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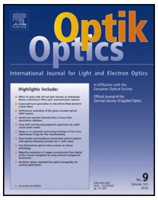

Original research article

Laser pulse peak estimation based on photon capture mode of quadrant photodetector

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ABSTRACT

Laser pulse peak estimation theory on quadrant photodetector (QPD) corresponding to all spots center on QPD surface is derived. The model of receiving echoed laser pulse from the target by QPD, and the composite photon detection model containing the inverted parabolic laser pulse and the ambient background noise submitted to Poisson distribution is established. The Cramer Rao lower bound (CRLB) estimation algorithm of laser pulse peak in one quadrant of QPD is derived based on the CRLB theorem. Taking the symmetry of QPD into account, laser pulse peak power CRLBs of each quadrant are calculated for all laser spots center which are located only in quadrant A of QPD, and different coefficients such as the laser pulse width factor and ambient background noise power are considered. Furthermore, the statistical mean and variance estimations of laser pulse peak power are simulated for each quadrant by Monte Carlo simulation method. The results show that: For the same spot center position, laser pulse peak power CRLBs of each quadrant are different. For different spots center positions, CRLBs of one quadrant are also different. The smaller pulse width factor, or the larger ambient background noise, the bigger laser pulse peak power CRLB.

1. Introduction

As a position sensitive device, laser quadrant photodetector (QPD) is widely used in laser tracking field such as laser guided weapon, laser radar, space optical communication etc., [1–3] for the advantages of high sensitivity, high accuracy, and simple calculation. With the development of high speed ADC chips and high speed processors, QPD measurement can be used for all digital circuit to achieve higher dynamic performance and accuracy. In the echoed laser pulse detection mode, according to certain algorithms, the position deviation between the target and the detector axis could be obtained by measuring the laser pulse peak [4]. Thus, the laser pulse peak measurements of each quadrant of QPD are the basic procedure of the whole spot position deviation measurement. Since uncertainty of the measurement is existing, the estimated statistical performance of the laser pulse peak for each quadrant is also uncertain. Meanwhile, when QPD is capturing laser pulses, ambient background noises are also captured by QPD photosensitive surface [5], generating biases for laser pulse peak estimation in each quadrant of QPD.

Zhao Xin [6], Zhang Hui [7] and Manojlović [8] have studied spot position measurement accuracy by QPD for several factors, including noises, but all of them are analyzed based on the position measurement algorithm, and not involving

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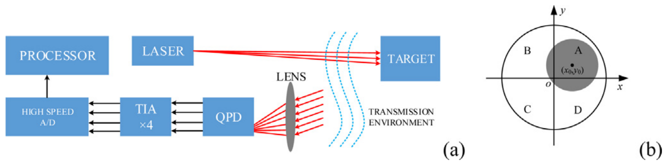

Fig. 1. System models. (a) Process of spot position deviation measurement. (b) QPD photosensitive surface with a coordinate system and a laser spot.

specific laser pulse signals captured by the QPD quadrants. When using QPD for digital circuit to measure position deviations, the first thing is to measure the laser pulse peak in four quadrants of QPD, of which precision can influence subsequent position measurement accuracy. So it is essential to analyze the ability of capturing laser pulse signal peak for each quadrant of QPD.

In this article, based on the photon capture model on QPD photosensitive surface, the composite photon detection model containing the inverted parabolic laser pulse and the ambient background noise submitted to Poisson distributions is established. Referring to Cramer Rao lower bound estimation (CRLB) theory, laser pulse peak power CRLBs of each quadrant of QPD are calculated for all laser spots center on QPD photosensitive surface. Several factors which influence the CRLB are discussed, including laser pulse width factor and ambient background noise power. Furthermore, statistical mean and variance of composite signal peak captured by each quadrant of QPD are estimated by the Monte Carlo experimental method.

In the following, Section 2 introduces the detection models, Section 3 derives the laser pulse peak CRLB of one quadrant, and the calculations results are discussed in Section 4. In Section 5, the Monte Carlo simulation experiments are conducted.

2. Models

The process of spot position deviation measurement is as shown in Fig. 1(a). A laser target designator is used to emit laser pulse signal to the target in certain frequency, and after the target reflect the laser signal, the optical system of the receiver captures the echoed signal, and generating a uniform distributed laser spot on the QPD photosensitive surface. QPD convert laser energy into 4 current pulse signals in the four quadrants respectively. The subsequent transimpedance amplifiers convert the current pulse signals into voltage signals and amplify the signals, then the high-speed ADC chips convert the voltage pulse signals into digital ones. And finally, the processor calculates the peak of the pulse signals for each quadrant, and calculates the spot position deviation. The acquisition precision of pulse peak can influence subsequent position measurement accuracy. Only the process of capturing laser pulse by QPD photosensitive surface is involved in this article, and photoelectric conversion of QPD and subsequent processing circuitry are not covered. So only the QPD capturing laser pulse model is established as follows.

2.1. QPD model

In Fig. 1(b), *o-xyz* is QPD photosensitive surface coordinate system. In this coordinate system, the photosensitive surface is divided into four quadrants. This coordinate system is used to calculate the laser spot center position of uniform distribution on QPD photosensitive surface.

Through the optical system of receiver, the echoed laser pulse is defocused to a uniform spot with radius r on QPD surface, and the spot center is (x_0, y_0) in *o-xyz* coordinate system, as is shown in Fig. 1. It is not possible to access the precise spot center position by using QPD directly, but several algorithms can be used to obtain an estimate of the spot center position. The most common method is shown by the following equations [9]:

$$\begin{cases} x_0 = k\Delta x = k\dfrac{S_A+S_D-(S_B+S_C)}{S_A+S_B+S_C+S_D} = k\dfrac{P_A+P_D-(P_B+P_C)}{P_A+P_B+P_C+P_D} \\ y_0 = k\Delta y = k\dfrac{S_A+S_B-(S_C+S_D)}{S_A+S_B+S_C+S_D} = k\dfrac{P_A+P_B-(P_C+P_D)}{P_A+P_B+P_C+P_D} \end{cases}. \tag{1}$$

Where, S_i, i = A–D, represent the areas which are covered by the laser spot for each quadrant of QPD respectively. P_i, i = A–D, represent the peak powers for each quadrant of QPD respectively. Δx and Δy represent the normalized spots center coordinates, and k represents the scaling factor. Considering P is the imaginary total pulse peak of the spot, and S is the total area of the spot, then there are $\Sigma P_i = P$, $\Sigma S_i = S$. Assuming the QPD photosensitive surface diameter is $2r_1$, and $r = r_1/2$ is set up for the optimal spot radius [4].

As the geometry relationship in Fig. 1(b), in *o-xyz*, the relationship between the spot center and the spot boundary is

$$(x-x_0)^2+(y-y_0)^2=r^2. \tag{2}$$

In polar coordinate system, the spot center coordinate is (ρ_0, θ_0), and $x = \rho\cos\theta$, $y = \rho\sin\theta$. Converting Eq. (2) into the polar form:

$$\rho^2+\rho_0^2-2\rho\rho_0\cos(\theta-\theta_0)=r^2. \tag{3}$$