The Performance Improvement of the Target Position Determining System in Laser Tracking Based on 4Q Detector using Neural Network

A. Salmanpour, Sh. Mohammad Nejad

Abstract—One of the methods for detecting the target position error in the laser tracking systems is using Four Quadrant (4Q) detectors. If the coordinates of the target center is yielded through the usual relations of the detector outputs, the results will be nonlinear, dependent on the shape, target size and its position on the detector screen. In this paper we have designed an algorithm with using neural network that coordinates of the target center in laser tracking systems is calculated by using detector outputs obtained from visual modeling. With this method, the results except from the part related to the detector intrinsic limitation, are linear and dependent from the shape and target size.

Keywords—four quadrant detector, laser tracking system, rangefinder, tracking sensor

I. INTRODUCTION

THE laser tracking is a very accurate, noncontact system with the dynamic measuring ability that the broad performance confines, high sampling rate and automatic tracking are of its features [1]-[3]. With the development and improvement of the performance quality of the laser tracking systems, it is possible to use them in robots calibration, 3D measurements and controlling applications of automatic machines [1]-[4].

The method presented in this paper is one of the new methods used in tracking systems for movement and changing the direction to the desired position and recording it [2], [4]. This system benefits from a phase rangefinder, 2-axes tracking mechanism, 4Q detector, gimbal and sheet reflector [4]-[7].

In order to determine the target position, the laser tracking system uses distance information and the angel yielded in order from the rangefinder and the tracking mirror parts [4], [5]. The tracking is completed with measuring the amount of tracking error signal and alignment of the tracking mirror angels on the minimum of these errors [4]. But if the spot light reflected on the detector screen does not hit each of the four quadrants or if it is situated on the gap band, the detector does not give the desired results [8]-[11]. If the spot light reaches

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the edge of the detector, some errors occur in laser tracking system while determining the target position [8]-[11]. In this paper, through using artificial neural network, an algorithm is presented that calculates the target position without being dependent on these limitations.

II. LASER TRACKING SYSTEMS

A. Performance Analysis

In this system, there are tracking sensors and rangefinders separated from each other. Fig.1 shows the tracking system configuration. At first, the sent signal from the laser through the tracking mirrors is directed to the target on which sheet reflector is installed. If the radiation does not hit the center of the reflector, there will be offset that indicates tracking error (the lateral displacement) [4].
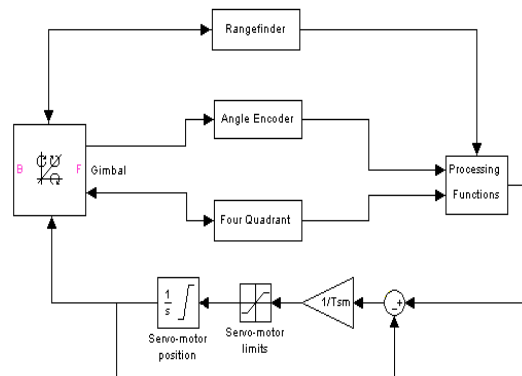

Fig. 1 The tracking system configuration

The amount of tracking error and distance is determined by the returned radiation from the target in 4Q detector and rangefinder parts after passing through the tracking system. The target tracking is done by using the error tracking signals Δx and Δy extracted from the 4Q detector. These signals are used for calculating the correct angels of the tracking axes in order that the sent radiation hits the target center. Then the signals are sent to the motor drivers in order to align the tracking mirrors angels on this value.

The signals needed for tracking system correction that should be sent to the motor drivers are yielded though these relations [4]:

$$\Delta \alpha_s \cong \frac{\Delta y}{2l \cos^2 \beta} \qquad (1)$$

$$\Delta\beta_s \cong -\frac{1}{2l}(\tan\alpha.\tan\beta.\Delta y + \frac{\Delta x}{\cos\alpha}) \qquad (2)$$

Where Δx and Δy are yielded from the tracking sensor, α and β are the results of the angel encoders related to angels of tracking mirror axes and l is the amount of distance.

B. Tracking Sensor

The sensor part of the tracking system is made of the light transreceiver with the reflector. The performance mechanism is that at first the transmitter lightens the measuring field by the monotonous radiation that is equivalent to the view angel of the receiver. Some part of the reflected light from the reflectors is focused on the 4Q by the receiver lens; in this situation the radiation offset from the center of the detector demonstrates the reflector angel displacement from the receiver lighting axis. This amount for the little angels is yielded by the relation below [8], [9]:

$$\alpha \approx \frac{\Delta s}{f} \qquad (3)$$

Where Δs is the amount of the spot offset from the center of the detector and f is the effective focal length of the receiver. The schematic illustration of the sensor part is given in Fig. 2.
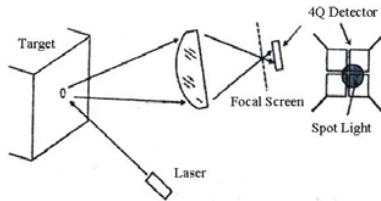

Fig. 2 The tracking sensor part schematic

The 4Q detector is made of monotonous silicon screen with two gaps of about $10\,\mu m$ length that passes through its middle with four electrodes equal and dependent on its surface [4].

The radiation location on the detector surface is defined by the amount of light power that reaches to each of the quadrants. If the radiation symmetrical to the center of the detector is focused on it, detector will produce the equal light currents in each of four quadrants and if the radiation displaces from the center of the detector, the electrodes output currents will also change and thereupon the processing algorithm shows some offset Δx, Δy from the center. The amount of offset in x and y directions is yielded through the relations below [4]-[9]:

$$\Delta x = K\frac{(i_B + i_D) - (i_A + i_C)}{i_A + i_B + i_C + i_D} \qquad (4)$$

$$\Delta y = K\frac{(i_A + i_B) - (i_C + i_D)}{i_A + i_B + i_C + i_D} \qquad (5)$$

$$r = \sqrt{(\Delta x)^2 + (\Delta y)^2} \qquad (6)$$

$$\theta = \tan^{-1}(\frac{\Delta x}{\Delta y}) \qquad (7)$$

Where i_A, i_B, i_C and i_D are the output currents from each of the electrodes, K is the scale factor proportional to the diameter of the light spot on the surface of the detector and (r, θ) is the polar coordinates of gravity center of the target image.

The location of the spot on the surface of the detector is determined by the amount of the lighting flux that reaches to each of the four quadrants (sensors) that this quantity is changed for each angels of the input radiation to the detector active surface. To minimize the offset caused by this factor using the lenses with the long focal length is recommended.

With this assumption that the center of the spot in the detector surface is (x_0, y_0) and the center of the detector is $(0,0)$ (i.e. $y = y_0$) the total intensity at the top of the x axis for the defined amount of y_0 is yielded from the following relationship:

$$I_{total}(y_0) = \int_{-\infty}^{\infty}\int_{0}^{\infty}\left(\frac{\pi R^2|d|}{\lambda f^2}\right)\frac{4J_1^2(\sqrt{x^2 + (y - y_0)^2})}{x^2 + (y - y_0)^2}dxdy \qquad (8)$$

In this equation, J_1 is the bessel function of first order, f is the lens focal length, R is the receiver lens radius and d is height of the spot in detector surface. So that the response of the detector theory in y direction for the various amount of θ is calculated as follows:

$$\theta_y(\theta) = \frac{I_{total}(kR\theta) - I_{total}(0)}{I_{total}(0)} \qquad (9)$$

Fig. 3 shows the amount of spot offset on the detector surface from the primary situation of $x_0 = 2\times10^{-3}$ and $y_0 = 10^{-3}$ in y direction for the various amount of θ with considering a detector with dimensions (12.5×12.5) mm while one lens with 50mm radius and focal length 180mm is used in the system.

C. Modeling of 4Q Determining Error System

Instead of four current values we can use the areas of spot light that overlap with four various quadrants. We can calculate these areas according to the geometrical coordinates of spot center situation. Using the areas instead of currents does not make any difference in calculation results, because the normalized currents (or the areas) are used in this method.

If our targets are square or rectangular and (4), (5) are used for finding the coordinates of the target gravity center there will be no difficulties. Until these targets overlap with all four

quadrants, distance error and target angel error are able to be detected completely linear [12], [13]. But for circular targets,
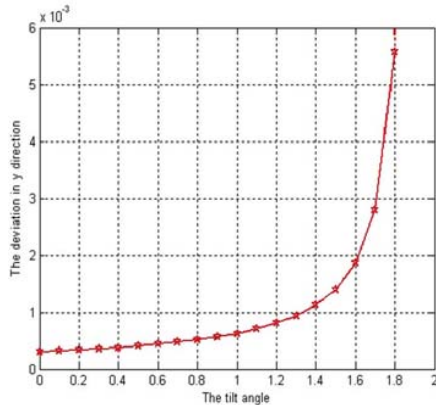

Fig. 3 The detector theory response to the input radiation angel

these transmission features are nonlinear, because spot displacement transmitted among adjacent quadrants (sensors) is not proportionate with some percent of area [12], [13]. As shown in Fig. 4, the error increases in spot center estimation as the spot center moves away from the center of the detector [12].
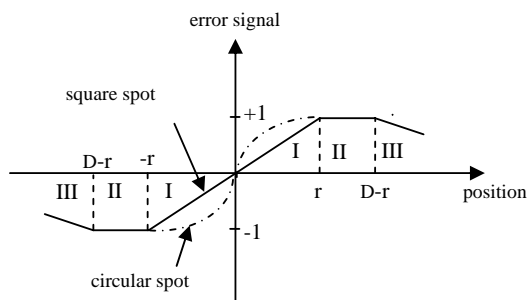

Fig. 4 The error signal according to spot position on the detector

There are three important limitations in detecting the target different positions by using the 4Q detector. The first one is that the reflected radiation (spot) should overlap with all four parts of the detector in order to yield the coordinates of the target image center, i.e. if the light spot moves far away from the detector center, its output signals will not be able to give accurate information about the position of the spot gravity center. How much bigger the size of the spot will be, the linear area will be bigger too, so one way to avoid this limitation is to diverge the input radiation.

The next limitation is when spot light reaches the edge of the detector, in this situation because some of the spot energy is wasted, we will face with some difficulties in estimation of the accurate location of gravity center. If the spot diameter is too long, with a little displacement, some part of it will be outside of the detector. So how much the size of the spot is smaller, it can travel more distance before reaching the edge of the detector.

The third problem that exists in these detectors is the width of separating part (gap) between sensors. If the target image become like a small focal spot, when this spot is set on the gap it will create wrong information.

The area of the parts in which quadrants overlap with the target image can be yielded according to the target center coordinates [14], but because these relations [14] are completely nonlinear they cannot be inverted, i.e. it is not possible to yield the coordinates of the target center by these relations with having four areas.

Our target is to find the best way that can work for all spots wherever they are. For this reason we have suggested the neural network that will be discussed in next part.

III.   RESULT AND DISCUSSION

A.   Statement of the Solution

In this paper, with both visual simulation method and mathematic modeling, we yielded these areas for several coordinates of the target center that are randomly selected on the surface of the detector. After designing the neural network these data can be used for teaching network. The neural network chosen for this issue is the perceptron neural network with several layers. The number of layers is 2 and that of the neurons is 30.

For considering the nonlinear relation between input and output of stimulation function of first layer we have chosen the hyperbolic tangent. For output layer we have selected linear function for stimulation.

The Levenberg-Marquardt algorithm is chosen from among the training algorithms for this network, this algorithm seems to be the fastest way for progressive neural network training with limit amounts. Generally we are looking for a function that takes the amount of detector output as input arguments and give the position of the spot center.

B.   Simulation Results

After teaching the network with importing areas yielded from the overlapping target image and that of quadrants, it is possible to estimate the approximate position of the target center. Because obtaining the off-line network coefficients is also possible, we are not sensitive about time consuming characteristic of teaching network.

The given results from modeling with the help of the artificial neural network for the target various positions is shown in Fig. 5 and 8, here we can see that when the target does not overlap with all 4Qs (the saturation region in Fig.5) or when one part of it is outside of the detector (the nonlinear part in Fig. 6), the accurate estimation of the center position is not possible, because of intrinsic detector limitations, but the important point is that this model is usable for any kind of target image. We can observe this issue with comparing Fig. 5 and 6 with Fig. 3 for circular light spot.

IV.   CONCLUSION

In 4Q detectors in order to obtain accurate information about target position in laser tracking view field, there are two kinds

of limitations. One of these limitations is natural and is related to the structure and nature of this kind of detector. Another
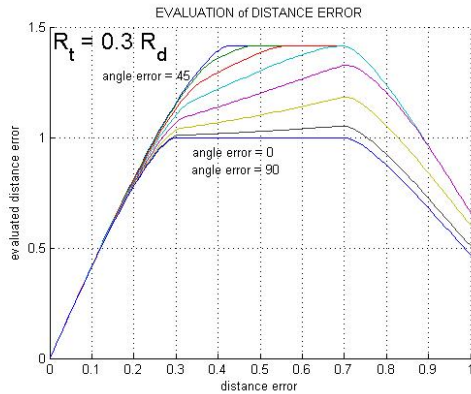

Fig. 5 the modeling with neural network results for medium circular target (R_t is target radius and R_d is detector radius)
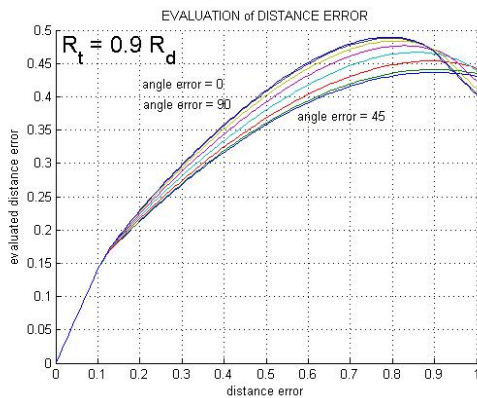

Fig. 6 the modeling with neural network results for large circular target (R_t is target radius and R_d is detector radius)

limitation is connected to the relations by which we extract the target position information from the currents obtained from quadrants. Even if the relations, used previously for this process, present acceptable response for square and rectangular shape, but for circular light spot these responses are nonlinear. Thereupon as the target position change, the values yielded for Δx and Δy change nonlinear and more important that it is also dependent on the target size (spot diameter). In the suggested method an artificial neural network designed that is taught according to the target various positions and the values obtained for 4Q outputs with visual simulation. If the coefficients matrixes of this network are used instead of previous equations, the being nonlinear difficulty of the detector response to the circular targets and the response being dependent on the target size is eliminated according to its results.

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