E. G. Yousif et al., Iraqi J. Laser A 1 (1) 47-51 (2002)

Iraqi J. Laser, Part A, Vol.1, No. 1, pp. 47-51 (2002)

**IRAQI
JOURNAL
OF
LASER**

Laser Detection and Tracking System Using an Array of Photodiodes with Fuzzy Logic controller

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(Received 3 August 2002; accepted 8 October 2002)

Abstract: In this work laser detection and tracking system (LDTS) is designed and implemented using a fuzzy logic controller (FLC). A 5 mW He-Ne laser system and an array of nine PN photodiodes are used in the detection system. The FLC is simulated using MATLAB package and the result is stored in a lock up table to use it in the real time operation of the system. The results give a good system response in the target detection and tracking in the real time operation.

Introduction

Laser detection and tracking system basically means collecting information about distant objects or targets by sending a laser beam to them, and picking up the scattered or reflected laser beam that is reflected back by these objects. The controller and the servo systems moves the laser head so that the laser beam always points to the target [1]. It consists of a laser transmitter capable of transmitting a large power or energy through a highly directional optics system. The reflected beam back by the object is now picked up by another optical system and given to the detectors which process this signal and supplies this information to the controller. This will generate the optimal control signal if it is injected to the servo system, the transmitted laser beam will move toward the target position directly.

Position Sensitive Devices

Suppose a light beam from a source at a large distance (say, a distance much longer than any of the optical system dimensions) is collected by a lens, and focused onto a position sensitive detector. From geometrical optics, one can calculate the angle between the incoming ray bundle and the optical axis common to the objective and detector (or boresight), see Fig. (1), such that $y = f \times \tan a$. In Fig. (1), a has small value so that $\tan a = a$, thus $y = f a$ where y is the lateral displacement of the image at the focal detector plane of the objective lens, f is the focal length of the lens, and a is the angle (in radians) between the incident ray and optical axis.

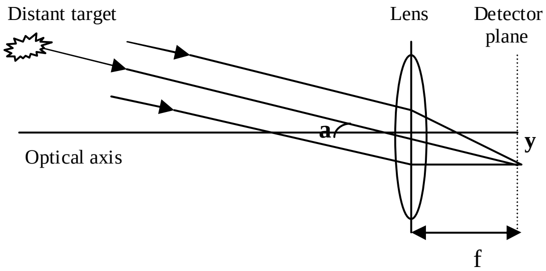

Fig. (1) Formation of an image from a small source at angle (a) from the optical axis.

It is worth noting that longer focal-length receiving systems produce a larger-displacement of the focal plane. Therefore longer focal length objectives are more sensitive in detecting off-axis displacement.

If the focal length of the objective lens and the linear displacement of the image from the optical axis are known, the angle between the object and the optical axis can be calculated [1]. The devices that allow this measurement usually produce an output voltage that corresponds to the position of the image on the focus of the detector (active area). The most common position-sensitive detectors are: quadrant photodiodes [2], silicon positions sensors, image-dissector tubes and vidicons. In this work an array of nine laser detectors (PN photodiodes) is used to detect and track the target are arranged as shown in Fig (2).

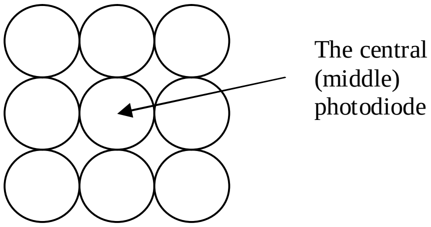

Fig. (2) The arrays of the nine laser detectors

Laser Detection and Tracking System (LDTS) Controller

The extensive application of using the laser beam in detection and tracking a target or missile emphasizes the need for an efficient, accurate and fast controller which controls the attitude of the laser beam and maintains it locked to the target by adjusting the position of the laser head continuously. The laser head rotating speed depends on the target position (target position is sent from the optical detectors and its electronic supports). Therefore the laser head velocity increase or decrease depends on the error and the rate of change of error in the target position. The general block diagram of LDTS is illustrated in Fig. (3).

Detection and Tracking Technique

Nine photodiodes and their electronic supports are used to detect and track the target. The detection and tracking process depends on sensing the reflected laser beam from the target (in this work the target is assumed to be a specular target, which is deterministically defined [2]). These nine photodiodes are arranged as shown in Fig. (2). This simple detection array is mounted directly on the top of the laser output window. The central photodiode should be placed accurately at the top of the output transmitted laser beam window.

At the beginning the LDTS is in detection mode (scanning mode) and the laser beam scans the space around it. At any time any one of the nine photodiodes receives a reflected laser signal from the target that means the LDTS detects a target. Then the system records the target position with respect to the virtual staring point. The target position is supplied to the controller and the later will point the laser beam towards the target directly. The middle (central) photodiode will receive the reflected laser beam from the target. After LDTS detects a target, the LDTS enters in the tracking mode. If the target moves towards the right photodiodes the reflected laser beam will fall on one of these photodiodes. This photodiode with its electronic supports will generate an electrical signal, which is supplied to the controller. The latter generates the control action and it injects this control signal to the DC servomotors to move the laser head towards right photodiodes. In other words the controller will generate a control signal and injected it to the DC servomotors and changing the laser head position so that as a result the transmitted laser beam points to the target. Therefore the reflected laser beam from the target will fall on the middle (central) photodiode again.

Description of the System

The main parts of the LDTS are the laser system, detectors, position transducer, controller, servo system and finally the personal computer.

He-Ne laser system (λ=0.632 μm) is used in this work as a transmitted laser beam. Some optical components are used to collimate the transmitted laser beam. Nine PN photodiodes are mounted at the top of the laser head structure. These detectors are arranged as an array, these photodiodes are used to detect the target and sense any change in its position by receiving the reflected laser beam from the target, i.e. these detectors supply the controller with the important information about the change in the target position.

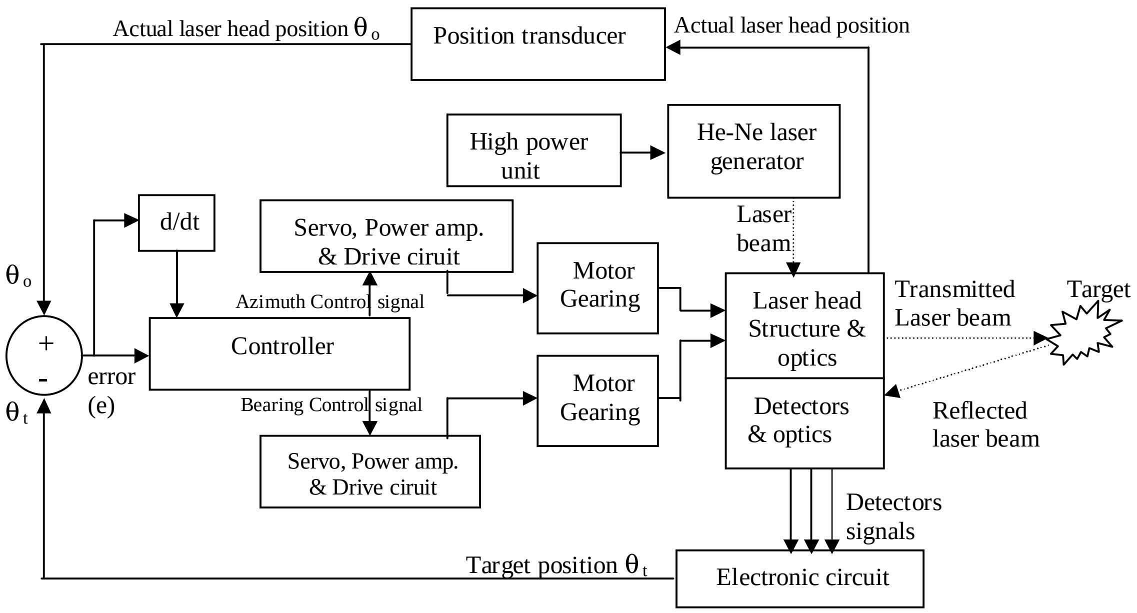

Fig. (3) General block diagram of the laser detection and tracking system (LDTS)

Two linear continuous rotation (endless) high accuracy potentiometer is attached coaxial to the axis of the laser head (bearing and azimuth) [3]. The potentiometer is mounted on an axially sliding shaft to allow free movement of the laser head during positioning. The output of the potentiometer is an analogue voltage, which is proportional to the laser head position, so that the potentiometer acts as a position transducer in this system.

The laser head is mounted in a chamber modified to accept a ball bearing and a belt slot. The laser head is driven about its azimuth axis and bearing by DC servomotors, a power amplifier, and drive circuit are used to drive the motors directly according to the control action information.

The computer receives actual laser head position θ_o, which is given to the computer via the position transducer and its electronic circuit supports. Also the computer receives the target position θ_t which is given to it via the detection circuit. Then the computer evaluates the error ($\theta_o - \theta_t$) and the change in the error [e(k) – e (k–1)] in order to generate the actuating signal to the system according to the control algorithm, which is stored in the computer memory.

Fuzzy logic controller (FLC)

The idea behind using FLC can be summarized in the following words. Without using the system mathematical model, it must be designed a FLC to control the laser head position with fast response and minimum steady state error. The block diagram of the FLC is shown in Fig. (4).

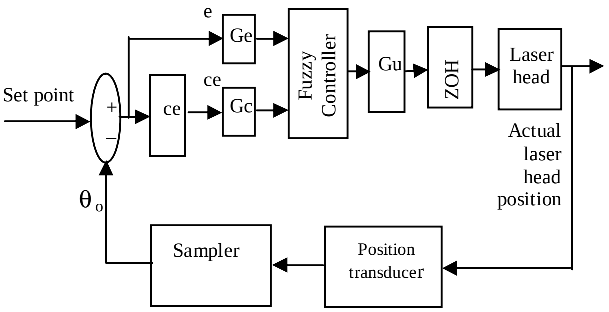

Fig. (4) Block diagram of fuzzy logic controller (FLC)

The actual head position is read from the position transducer and its electronic supports. Then the error and change of error are evaluated and they are passed through scaling gain stages Ge and Gc. The outputs of the later are “fuzzified” that is the values are converted to their fuzzy representations. These values execute all the rules in the knowledge repository that have the fuzzified input in their premise, resulting in a new fuzzy sets representations for the output variable (control action). Center of gravity deffuzification method is used, the output of the FLC is applied to the system through a scaling gain stage (Gu) and zero order hold (ZOH), and the new states are picked up by the aid of the position transducer and the procedure is returned again. The error and the change in error are given by: $e = \theta_o - \theta_d$ and ce=[e(k) – e(k–1)] where e is the error, ce the change in error, θ_0 is the actual laser beam position, θ_d is the desired laser head position, e(k) is the instantaneous error and e(k – 1) is the previous error. Each combination of the inputs fuzzy sets describing (e and ce) are associated with a fuzzy set for the appropriate control action. The linguistics rules that are used in FLC are found by the dependence on the background information and expert knowledge of the system. 49 rules are used with the fuzzy controller (see Appendix). The memberships of the FLC are shown in Fig. (5).

Results and Discussion

Fig. (6) illustrates the obtained results of applying the FLC shown in Fig. (1) using different sampling times (0.001, 0.01, and 0.1 second). It is clear that the FLC works well with the first case (Ts=0.001s), because it is closest to the continuous case from other cases.

Fig. (7) shows the step response of the bearing angle of the laser head when FLC is used. It is clear that the system reaches the desired position with fast response and zero study state error without oscillation about its final position of the laser head.

The tracking performance of the system for different target positions is shown in Fig. (8). In this experiment the target position is changed with constant velocity, it is clearly from this Fig that the laser head and beam always locks to the target position (since the target velocity is less than the maximum velocity of the detectable target [1]). The target that is used in this experiment is a small size of about 50% reflected marital mounted on a target holder and it moves automatically by using servo system controlled by the computer.

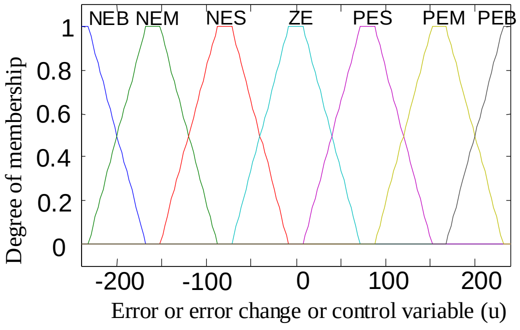

Fig. (5) Membership functions of the FLC for error e change in error ce and output u.

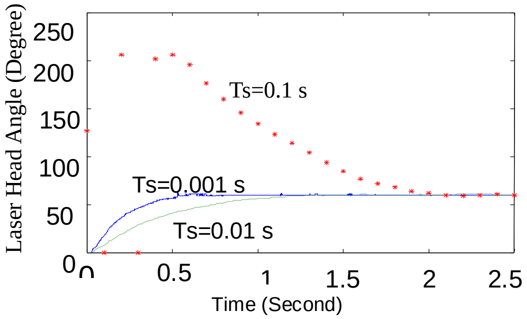

Fig. (6) Step response of the FLC for different sampling times (Set point is 70^0)

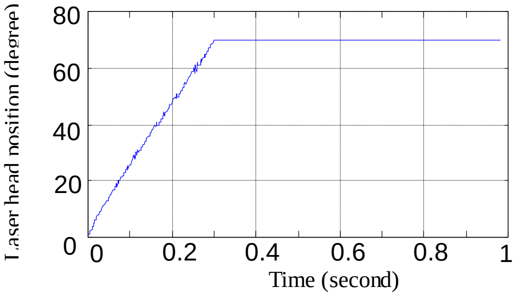

Fig. (7) Step response of the system using FLC controller. (Set point is 70^0)

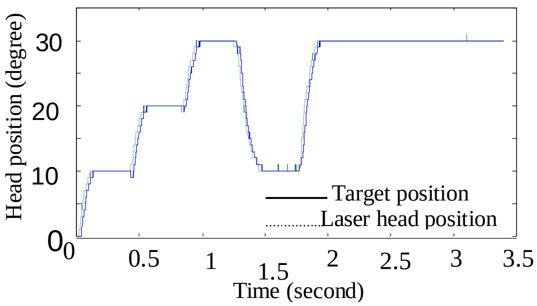

Fig. (8) System tracking performance using FLC

Conclusions

The laser detection and tracking technique proposed in this work (which depends on the observation of the outputs of an array of nine conventional photodiodes) gives a good result when experimentally tested with different types of controllers namely; PD controller, fuzzy logic controller, fuzzy logic controller with fine tune, and hybrid fuzzy logic and PD controller [1,4].

The accuracy of the LDTS to detect, track, and confine the target in small area depends on many parameters such as:

1. The lateral distance between two adjacent detectors is important because when this distance decreases the maximum error in the target position decreases too, and the target will be confined in smaller area.
2. The tracking accuracy depends on the step resolution of the controller or minimum step change in the laser head position in the azimuth and bearing. If the step change of the laser head decreases the LDTS will confine the target in smaller area and the maximum error in the target position with respect to the optical axis will decrease too.
3. As the settling time of the step change in the laser head position decreases the LDTS can track faster targets
4. When the sensitivity of the optical receiver increases, LDTS can sense or detect targets at longer ranges and lock to them [5,6]. The sensitivity of the optical receiver is increased by using low noise, high quality and high sensitivity components. Moreover, the laser type must be used that has low propagation loss in the atmosphere and can propagate in the air easily with minimum losses.
5. In the case of using pulsed laser system the maximum detectable target velocity depends on the settling time of the LDTS and the repetition rate of the output laser pulses [1].

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Appendix

49 rules of the FLC change in error ce

	NCB	NCM	NCS	ZC	PCS	PCM	PCB
NEB	PUB	PUB	PUB	PUB	PUM	PUS	ZU
NEM	PUB	PUB	PUB	PUM	PUS	ZU	NUS
NES	PUB	PUB	PUM	PUS	ZU	NUS	NUM
ZE	PUB	PUM	PUS	ZU	NUS	NUM	NUB
PES	PUM	PUS	ZU	NUS	NUM	NUB	NUB
PEM	PUS	ZU	NUS	NUM	NUB	NUB	NUB
PEB	ZU	NUS	MUS	NUB	NUB	NUB	NUB

Error

منظومة كشف وتتبع ليزرية باستخدام مصفوفة دايودات ضوئية مع مسيطر المنطق المضبب

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الخلاصة

تم تصميم وبناء منظومة لكشف وتتبع الأهداف بواسطة الليزر وباستخدام مسيطر المنطق المضبب. استخدم ليزر الهليوم - نيون بقدرة 5 ملي واط ومصفوفة مكونة من تسع ثنائيات (دايودات) ضوئية لغرض كشف الأهداف. تم تنفيذ جميع خورازميات المسيطر المضبب في الحاسب الشخصي باستخدام برمجيات MATLAB وخزنت النتائج في جدول خاص والاحتفاظ به لغرض استخدامه في التشغيل العملي للمنظومة في الزمن الحقيقي . أعطت المنظومة نتائج استجابة جيدة في تتبع وكشف الأهداف عند فحصها عملياً .