카메라와 초기상태 정보가 없는 INS간 물리적 관계를 위한 수학적 모델링
A Mathematical Modeling for the Physical Relationship between Camera and the Unknown Initial State of INS

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Abstract

모바일 맵핑시스템에 장착되어 있는 카메라와 INS의 물리적 관계 (두 좌표축 간의 거리(lever-arm) 와 각도(boresight)) 캘리브레이션은 카메라 영상의 지리적 정보를 생성하기 위해 필요로 한다. 이 목적을 위해 기존연구는 카메라 캘리브레이션을 통하여 이 물리적 관계를 추정하고 있다. 카메라 캘리브레이션은 3차원 좌표가 할당된 타겟을 이용하여 움직이는 카메라의 렌즈 왜곡과 내/외부 표정 계산하는 것이다. 이 추정에서, 저가의 INS의 초기 상태인 자세, 각도는 사용자의 측량에 의해 결정이 된다. 만약 정교한 측량이 없을 경우, 카메라 영상의 지리적 정보는 잘못된 정보를 제공 할 것이다. 정교한 측량의 어려움을 피하기 위해, 본 논문은 카메라와 초기상태 정보가 없는 INS간의 물리적 관계를 위한 수학적 모델을 설계 하였다. 시스템에 장착된 카메라와 INS의 초기 기준 좌표계의 관계는 lever-arm과 boresight을 이용한 좌표축 변환으로 정의 될 수 있으며, 이 시스템이 이동 후, 카메라 초기 기준 좌표계에서 INS의 위치는 두 개의 벡터 경로로 정의 될 수 있다. 이 두 벡터 경로는 카메라와 INS의 상대 외부표정의 관계를 이용하여 계산된 벡터들의 조합으로 정의된다. 본 논문은 여러 쌍의 경로로 부터 lever-arm과 boresight을 추정 하였다.

1. Introduction

When creating geo-reference frames from cameras mounted on a moving non-flexible system, such as airborne, vehicle, and terrestrial robots, along a road, the orientation of image frames is one of important properties. In photogrammetry field, the orientation of these image frames without supporting any sensors is estimated by using the slow and costly establishment of ground control points (Edward et al, 2001), conventionally. In computer vision field, detection of optical flows, conjugated points, is used to estimate the orientation for low-cost and fast achievement (Han and Park, 2000, Pollefeys et al, 2000, Chon et al, 2004). After several hundred frames, approaches based on optical flows are impossible to estimate the orientation because of the accumulated error of the orientation (Chon, 2005). Mobile Mapping System (MMS) or terrestrial robot has been adapting to avoid the accumulated error and to fast measure of the image frame orientation (Schwarz et al, 1993, El-Sheimy and Schwarz, 1999, Mostafa, 2003, Bayoud, 2005).

A MMS consists of several cameras or multi-spectral pushbroom scanner, laser ranges, Inertial Navigation Sensor(INS) or Inertial Measuring Unit (IMU), Global Positioning System (GPS), etc. To get geo-reference frames, the orientation of the rigid body of MMS is measured by using Kalman filter with the data of INS and GPS, the orientation of image frames isthen simply determined by using a coordinate transform (Schwarz et al, 1993). Using a point as a medium in the body of MMS, a lever-arm and boresight, which mean the spatial offset and angle misalignment between camera frames and INS, determine the coordinate transform. Conventional researches have been estimating the lever-arm and boresight through a camera calibration. The camera calibration using targets assigned 3D data calculates the lens distortion, internal and external orientations of a moving camera to the global coordinate system (Brown, 1971, Tsai, 1987, Heikkil and Silven, 1997, Zhang., 1999). In the estimation, they assumed that the initial state, such as position and pose, of INS represented in the global coordinate system is basically known or used additional sensors for setting the initial state in itself. The additional sensors determine the inclination and roll angles by using a 3-axis micro-machined accelerometer to measure the direction of earth's gravity. The azimuth angle is determined by measuring the earth's magnetic field using a 3-axis magnetometer subsystem. The cost of these INSs with self calibration functions is extremely expensive. In case of low-cost INS composing rate gyroscopes and accelerometer onlyor MicroElectroMechanical Sensor (MEMS) INS, the initial state isset by using manual method, generally. If there is no an elaborate initial setting skill, as time goes on, the accumulated error of the orientation of a camera will be huge, quickly. Then geo-referenced frame will give fault information.

To avoid difficulty of these elaborate settings, we design a novel mathematical model defining the physical relationship between a camera and the unknown initial state of INS. Relationship of the initial reference coordinates of a camera and an INS mounted on a non-flexible systemcan be defined by a coordinate transform with the lever-arm and boresight. After moving the system, the position of INSto the initial camera coordinatesystem can be defined two paths. The two paths are defined by summations of vectors calculated by using the relative orientations of the camera and the INS. We estimated the lever-arm and boresight from several sets of the two paths a simulation test.

2. Approximation of the Physical Relationship

For the lever-arm, $L_I^C = l[\cos\alpha\cos\beta \quad \sin\alpha\cos\beta \quad \sin\beta]^T$, and boresight, $\Omega_I^C = [\omega_I^C \quad \phi_I^C \quad \kappa_I^C]^T$, we can obtain function F, our mathematical model, following as:

$$[F_1(t) \quad F_2(t) \quad F_3(t)]^T = P_{C(t)}^C + R(\Theta_{C(t)}^C)L_I^C - L_I^C - R(\Omega_I^C)P_{I(t)}^I \tag{1}$$

$$\begin{bmatrix} F_4(t) & F_5(t) & F_6(t) \\ F_7(t) & F_8(t) & F_9(t) \\ F_{10}(t) & F_{11}(t) & F_{12}(t) \end{bmatrix} = R(\Theta_{C(t)}^C)R(\Omega_I^C) - R(\Omega_I^C)R(\Theta_{I(t)}^I) \tag{2}$$

In which $R\left(\Theta = \begin{bmatrix} \omega \\ \phi \\ \kappa \end{bmatrix}\right) = R_\omega R_\phi R_\kappa = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\omega & -\sin\omega \\ 0 & \sin\omega & \cos\omega \end{bmatrix} \begin{bmatrix} \cos\phi & 0 & \sin\phi \\ 0 & 1 & 0 \\ -\sin\phi & 0 & \cos\phi \end{bmatrix} \begin{bmatrix} \cos\kappa & -\sin\kappa & 0 \\ \sin\kappa & \cos\kappa & 0 \\ 0 & 0 & 1 \end{bmatrix}$ is a 3 by 3 rotation matrix, $P_{C(t)}^C$ and $\Theta_{C(t)}^C$ are the position and pose of the camera at time t represented in the initial camera coordinate system, and $P_{I(t)}^I$ and $\Theta_{I(t)}^I$ are the position and pose of the INS at time t represented in the initial INS coordinate system. As Eq(1) and Eq(2) are non-linear and does not fit to approximate the unknown parameters, the lever-arm and boresight ,directly, it is needed to linearize the two conditions to obtain approximated functions using Taylor series. The partial derivatives with respect to the unknown parameters are necessary are following as:

$$F_i(t) = F_i^0(t) + \left(\frac{\partial F_i^0(t)}{\partial l}\right)dl + \left(\frac{\partial F_i^0(t)}{\partial \alpha}\right)d\alpha + \left(\frac{\partial F_i^0(t)}{\partial \beta}\right)d\beta$$
$$+ \left(\frac{\partial F_i^0(t)}{\partial \omega_I^C}\right)d\omega_I^C + \left(\frac{\partial F_i^0(t)}{\partial \phi_I^C}\right)d\phi_I^C + \left(\frac{\partial F_i^0(t)}{\partial \kappa_I^C}\right)d\kappa_I^C \quad (3)$$

in which i is the index of equations. Since the number of the unknown parameters is six and the number of equations to specific time t is six, there are generally necessary for at least one pair of camera orientation and INS data except an initial camera orientation. Since the property l is proportioned to the three equations, F_1, F_2, and F_3 ,of Eq (1), for the unknown six parameters, at least six pairs of the orientations of camera and INS data are needed. Since the nine equations of Eq (2) are originally separated from Eq(1), the nine equations are not counted as additional equations.

For the several pairs of the camera orientation and INS data, Eq (3) can be rewritten as:

$$B = J\Delta \quad (4)$$

where, $B_{12t\times1} = \begin{bmatrix} \vdots \\ -F_i^0(t) \\ \vdots \end{bmatrix}$, $J_{12t\times6} = \begin{bmatrix} \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \frac{\partial F_i^0(t)}{\partial l} & \frac{\partial F_i^0(t)}{\partial \alpha} & \frac{\partial F_i^0(t)}{\partial \beta} & \frac{\partial F_i^0(t)}{\partial \omega_I^C} & \frac{\partial F_i^0(t)}{\partial \phi_I^C} & \frac{\partial F_i^0(t)}{\partial \kappa_I^C} \\ \vdots & \vdots & \vdots & & \vdots & \vdots \end{bmatrix}$, and

$\Delta_{12\times1} = \begin{bmatrix} dl & d\alpha & d\beta & d\omega_I^C & d\phi_I^C & d\kappa_I^C \end{bmatrix}^T$ is the vector of six observational residuals. The vector of six observational residuals, Δ, is found with the aid of the classical least-square solution.

$$\Delta = (J^T J)^{-1} J^T B$$
$$\begin{bmatrix} \hat{L}_I^C & \hat{\Omega}_I^C \end{bmatrix}^T = \begin{bmatrix} \hat{L}_I^C & \hat{\Omega}_I^C \end{bmatrix}^T + \Delta \quad (5)$$

After few iterations of Eq(6), the unknown parameters, $(\hat{L}_I^C, \hat{\Omega}_I^C)$,can be determined.

3. Simulation

Table 1. The given data.

Camera Orientation	Index	1	2	3	4	5	6	7
	Position [Meter]	(10 10 10)	(20 10 10)	(30 10 10)	(40 10 10)	(50 10 10)	(60 10 10)	(70 10 10)
	Pose [Degree]	(1 2 3)	(3 4 5)	(5 6 7)	(7 8 9)	(9 10 11)	(11 12 13)	(13 14 15)
lever-arm [Meter]	(-1 -0.27 -0.72)							
Boresight [Degree]	(-30 -19 105)							

For the simulation, the given camera orientation and the given lever-arm and boresight are shown in table 1. For displaying the relative orientation of INS, which is estimated using the given data, in the global coordinate system, we convert the relative orientation from the initial INS coordinate system to the initial camera coordinate system and from the initial camera coordinate system to the global coordinate system. Fig.1 shows the given lever-arm and boresight and the orientation of camera and INS represented in the global coordinate system. In table 2 showing the simulation result, we know that the estimated figures of the lever-arm and boresight are closed to the given data. When giving various data in other way, the estimated figures are closed to the given data, too. In view of the simulation results, it is clear that our mathematical model has no mathematical or physical problems.

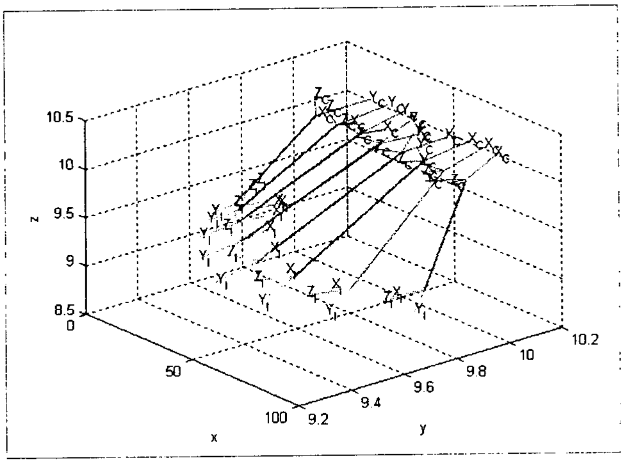

Fig. 1. The orientation of camera and INS in 3D space.

Table 2. The estimated lever-arm and boresight.

	Initial	Estimated
lever-arm [Meter]	(0.1 0 0)	(-0.99019 -0.27181 -0.72125)
Boresight [Degree]	(0 0 0)	(-29.982 -19.017 105.01)
$\frac{\sum \lvert F \rvert}{n} = 0.00840$ and iteration number is 19.		

4. Conclusion

We have designed a novel mathematical modeling for the physical relationship, the lever-arm and boresight, between camera and the unknown initial state of INS mounted on a moving non-flexible body. Our mathematical model defines the position of INS at time t by using two paths. The two paths are defined by summations of vectors calculated by using the relationship with the relative orientations of the camera and the INS. We prove that our mathematical model has no mathematical or physical problems through a method of numerical analysis.

Since the advent of low cost, MEMS INS offers the opportunity for applying inertial navigation for a wide variety of new applications, systems composing charge coupled device (CCD) combined with the MEMS INS will be widely used. Our mathematical model will be usable for calibrating the physical relationship between the CCD camera and MEMS INS of these systems

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