Precision Laser Beam Path Tracking Control System for Position Measurement Using PSD Sensor

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Abstract. Position sensitive detector (PSD) is an optical position sensor that can measure a position of the light spot in one or two-dimensions on sensor surface. The PSD is precision semiconductor optical sensor that produces output currents related to the “Centre of mass” of light incident on the surface of the device used in the measurement there are many advantages including a good positioning accuracy for fast response time and very simple signal conditioning circuits. A precise control system has been designed in this paper using a new and modern algorithm with a closed-loop system to obtain accurate tracking of the position and speed of the radiation used in the measurement of the specific physical process. The proposed control model about laser beam path controlled using a new type of controller named PSD fuzzy controller with feedback through PSD sensor, also the FOC method was applied to the hybrid stepper motor to control the position and speed with four rings feedback. The algorithm will realize better rise time and less overshoot better and detailed analysis is carried out to confirm the viability of the proposed system.

Introduction

Various kinds of optical sensor systems for tracking and displacement sensing are needed industrial and commercial applications. PSDs are used to track the position of the light spot in one or two dimensions. The main point of large and micro scale robotic applications involve high dynamic trajectory control. Rapid sensors for objects positioning are thus required, also combining high accuracy and reliability. Beam pointing stability is an important quality of a laser. Angular drift in a laser beam can be a serious concern in interferometer experiments where such drift can cause anomalous fringe shifts, skewing results. In most industrial projects, there are many problems that need one or two-dimensional sensors to measure an optimal position of a laser-beam path with high speed and continuous correction and accuracy. Laser beam pointing of a laser-beam plays a very important rule in the optoelectronic system to prevent error. Therefore, the angle deviation of a laser-beam must be corrected continuously through the controller as a result, the system must have high-reliability control [1].

This sensor is called a position sensing detector (PSD) which consists of a special monolithic PIN photodiode with several electrodes in order to achieve detection in 1D or 2D compared to discrete element detectors, PSDs have many advantages including high position resolution, fast response time and very simple signal condition circuits. The PSD is silicon optical which has the capacity to convert an incident light spot position into a series of analog signals. The property to generate continuous data represents the basic feature and advantage of a PSD according to surface structure. All types of PSDs show very fast response times, in the microsecond range, other important features are their good resolution and linearity over wide of light intensities [2].

The robotic applications have usually been designed for running repetitive and tedious tasks in unstructured environments, and there is some complex industrial operation (e.g. debarring, polishing, and manufacturing inspection). In this case, the PSD was used to locate the spotlight needed to determine the laser path and enable the control system of the specified measurement process, the system was implemented as a simulator before real-time vision-guided robot application.
We conclude the potential exists for PSDs as cost-effective sensors generating continuous and large-free data which could be fed into PID controllers with minimal processing in many fields of activity. The simple conditions circuit and algorithms can be embedded in a microcontroller system.

The main purpose of this paper is to design a high-reliability control system of laser spot tracking for measurement purposing (combustion systems) by developing the algorithm of the system. The spotlight laser tracker most nearly the universal tool for metrology and alignment [3], [4]. It has demanding requirements of the realize control system in terms of dynamic response purpose for tracking performance it has demanding. One of the themes of this paper will deal with track and adjust the position and speed of spot laser light to realize accuracy and stability using the control method, rules are formulated. Fuzzy PSD controller is designed, the feedback signal from the PSD location is extracted and embedded into fuzzy rules through a special program (software).

**Description of the Experimental System**

The main components of the laser beam path control experiment shown in fig. 1 and the overall block diagram.

![Laser beam path control experiment right side: 2 motors with mirrors. Left side: beam splitter and PSD sensor and 2 photo laser diode (one is a source and the other for calibration) mid-point are gas cells for measurement purposes](image)

Figure 1. Laser beam path control experiment right side: 2 motors with mirrors. Left side: beam splitter and PSD sensor and 2 photo laser diode (one is a source and the other for calibration) mid-point are gas cells for measurement purposes

![Optoelectronic control System working schematic](image)

Figure 2. Optoelectronic control System working schematic
The system in fig. 2 shown the laser light induced from the laser photodiode reflect between target and shifted mirrors directly to the gas cell (measurement area), the beam splitter divided the laser ray into two parts, first one pass to the photodiode for calibration purpose, and the second part pass to the optical sensor (PSD) which contains high precision one dimensional camera to calculate the spotlight position. PSD fuzzy controller calculates the position depending on the fuzzy rules and controls Photodiode PSD Motor Control system Beam splitter Gas cell Shifted mirror Target mirror Dynamic tracking algorithm to achieve ideal position and minimum error then send the control signal to the motor. The motor correct mirror deviation angle continuously.

Hardware and Software of the System

The real system consists of an optical probe, a filter assembly, a CCD, DACs and image processing software for data acquisition. Fig.6 shows a schematic diagram of the sensing system. The sensor converts the physical property (laser ray) into an electrical signal, actual voltage. Then, and the signal must be converted to digitized, displayed, transfer to make the decision through the controller described all steps in fig 3. The CCD camera in conjunction with an optical probe has wide–viewing data(x-y location of the spotlight). Data acquisition systems use ADC (analog to digital converters) to digitize the signal. The PSD sensor connects with data acquisition chip contain signal condition circuit to collect the data from the field then processed by data processing algorithms to calculate parameters are finally calculated and presented in numerical forms.

According to structure design, the system consists of an optical probe, a filter assembly, two-hybrid stepper motor, one beam splitter, a CCD, DACs and image processing software in a small chip. The CCD camera in conjunction with an optical probe has wide–viewing data(x–y location of the spotlight). Data acquisition systems use ADC (analog to digital converters) to digitize the signal. The PSD sensor connects with data acquisition chip contain signal condition circuits to collect the data from the field then processed by data processing algorithms to calculate parameters are finally calculated and presented in numerical forms.

Figure 3. Schematic diagram of the sensing system. Figure 4. Block diagram of the proposed control model. Tracking control approach

To detect the spotlight position must be developed three main parts motors, sensors, controllers shown in fig 4, it has to be mentioned that the control process is identical for the x.y-axis of the PSD sensor described in fig 5.
The first part is Stepper motors found a wide kind of applications in machines and devices where robustness, accuracy and small size at a low cost are needed. The hybrid stepper motor is used in the experiments, block shown in fig 4, represents the complete FOC method apply to the hybrid stepper motor. It is relatively simple and successful control strategies for a closed-loop system with four rings used to control four parameters, torque, speed, current, and position of the motor. The mathematical model equations for a hybrid stepper motor are given below. Relevant design of dynamics model based on a differential equation, equation (1) and (2) are the electrical equations, (3) and (4) are the mechanical equations of the hybrid stepper motor. The variation in torque, inductance is neglected in this model [5].

\[
\begin{align*}
\frac{di_a}{dt} &= \frac{u_a + k_m \omega \sin(N\theta) - Ri_a}{L} \\
\frac{di_b}{dt} &= \frac{u_b + k_m \omega \cos(N\theta) - Ri_b}{L} \\
\frac{d\omega}{dt} &= \frac{k_m i_b \cos(N\theta) - T_i - k_m i_a \sin(N\theta) - k_v \omega}{J} \\
\frac{d\theta}{dt} &= \omega
\end{align*}
\]
The second part is the PSD fuzzy controller. All modern control for optimization purposes we need to create a special type of controller to adapt the entire control system. Fig 6 describe control process between of the whole systems fuzzy controller is a new type of controller used in the model to track the reference signal, it consists of combined of 2DOF PID with the fuzzy controller, this design based on the trajectory tracking of the fuzzy control rules and the membership, the controller generates an output based on the difference between the reference signal and the feedback signal illustrated in fig. 7, automatic tuning complete through the system work, controller gains are tunable manually.

The third part is the PSD sensor contains the current introduced by the laser light 1024 nm light source after adjusted the spotlight in the midpoint of four photodiodes, then adjust vertical and horizontal axis to ensure the mirror tracks the reference signal. The best candidates for long-range displacement sensing applications are digital PSD, phototransistor PSD and tracking [6]. Fig. 8 illustrated detect of the spotlight.

The signal processing procedure for a PSD using vertical /horizontal motion algorithm shown in fig. 9 is addressed in this paper, the PSD algorithm validated by using experimental approaches, this data contains 24 characters calculated from the equations as shown below:

\[
\text{PosX} = \frac{(V(D01) + V(D11) - V(D00) - V(D10))}{V(D00) + V(D01) + V(D10) + V(D11) + 1} \times 50
\]  

(5)
The PSD sensor connects with data acquisition chip contain signal condition circuit to collect the data from the field then processed by data processing algorithms to calculate parameters are finally calculated and presented in numerical forms.

\[
F_{xy} = \left( \frac{V(D10) + V(D11) - V(D00) - V(D01)}{V(D00) + V(D01) + V(D10) + V(D11)} + 1 \right) \times 50
\]  

The PSD sensor connects with data acquisition chip contain signal condition circuit to collect the data from the field then processed by data processing algorithms to calculate parameters are finally calculated and presented in numerical forms.

**Experimental Results**

The comparisons of experimental results have shown excellent results of the proposed fuzzy-PSD controller and are well demonstrated for uncertain nonlinear conditions. Various kinds of popular control algorithm have been described for the controller design in our work have been presented to show the effectiveness of the proposed model and analysis.

The hybrid stepper motor is investigated on open-loop control. This investigation includes the study of the motor position, speed is shown in the figures (10, 11) to track the laser signal.

To determine the correctness of the prototype system, we conducted a series of experiments to illuminate and ensure the controlled laser beam path in the laboratory, and to obtain the best step response by responding and minimize errors.

Figures (12, 13, and 14) show a spot of laser ray light monitored tracked positioned after absorption of the PSD sensor. PSD fuzzy control setting work in receiving signals from PSD sensor (D00, D01, D10, D11), and make the process according to the fuzzy control algorithm and rules mentioned in this paper. The calculation of position is based on some steps of special equations.

The CCD camera containing the lens is an imaging device, and the video signal output from the AV side is PAL-style, The frame rate is 25 frames per second, where the CCD driver board also collects
data from the input video signal for 25 frames per second. Each frame of video is collected, the image data is preprocessed to filter out the noise (such as the moderate bright spots in the CCD pixels). Then the data of the whole image is divided into four parts: D00, D01, D10, and D11. The driver card collects 600 pixels in the crosswise direction of the CCD light-sensitive surface, and 500 lines in the longitudinal direction. The data thus collected is clustered into four parts, centered on points 300 (horizontal) and 250 (vertical). The data are then collected in four parts. Image data points in the 1-300 (crosswise), 1-250 (vertical) range are classified as D00 arrays, The data in the 301-600 (horizontal), 1-250 (vertical) interval are grouped as D01 arrays. The data in the 1-300 (horizontal), 251-500 (vertical) interval are classified as D10 arrays, The data in the 301-600 (horizontal), 251-500 (vertical) intervals are grouped as D11 arrays. The whole CCD light-sensitive surface is thus divided into four parts, equivalent to the four quadrants of the four quadrant detector, which we call the digital quadrant here. Sum the pixel data in arrays D00, D01, D10, and D11 (each array has 300X250=75000 digits), respectively, V (D00), V (D01), V (D10) and V (D11) are used to show the strength of the four digital quadrants, The driver board sends out the strength of the four numeric quadrants in the form of a string through the serial port protocol, and the receiver (such as the host computer) receives the strings after receiving them. Using the above formulas 1, 2, 3, and 4, the strength of the four numeric quadrants is calculated, respectively.

![Figure 10. Initial result for normal mode speed.](image1)

![Figure 11. Initial result for normal mode position.](image2)

The practical experiment was carried out to determine the optimal position of the laser beam path. Practice result using the PSD fuzzy controller to correct the laser path. Special codes and programming equations were used to obtain the optimal position for the deviation of the radiation. Figures (15, 16) of the result show the position in two dimensions and the error variable with time respectively.

![Figure 12. Initially spotlight position.](image3)

![Figure 13. The first step after motors moved one step horizontal.](image4)
Figure 14. Laser beam optimal position.

Figure 15. Target position two-dimensional test curves.  Figure 16. Beam path position error.

Figure 17. The proposed control system response before fuzzy PSD controller.
Conclusion
The laser source we use in the experiment is 1100. The data width of the ADC output is 24 bit and the sampling frequency of the ADC is 100MH. In this work, my experiment to determine the position of the laser path was accomplished by taking data packets at specific time intervals. The system response practical experiment to ensure that the process of handling the signal was finished in the right way to ensure optimal control.

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