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Study on Line of Stabilization Method

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Abstract. In order to meet the demand of line of sight stabilization (LOS) in motion conditions, according to the same attitude calculation process of carrier movement when get position or make target/direction stability, and the LOS implementation can be based on strapdown inertial navigation process. A kind of indirect stabilization method is studied, and model of attitude compensation is deduced, verification platform for attitude compensation is built up in laboratory. Through the data measured, angular of attitude compensation is calculated, the results show that the research method can satisfy the calculation accuracy requirement of attitude compensation. The method can be helpful for miniaturization design and system integration design.

1. Introduction
In the modern warfare, to reduce the damage rate of the combat personnel and equipment, and realize the accurately strike the target, the combat capability of the equipment is required to improve under the condition of the movement [1-3]. Line of sight stabilization is a key technology to improve the operational capability of the equipment, and it is also a problem to be solved urgently. In recent years, it has become the hot spot of research [4-6]. Line of sight stabilization is the process which can reduce disturbance of the carrier for target / detection equipment at the dynamic carrier condition [7, 8]. The realize method mainly includes direct stabilization and indirect stabilization. Indirect stabilization use the equipment inherent attitude information, using mathematical solution to give a result of attitude compensation amount, the upgrading of equipment performance can be realized by the improved algorithm, eliminating the need for hardware sales for the upgrading of products; can avoid complex structure design, in achieve miniaturization and system integration aspects have a considerable advantage [9][10]. The existing research theory all most focus to study on the control algorithm, in the indirect line of sight stabilization, the research is multi related theories based on stabilized platform, strapdown inertial navigation system (SINS) and indirect line of sight stabilization to achieve unity is of less; therefore make the strapdown inertial navigation theory as the foundation, an indirect stabilization method based on strapdown attitude measurement is studied, in-depth study of the method will help to inertial navigation/line of sight stabilization integration to achieve.

2. Method of Strapdown Indirect Line of Sight Stabilization
Indirect line of sight stabilization (ILOS) based on strapdown attitude measurement is a method which make attitude measurement devices fixedly connect to the carrier system, by strapdown mathematical solution obtained attitude change between carrier system relative to the reference coordinate system in real time, combined with the angular position the aim/search axis in the carrier system, the attitude compensation amount on ILOS was calculated, and the servo system make attitude compensation for aim/search axial achieved. Taking the roll angle of the carrier as an example, the ILOS is shown in Figure 1,
O-X₀Y₀Z₀ represents carrier coordinate system, O-X₁Y₁Z₁ (Department of Geography) as the reference coordinate system, ILOS is to make aiming/search equipment isolates from carrier attitude disturbance, making aiming/search equipment axial relative to the reference coordinate system is stable. In practical applications, vehicle attitude is variable before and after, the loading system and the reference system may be arbitrary angle relationship exists, when the initial attitude of carrier is arbitrary, the basic implementation flow of ILOS is shown in Figure 2.

According to the angular position of the axis $M(\gamma^B, \theta^B, \phi^B)$ relative to the reference position angle $A(\psi^A, \theta^A, \phi^A)$, the strapdown attitude measurement change is obtained in the real-time, combined with the carrier attitude changes aiming/search equipment axial relative to load system $B(\psi^B, \theta^B, \phi^B)$, targeting/search equipment to the reference frame after loading system and the reference angular position relationship $N(\gamma^B, \theta^B, \phi^B)$, the reference angle position mapping to the carrier system, make subtraction between $M$ and $N$, the attitude compensation is obtained for ILRS.

3. Mathematical Model of Attitude Compensation
Using geographic coordinate frame as reference, in the initial condition, a target/search equipment
axial stably point to target direction in carrier system $O_bX_bY_bZ_{b_l}$, when its attitude change, for the pitch angle; when the carrier attitude change (as $O_bX_bY_bZ_{b_l}$ to $O_bX_{b_l}Y_{b_l}Z_{b_{l_l}}$), aiming/search equipment axial direction as $O_bW_1$. And the azimuth as $\gamma_1'$, pitch angle as $\beta_1'$, vehicle attitude variation caused axial variation process as shown in Figure 3.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure3.png}
\caption{The axial change process with attitude change}
\end{figure}

Obviously, in order to make the target/search equipment stably point to target, the target/search device is required to move to $O_bW_0$. As in the reference system, the azimuth variation is $\Delta \gamma'$, the pitch variation is $\Delta \beta'$, then

\begin{equation}
\begin{aligned}
\Delta \gamma' &= \gamma_1' - \gamma_0' \\
\Delta \beta' &= \beta_1' - \beta_0'
\end{aligned}
\end{equation}

Known targeting/search equipment axial angular position relative to the reference system and angular position change, to make the axial stable pointing in the direction of the target, through the servo system control the azimuth and pitching angle in the loading system, to make the projection range variation such as azimuth variable amount $\Delta \gamma'$ and pitch variable amount $\Delta \beta'$ was 0 in the reference frame. Before the vehicle attitude variation, targeting/search axial is pointing to the target, in the carrier system azimuth angle is $\gamma_0'$, the pitch angle is $\beta_0'$, azimuth angle in the reference system is $\gamma_0$, the pitch angle is $\beta_0$. After carrier attitude change, the azimuth of axial direction in the frame of reference is $\gamma_1'$, the pitch angle is $\beta_1'$, the azimuth range change is $\Delta \gamma'$, the pitch change is $\Delta \beta'$. To stabilize the axial direction, the angle position of the axial in carrier system such as azimuth, the pitch is needed to control to make angle $\Delta \gamma'$ and $\Delta \beta'$ are 0.

As the attitude of the carrier is not changed in the attitude control, and the attitude matrix $C_{t}^{b}$ and $C_{t}^{b}$ attitude are consistent with the corresponding attitude measurement. To make $\Delta \gamma' = \Delta \beta' = 0$, then $\gamma'$ and $\beta'$ is need to meet

\begin{equation}
\begin{pmatrix}
\cos \beta' \sin \gamma' \\
\cos \beta' \cos \gamma' \\
\sin \beta'
\end{pmatrix} = C_{t}^{b} \begin{pmatrix}
\cos \beta_0' \sin \gamma_0' \\
\cos \beta_0' \cos \gamma_0' \\
\sin \beta_0'
\end{pmatrix}
\end{equation}
When $C_{ij} = (a_{ij})_{3 \times 3}$, then

$$\begin{align*}
\tan \beta^b &= \frac{a_{11} \cos \beta^b \sin \gamma^b + a_{12} \cos \beta^b \cos \gamma^b + a_{13} \sin \beta^b}{a_{21} \cos \beta^b \sin \gamma^b + a_{22} \cos \beta^b \cos \gamma^b + a_{23} \sin \beta^b} \\
\sin \beta^b &= a_{11} \cos \beta^b \sin \gamma^b + a_{12} \cos \beta^b \cos \gamma^b + a_{13} \sin \beta^b
\end{align*}$$

(3)

When

$$\begin{align*}
\gamma_G^b &= \arctan\left(\frac{a_{11} \cos \beta^b \sin \gamma^b + a_{12} \cos \beta^b \cos \gamma^b + a_{13} \sin \beta^b}{a_{21} \cos \beta^b \sin \gamma^b + a_{22} \cos \beta^b \cos \gamma^b + a_{23} \sin \beta^b}\right) \\
\beta_G^b &= \arcsin(a_{11} \cos \beta^b \sin \gamma^b + a_{12} \cos \beta^b \cos \gamma^b + a_{13} \sin \beta^b)
\end{align*}$$

(4)

According to the axial position in the carrier system, whatever the axial direction, the angle with the carrier plane is always in $[-\pi/2, \pi/2]$, therefore, $\gamma^b$ calculation is as follows

$$\begin{align*}
\gamma^b &= \gamma_G^b, \quad \cos \beta^b \cos \gamma^b > 0 \\
\gamma^b &= \gamma_G^b + \pi, \cos \beta^b \cos \gamma^b < 0 \text{ and } \cos \beta^b \sin \gamma^b \geq 0 \\
\gamma^b &= \gamma_G^b - \pi, \cos \beta^b \cos \gamma^b < 0 \text{ and } \cos \beta^b \sin \gamma^b < 0
\end{align*}$$

(5)

If $\cos \beta^b \cos \gamma^b = 0$, then, the calculation of $\gamma^b$ is as follows

$$\begin{align*}
\gamma^b &= 0, \quad \cos \beta^b \sin \gamma^b = 0 \\
\gamma^b &= \pi/2, \quad \cos \beta^b \sin \gamma^b > 0 \\
\gamma^b &= -\pi/2, \cos \beta^b \sin \gamma^b < 0
\end{align*}$$

(6)

If $\cos \beta^b \cos \gamma^b = 0$, then, the calculation of $\gamma^b$ is as follows

$$\begin{align*}
\gamma^b &= 0, \quad \cos \beta^b \sin \gamma^b = 0 \\
\gamma^b &= \pi/2, \quad \cos \beta^b \sin \gamma^b > 0 \\
\gamma^b &= -\pi/2, \cos \beta^b \sin \gamma^b < 0
\end{align*}$$

(6)

If $\cos \beta^b \cos \gamma^b = 0$, then, the calculation of $\gamma^b$ is as follows

$$\begin{align*}
\gamma^b &= 0, \quad \cos \beta^b \sin \gamma^b = 0 \\
\gamma^b &= \pi/2, \quad \cos \beta^b \sin \gamma^b > 0 \\
\gamma^b &= -\pi/2, \cos \beta^b \sin \gamma^b < 0
\end{align*}$$

After obtain $\gamma^b$, the corresponding attitude compensation amount $\Delta \gamma^b$ and $\Delta \beta^b$ can be expressed as

$$\begin{align*}
\Delta \gamma^b &= \gamma^b - \gamma_0^b \\
\Delta \beta^b &= \beta^b - \beta_0^b
\end{align*}$$

(7)

The above is the calculation process of the attitude compensation amount in the carrier coordinate system.

4. Experiment and Analysis

In order to verify the attitude compensation amount calculation results of ILOS, under the laboratory environment, this paper builds a simple compensate attitude verification platform, as in Figure 4.
The tripod simulate carrier, using red laser pointer simulate aiming orientation device, through the triangle frame rotating simulate the rotation of the system and homemade a simulated target. After leveling the tripod, tripod center projection point in ground and target surface center projection points in ground apart 8.213m, target surface as a rectangle which has 0.208m×0.226m, the plate above tripod can be seen as the platform of attitude measurement system and aiming equipment.

On initial conditions, adjust the plate to maintain the level, making the laser pointer pointing to the center of the target plane. Under laboratory conditions, using geographic coordinate frame as reference, the axial aiming and vector axis are parallel to the direction, in the initial state, respectively make pitching motion, azimuth motion and combined motion, laser pen aiming point deviation from the target surface. To the laser pointer to the re targeting the center, it need to adjust the laser pen in the angular position of the system, the angular position change quantity is attitude compensate amount. According to the distance between carrier and target surface, consider the target surface size, the line of sight will deviate from the target surface if the axial in the frame of reference pitching motion is greater than ±0.7907° or azimuth motion is greater than ±0.7277°, namely under the above conditions, pitch and azimuth combination after exercise, attitude compensation value in the reference system is Δγ′ = −0.7277°, Δβ′ = −0.7907°.

When the servo control system and the axial angular position in carrier system are seen as no output error, strapdown attitude measurement error will be the main error of ILOS. In the above condition, after azimuth and pitch motion, attitude compensation value is calculated as below. In the experiment, the IMU sampling frequency is 100Hz, the IMU output can be used to get attitude, to get the initial continuous attitude output results as Figure 5, which can be seen as the initial state, the carrier attitude near the value0.

**Figure 4.** Attitude compensation verification platform of LOS
After the carrier movement, the attitude is calculated with IMU output data, and the output is obtained as shown in Figure 6.

After the subtraction between the attitude output results before and after exercise, which result can be seen as attitude change amount of carrier, and the attitude compensation amount can be calculated in the carrier and reference system, the results were obtained as shown in Figure 7.
Analyzing the result, in above experimental conditions, the attitude compensation is amount in the reference frame calculation error $-0.0821^\circ \leq \delta \gamma' \leq 0.1789^\circ$, $-0.0833^\circ \leq \delta \beta' \leq 0.1640^\circ$. To give the above result an average, get $\delta \gamma' = 0.0537^\circ$, $\delta \beta' = 0.0450^\circ$. The data show that, in this experiment, calculation error of attitude compensation amount in ILOS within $0.18^\circ$, error calculation of $\Delta \beta'$ is within $0.17^\circ$. The large errors appear in a few sampling points, and most sampling’s attitude compensation calculation error is within $0.1^\circ$. The average of calculation error is near $0.05^\circ$ in the left and right sides, basically meet the requirements of calculation accuracy in the attitude compensation.
for ILOS.

5. Conclusion
In the moving condition, line of sight stabilization is a key technology to realize the precision strike. In the realization about line of sight stabilization, a kind of indirect method is studied. The method can combine with the inherent information of equipment to get attitude compensation result. Based on the derived mathematical model of attitude compensation, the calculation accuracy is verified. It can help to miniaturize weaponry, and provide a theoretical reference for the integration implement include LOS and INS. The research will plant important military significance and application value.

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