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Spiral Scan Pattern Generation for Laser Spot Tracker

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Abstract: The necessity of gimbaled seeker arises to provide the capability of scanning a large area, as the field of view (FOV) of the seeker alone is limited due to many reasons. In this work, a generalized method of spiral scan pattern generation has been proposed. This will be very efficient in terms of control efforts, scanned area, overlapping and scanning time. Also, a scheme has been given which will enable the seeker to start scanning from its nearest position when target is lost during tracking. Presented seeker is able to distinguish the target being illuminated with coded laser pulses and scans wide area in small time with less control effort.

Keywords: Scan Pattern, Control Effort, Gimbaled Laser Seeker (GLS), Quadrant Detector (QD), Pulse Repetition Frequency (PRF).

1 INTRODUCTION

The gimbaled laser seeker (GLS) is consisting of a laser seeker mounted in a set of gimbals. The motion of this seeker is to be controlled to enable the wide area scanning and tracking of the laser radiation scattered from illuminated target. The target is illuminated with a laser designator with predefined coding in order to distinguish the illuminated target and to avoid any possible camouflaging by the enemy. The laser pulses reflected from the target are collected by an optical system which focuses them on a quadrant detector. The GLS lock on to the incoming laser pulse if the code matches. The departure of the target from the line of sight of the seeker optics module is determined by the ratio of energy falling on different quadrants of the detector, which is then fed to the guidance system platform to steer it towards the designated target.

Wider the field of view of the optical system, greater is the probability to detect light reflected from a target over a larger spread of the area being scanned. The designed optical system (i.e. Laser Seeker) has a limited field of view. To increase the search area further, the seeker is mounted on a set of gimbals and thus a wider area can be scanned for target detection. Gimbaled laser seeker, scans the area of interest as per the commanded motion profile, i.e. scan command. This scan command is very critical, as it has to cater for certain contradictory requirements i.e. scanning speed, scan area, scanning time and the control effort. The scanning speed is restricted by the pulse repetition frequency (PRF) of laser code. Scanning time available is generally very less (of the order of 6 ~ 8 seconds). In this limited time, an optimal scanning pattern is to be designed, which optimizes total scanning time, scanning speed commensurate with PRF, control force, overlays in scanning and peak acceleration. Peak acceleration will decide the torque requirements.

In the following sections, a generalized method of spiral scan pattern generation has been presented which will be very efficient with respect to control efforts and scanned area with overlapping. The constraints on velocity and acceleration of the scan command of the system have been discussed. Also, a scheme has been presented to start the scan from the nearest scan point, if target is lost during tracking.

2 GENERALIZED METHOD OF SPIRAL SCAN PATTERN GENERATION

Due to the requirement of large field of regard (FOR) with limited FOV seeker, the seeker is mounted in a set of gimbals. The gimbals provide freedom of movement to the seeker and, thus with the seeker's limited field of view, the entire area of interest can be scanned. It is required to maximize the scanning area in the minimum time, keeping in view the constraints of limited field-of-view, PRF and available control energy. Therefore, optimization of the scanning pattern is very critical.

Circular/conical, rosette and spiral scan patterns are generally used for seekers. In circular scanning pattern, the requirement of acceleration is tremendously high while changing the circular path. Also, in rosette scan pattern, scan time is very high for a given field-of-regard. Therefore, circular and rosette scan patterns have not been discussed here. A simulation result has been presented for spiral scan patterns. The following four constrains have been taken into consideration, while carrying out the simulation:

- Time available for scanning = 9s (Complete Scan-In-to Out and Out-to-In).
- Max. Permissible rate of scanning ≤ 150°/s (due to PRF of 20 Hz)
- Field of View (FOV) of the seeker = ±7.5°
- Field of Regard (FOR) of the seeker = ±28°

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2.1 Calculation for Maximum Permissible Scanning Rate

Maximum permissible scanning rate depends on the PRF of the laser designator. With lower PRF, permissible scan rate will be less. Otherwise, there will not be sufficient time to decode laser pulses.

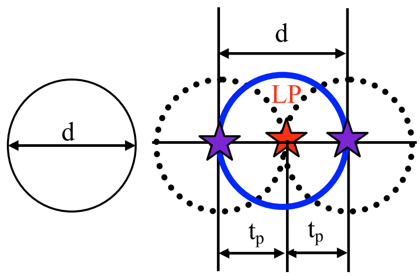

Fig. 1. Estimation of Maximum Permissible Scan Rate

Here, a seeker is considered with FOV, d= ± 7.5°, Pulse Interval for 20 Hz, t_p=0.05s and LP as the last received Laser Pulse. For the time coded laser pulses, two consecutive pulses are required to decode the valid Laser Pulse. Taking the worst case as shown in Fig. 1, where the seeker is moving with a velocity v, and receives Laser Pulse (LP) at its centre. Laser pulse validation requires that the second pulse should be received at edges depending on direction of motion. This implies that maximum scanning speed should be such, the seeker should not move by more than half of its FOV (d/2) while receiving consecutive Laser Pulses (tp). Hence maximum permissible scanning rate, v_{max}=(d/2)/t_p

= (15/2)/0.05

=150°/s

This is the maximum permissible speed of seeker for code detection. If laser pulses fall beyond the centre of seeker, permissible speed will decrease accordingly.

2.2 Spiral Scan Pattern Generation

For spiral scanning to cover entire wide area, required position commands (x & y) are sinusoidal inputs with varying amplitude. To optimize the rate and acceleration requirements, frequency of the sinusoidal input has also been varied. First, inward to outward spiral scanning pattern has been generated. This motion pattern has also been used for outward to inward motion. Here, spiral scan pattern has been generated from the pattern known as the Archimedean spiral. A property of this curve is that its pitch P, which is the distance between two consecutive intersections of the spiral curve with any line passing through the origin, is constant. This property is quite important for scanning purposes as it ensures that the area of interest is scanned uniformly. I A Mahmood and S O Reza Moheimani [1] have derived a spiral scan pattern varying the amplitude of the sinusoidals and keeping the frequency constant. However, linear velocity and acceleration are not uniform. I A Mahmood, SOR Moheimani, B Bhikkaji [2] and Labinsky A N, Reynolds G A J and Halliday J [3] have generated spiral pattern by varying amplitude and frequency. Here, linear velocity is constant but linear acceleration is not uniform. We are presenting generalized method for similar scan pattern with constant peak linear acceleration and almost constant peak linear velocity. These patterns have been derived from a differential equation given in [3] as

$$v = \omega * r \tag{1}$$

$$\frac{dr}{dt} = \frac{P * \omega}{2 * \pi} \tag{2}$$

Where, v is the linear velocity, ω is the angular velocity, r is the instantaneous radius at time t and P is the pitch of the scan pattern. Governing equations for spiral pattern generated in [1]- Spiral-1, in [2] - Spiral-2 and proposed method-Spiral-3 have been listed in Table-1. Here, N is the number of times the spiral curve crosses through the line y=0. T_{end} is the inward-to-outward scan time and t is the instantaneous time. Other parameters have been mentioned along with equations. Derivations of governing equations have been given in *Appendix A*.

Table 1: Governing Equations for Spiral Scans

Spiral-1[1]	***Spiral-2[2]***	***Spiral-3 Proposed***
$P = \frac{2 * R_{end}}{N-1}$ $P = Pitch\ of\ the\ scan$ $N = Number\ of\ Revolutions$ $R_{end} = Spiral\ Radius$	$P = \frac{2 * R_{end}}{N-1}$ $P = Pitch\ of\ the\ scan$ $N = Number\ of\ Revolutions$ $R_{end} = Spiral\ Radius$	$P = \frac{2 * R_{end}}{N-1}$ $P = Pitch\ of\ the\ scan$ $N = Number\ of\ Revolutions$ $R_{end} = Spiral\ Radius$
--	$v = \frac{2 * \pi * R_{end}^2}{P * T_{end}}$ $v = Linear\ Velocity$	$a = (R_{end})^3 * \left(\frac{2 * \pi}{P * T_{end}}\right)^2$ $a = Linear\ Acceleration$
$\omega = \frac{2 * \pi * R_{end}}{P * T_{end}}$ $\omega = Angular\ Speed$	$\omega = (\frac{2 * \pi * v}{P * t})^{1/2}$ $\omega = Angular\ Speed$	$\omega = (\frac{2 * \pi * a}{P * t})^{1/3}$ $\omega = Angular\ Speed$
$r = \frac{P * \omega * t}{2 * \pi}$ $r = Instantaneous\ Radius$	$r = (\frac{P * v * t}{2 * \pi})^{1/2}$ $r = Instantaneous\ Radius$	$r = a^{1/3} * (\frac{P * t}{2 * \pi})^{2/3}$ $r = Instantaneous\ Radius$
$x = r * \sin(\omega * t), \quad y = r * \cos(\omega * t)$ $Xs = (x - x_{offset}) * scale,$ $Ys = (y - y_{offset}) * scale$	: Cartesian co-ordinate corresponding to r and ω : Offsetting and scaling to make scan pattern symmetrical to centre of the scan area(Xs=0, Ys=0)	