subscript n or n+1 is the sampling time. Therefore, T_nT_{n+1} 、 S_nS_{n+1} is the moving trace of the target and the platform between the n-th and (n+1)-th sampling time, while φ_n and φ_{n+1} is the angle of the target's trace to the camera's sightline at each sampling time.

The focus of optical system in the camera is supposed as f_n , f_{n+1} at the n-th and (n+1)-th sampling time, while the size of the line segment feature in camera focal-plane is L_n , L_{n+1} at mean time. According to the geometry imaging principle, below could be concluded.

$$\frac{r_{n+1}}{r_n} = \frac{f_{n+1}}{f_n}\frac{L_n}{L_{n+1}}\frac{\sin\varphi_{n+1}}{\sin\varphi_n} \tag{2}$$

Based on equation (2), the following recursion passive ranging equation were derived in literature [1]

$$C_4 r_{n+1}{}^4 + C_3 r_{n+1}{}^3 + C_2 r_{n+1}{}^2 + C_1 r_{n+1} + C_0 = 0 \tag{3}$$

It has been proved in [6] that distance finder equation (4) has only one real number solution with engineering significance. A large number of simulation has been made for testing the conditions of the equation has no solution in the actual measurement, the results imply that if the ratio of the Ln+1/Ln doesn't surpass certain value, equation (3) would has its real number solution. It is not difficult work to get the Ln+1/Ln through image sequence matching.

In literature [2], a three point matching method was used for determine the ratio of Ln+1/Ln.

In the equation (3), the rn, each n-th distance from a target to the camera, could be recursive obtain if the very initial distance information r0 is known, say through a Radar or a Lidar.

In practice, the ranging equation (3) would be invalid, if the r0 is not known or the target is missing in tracking. So, a ranging equation without an initial distance is rather important.

If we know some certain target's characteristic line, the distance difference between two sampling time could get as below

$$\Delta = r_{n+1} - r_n = fx_0 \frac{L_n - L_{n+1}}{L_{n+1} \cdot L_n} \tag{5}$$

With equation (5), literature [7] developed a passive ranging method which similar to equation (3). But the method in literature [7] is valid for cooperate target only. For realization non-cooperate target ranging, distance difference is not suitable. We must try other method.

For realization non-cooperate target ranging, distance difference is not suitable.

Let the ratio of distance from the camera to the target at adjacent sampling time as equation (14) below

$$\rho = r_n / r_{n+1} = L_{n+1} / L_n \tag{6}$$

By further derivation and simplification, equation (3) turned into a quadratic equation [8]

$$D_2 r_{n+1}^4 + D_1 r_{n+1}^3 + D_0 r_{n+1}^2 = 0 \tag{7}$$

Where

$$D_2 = (\rho^4 - H')[(l_{n+1}l_n + m_{n+1}m_n + n_{n+1}n_n)^2 - 1] \tag{8}$$

$$D_1 = 2H'\{l_{n+1}(x_{n+1}-x_n)+m_{n+1}(y_{n+1}-y_n)+ n_{n+1}(z_{n+1}-z_n)-(l_{n+1}l_n+m_{n+1}m_n+n_{n+1}n_n) [l_n(x_{n+1}-x_n)+m_n(y_{n+1}-y_n)+n_n(z_{n+1} -z_n)]\}+2\rho^3\{l_n(x_{n+1}-x_n)+m_n(y_{n+1}- y_n)+n_n(z_{n+1}-z_n)-(l_{n+1}l_n+m_{n+1}m_n+ n_{n+1}n_n)[l_{n+1}(x_{n+1}-x_n)+m_{n+1}(y_{n+1}-y_n) +n_{n+1}(z_{n+1}-z_n)]\} \tag{9}$$

$$D_0 = H'\{[l_n(x_{n+1}-x_n)+m_n(y_{n+1}-y_n)+n_n (z_{n+1}-z_n)]^2+(x_{n+1}-x_n)^2+(y_{n+1}-y_n)^2 +(z_{n+1}-z_n)^2\}+\rho^2\{[l_{n+1}(x_{n+1}-x_n)+ m_{n+1}(y_{n+1}-y_n)+n_{n+1}(z_{n+1}-z_n)]^2- (x_{n+1}-x_n)^2-(y_{n+1}-y_n)^2-(z_{n+1}-z_n)^2\} \tag{24}$$

And then, the imaged target distance estimation could be done by solving a quadratic equation. In fact, for always get the meaningful root, D1, D0 should not be zero, this require the observer in moving.

Considered that the line segment feature domains the ranging error, literature [9] makes a thorough study on how to obtain a better line segment feature.

2.2. Line segment extration

It is inspired by the literature [1] and [10], literature [9] has developed an image matching algorithm based on P3P[11] guided SIFT key points, and then, the residual work is to study which line segment feature is the best one in the single-lens image sequence.

It is supposed that points A, B, C and A', B', C' are the matched points respectively in adjacent frame. We would determine the line segment feature from thus three points, A, B and C for example, as shown in figure 3. A circumcircle for points A, B and C with the center named O' could be determined, while O is the center of gravity for triangle ABC. If the direction $\overrightarrow{BM}$ is main SIFT direction of key point A, B and C. Parallel to the direction $\overrightarrow{BM}$, circumference string DE traversed point O could be determined. In Fig. 3, FG is an other circumference string traversed point O but it is vertical to $\overrightarrow{BM}$.

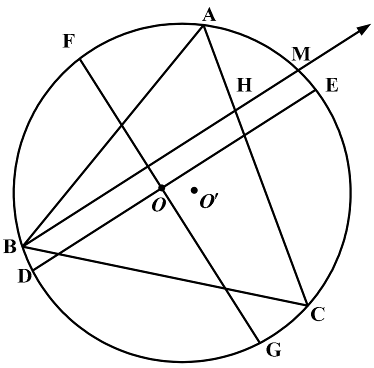

Fig. 3. Feature point A, B, C and the selecting line segment feature.

WANG [9] has carried on error analysis for equation (20). The result indicates the error of characteristic linearity nearly decides the ranging performance of equation (20), in addition, the relative error of target's distance is forth third times that of the characteristic linearity.

3. Experiments

Experiments with a reduced model indoors have been developed to test and verify the passive distance finding algorithm.

A set of integrated data from one of our experiments is given apart in table 1 and Fig. 4. For saving space, only even number of the 33 frames was shown in Fig. 4, the data in the first five columns in Table 1 were other corresponding information. All these data was captured through our hardware-in-loop experiment. Experiment results were given in Table 1 too.

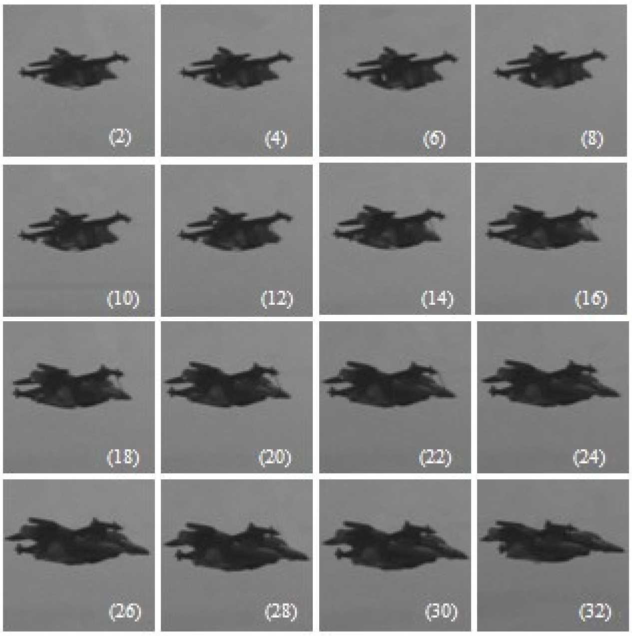

Fig. 4. Target sequence one for experiment, (2), (4), et al, is frame numbers.

In line segment feature extraction, both the SIFT or the Harris algorithm are used. It implied by our measurement that to match two 256×256 image will take 3.529 s or 0.186 s for SIFT matching or Harris matching respectively.

From the first to the end column, there are frame numbers, true distance from target to the camera, camera's position, azimuth, pitching and the measurement data in Tab1. According to Tab 1, both SIFT or Harris algorithm will obtain the target' line segment feature, and used for passive ranging. By our experiment, the biggest ranging error for these two methods is 9.51% and 10.07% respectively, but the error is a bit of big while the real time realization performance is better for Harris.

Because of measurement error, image matching error，in some condition, the ranging equation has no root. But this occurs in very small chance.

4. Conclusion

This paper introduces a ranging system based on single lens image and imaging direction. Based on 3-pairs points matching in adjacent frame image, a distance estimation equation was set up by other information added, such as the target's azimuth, pitching, line segment feature and the space coordinate of the camera. It has the merits of no initial information needed. Our experiment shows that with SIFT key point or the Harris corn matching, we can achieve a good ranging result. The relative experiments suggested that a relative ranging error less than ± 6% could achieve at most time, the biggest error is about 10%. This method is valid for a moving camera ranging.

5. Acknowledgment

This work was supported by a grant from the National Natural Science Foundation of China (No. 60872136).

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Table 1: experiment data and ranging result

frame	Distance/cm	Camera position / cm	azimuth	pitching	Distance [SIFT]	Error / % [SIFT]	Distance[Harris]	Error / % [Harris]
1	248	（0, 0, 0）	179°29.8'	275°40'				
2	247	（0,-3,0）	179°35'	275°50.7'				
3	246	（0,-6, 0）	179°40'	275°50.7'	250.73718	1.93%	253.57515	3.08%
4	245	（0,-9, 0）	179°40'	275°50.7'	243.58886	0. 58%	239.54272	2.23%
5	244	(0, -12, 0）	179°40'	275°50.7'	240.98883	1.23%	237.08714	2.83%
6	243.5	(0,-15,0）	179°55'	275°50.7'	240.98883	1.03%		
7	242	(0,-18,0）	179°57'	275°50.7'				
8	241	(0,-21,0）	179°57'	275°50.7'			237.21477	2.78%
9	242	(0,-24,0）	180°7.5'	275°50.7'	256.24633	5.89%		
10	242	(0,-27,0）	180°19'	275°50.7'	251.06253	3.74%	252.76064	4.45%
11	241	(0, -30,0）	180°19'	275°50.7'	235.86765	2.13%	243.71336	1.13%
12	238.5	(0, -33,0）	180°19'	275°50.7'	239.53737	0.44%	238.01889	0.20%
13	237.5	(0, -36,0）	180°46.5'	275°50.7'				
14	237	(0, -39,0）	180°46.5'	275°50.7'	237.51034	0.22%	233.42723	1.51%
15	235.5	(0, -42,0）	180°46.5'	275°50.7'			234.52938	0.41%
16	234	(0, -45,0）	181°17.5'	275°50.7'	237.51034	1.50%	234.52938	0.23%
17	232	(0, -48,0）	181°17.5'	275°50.7'	228.88762	1.34%	229.30463	1.16%
18	230	(0, -51,0）	181°25.5'	275°50.7'	236.67974	2.90%	243.83917	6.02%
19	228	(0, -54,0）	181°25.5'	275°50.7'	223.91062	1.79%	223.26969	2.07%
20	226	(0, -57,0）	181°49.3'	275°50.7'	223.91062	0.92%	223.33185	1.18%
21	224	(0, -60,0）	181°49.3'	275°50.7'	223.86652	0.06%		
22	222	(0, -63,0）	182°6'	275°50.7'	239.32678	7.80%	237.77005	7.10%
23	221	(0, -66,0）	182°17.5'	275°50.7'	232.36649	5.14%		
24	218.5	(0, -69,0）	182°21.8'	275°50.7'	227.56026	4.15%	218.80548	0.14%
25	217	(0, -72,0）	182°38'	275°50.7'	225.31538	3.82%	233.3557	7.54%
26	215	(0, -75,0）	182°53'	275°50.7'	235.447	9.51%	230.0896	7.02%
27	213	(0, -78,0）	183°11'	275°50.7'	228.42514	7.24%	234.44954	10.07%
28	211	(0, -81,0）	183°18.5'	276°8'				
29	209	(0, -84,0）	183°31.3'	276°8'	215.29842	3.01%	224.49737	7.42%
30	207	(0, -87,0）	183°58'	276°8'	215.29842	4.01%	224.49737	8.45%
31	206	(0, -90,0）	184°25.5'	276°8'				
32	210	(0, -93,0）	187°9'	276°8'				
33	209	(0, -96,0）	187°29.5'	276°8'	225.52733	7.90%		