OPTICAL RANGE FINDER BASE DON POSITION SENSITIVE DETECTOR

DISTANCIÓMETRO DE TRIANGULACIÓN LASER

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ABSTRACT

A range finder is any device capable of measuring the distance between two points. An red laser pulsing at one KHz is used as the light source, which is incident on a target. A PSD based optical receiver collects the reflected light from the target. The PSD produces two current signals that are amplified and passed through a band pass filter. The two signals are read by two 12-bit analogue to digital converters (ADC). These two readings are manipulated by a software package, Lab View. Mathematical manipulation by Lab View converts the two signals into a range in centimetres. The optical set up and the length of the PSD determine that range finder has a range of 20 – 80 cm in the prototype. At these two extremes, the received light spot goes past the ends of the PSD. Over this range accuracy is about 1%.

Key words.- Range finder, Metrology optic.

RESUMEN

Un telémetro láser es un dispositivo capaz de medir la distancia entre dos puntos. Un láser rojo pulsado a 1 KHz es usado como la fuente de luz, la cual impacta sobre un blanco. La luz reflejada por el blanco incide sobre un sensor óptico tipo PSD. El PSD produce dos señales de corriente que son amplificadas y filtradas. Estas señales son leídas por dos conversores análogos digitales (ADC) y son manipuladas en LabView. El programa en LabView convierte las señales provenientes del PSD en lecturas de distancias a la que se encuentra el blanco. El arreglo óptico y el tamaño del PSD determinan el rango de trabajo del telémetro, 20-80 cm en nuestro prototipo. En éste rango, la imagen del spot luminoso impactando sobre el blanco se mueve de extremo a extremo del PSD. Sobre éste rango la aproximación obtenida fue de aproximadamente el 1%.

Palabras clave.- Telemetría laser, Distanciometro laser.

INTRODUCTION

The origins of distance measurement by means of graduated lengths of material such as chain, tape measure or piece of knotted rope are lost to antiquity. Optical distance measurement also has a long history, and is usually taken to stem from the work of James Watt in 1771. Since James Watt, hundreds of different types of instrument have been produced to make indirect distance measurement using light possible.

There are several principles used to measure distance, using light, the most important of these with regards to using a Position Sensitive Detector (PSD), include instruments based on the range finder principles such as fixed base and fixed angle. Based on the above, the most important variable to determine range is the angle of incidence. The basis of this work was to design and build an inexpensive, accurate range finder that uses low power, red light sources, that could be used in different applications.

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THEORY

The starting point of this work was a PSD manufactured by SiTek Electro Optics. This device is most sensitive to Infrared light of 920 nm. See Fig. 1. These PSD's have various applications such as optical position and anglesensing, remote optical control systems, displacement and vibration monitors, laser beam alignment, automatic range finding and the motion analysis of human beings [1]. The basic principles on which all of these range finders operate are all similar and two variables cover them all. These give the choice of using a fixed base length and determining the angle subtended by this base (parallactic angle) at different distances or alternatively, using a fixed angle (anallactic angle) and determining the base length [2 and 3].

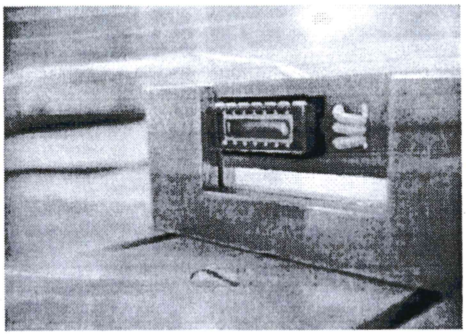

Fig. 1 *PSD manufactured by SiTek Electro Optics.*

For the PSD, the most applicable method will be the Fixed Base Principle. This works from a fixed base of length AB = b and a fixed angle at A. The angle at B (= α) is measured. The distance to the target, AY can then be determined from this angle, α and the constant b. See Fig. 2 for details.

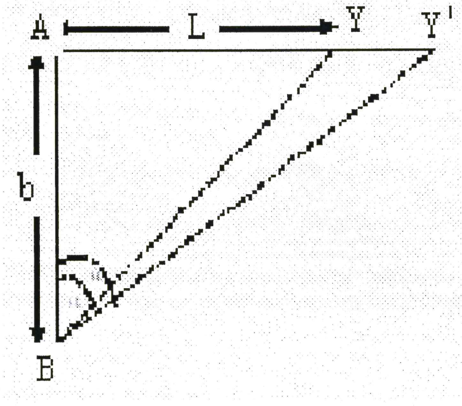

Fig. 2 *Fixed base principle.*

The PSD's themselves are lateral effect photodiodes that are analogue photodetectors that can provide continuous information about the position of a light spot on the detector's active surface. The position is derived, by dividing carriers generated in the illuminated region between the electrodes in proportion to the conductance of the current paths between the illuminated region and the electrodes. Since the photon-generated current through each of the lateral contacts is a function only of the distance of the light spot from the centroid from these contacts, position information can be extracted by measuring the currents of the contacts [4].

In detail, the photolateral effect is when light illuminates a p-n junction it generates carriers that are separated by the electric field of the junction. When the surface of the diode is not uniformly illuminated, the photogenerated carriers locally cancel part of the potential barrier. A lateral photovoltage is produced as a result of the separation process with the reduction of the barrier potential at the point of illumination. The lateral photovoltage induces lateral flows of carriers away from the irradiated region, which will also reduce the potential barrier [5]. See Fig. 3.

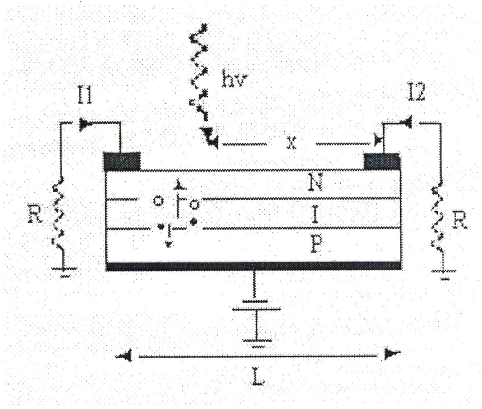

Fig. 3 *A non-uniformly irradiated P-I-N diode. The currents I_1, I_2 containing the position information from the top layer through two lateral ohmic contacts [5].*

Incident light falling on the PSD is converted photo electrically and detected by the two electrodes on the P- layer as photocurrent. This is proportional to the light energy incident on the PSD [1]. These photocurrents can then be used to determine the position of the incident light spot. Examine Fig. 4.

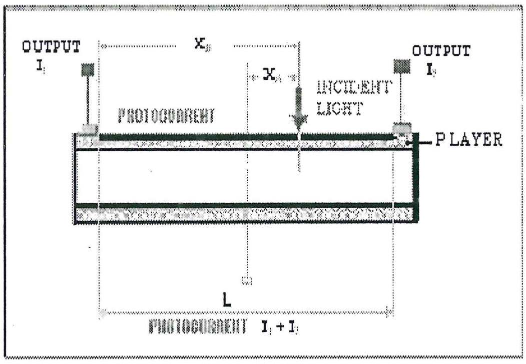

Fig. 4 *Cross Section of PSD, showing the relationship Between incident light spot position, photocurrents and output pins [8].*

When the centre point of the PSD is set at the original point [8], the exact position of a light spot can be determined following the formula:

$$\frac{I_2 - I_1}{I_2 + I_1} = \frac{2X_A}{L} \tag{1}$$

Where: I_1 and I_2 represent the output photocurrents of the electrodes, X_A is the position of the light spot, L is the inter electrode separation.

Alternatively, when the end of the PSD is set at the original point [8], the exact position of a light spot can be determined following the formula:

$$\frac{I_2 - I_1}{I_2 + I_1} = \frac{2X_B - L}{L} \tag{2}$$

Where: I_1 and I_2 represent the output photocurrents of the electrodes, X_B is the position of the light spot, L is the inter electrode separation.

The source of the light spot on the PSD is the reflected red light from the target. The amount of light that is returned is characterised by the reflection coefficient ρ. The two extremes are diffuse reflection (from rough surfaces) and specular reflection (mirror-like surface). The reflecting behaviour of most surfaces lies somewhere between these and is relevant when choosing the target [6].

Between the PSD and the target and between the red light source and the target there needs to be two converging lenses. The lens between the red light source and the target is used to collimate the incident light to from a small spot on the target. The lens between the target and the PSD focuses the incoming light onto the PSD. See Fig. 5.

The focal length of this lens f, and the distance to the light detector remains constant. The position of the spot at which the reflected light is focused, x, relative to the centre of the lens is determined by the range of the target. A decreased range to the target will result in a greater angle to the lens and hence the light will be focused at a greater divergence, therefore increasing the value of x. The ratio of f and x can then be used to determine the angle of the reflected light.

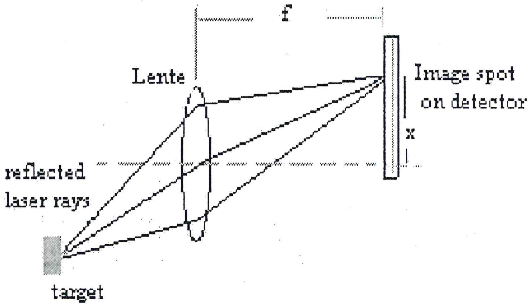

Fig. 5 *Light paths between the target and thePSD [2].*

Once the angle is known, the range of the target can be determined from the similar triangles rule, see Fig 6. From this arrangement, it is clear that the measurement of the incident angle is paramount to the accuracy of the instrument, and this angle is dominated by the precision of the light position detector [2].

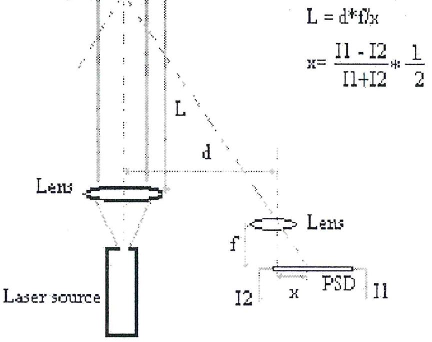

Fig. 6 *Relationship between target distance and position of ligth spot on PSD [2].*

EXPERIMENT

Design of optical range finder

The range finder will have multiple sections for it to operate. These major sections include:

- Electronics Section
- Optical Section
- Personal Computer with Specialized I/O card
- Application Software

To help understand how each of these various sections will be put together and how they will interact; a block diagram is shown in Fig. 7.

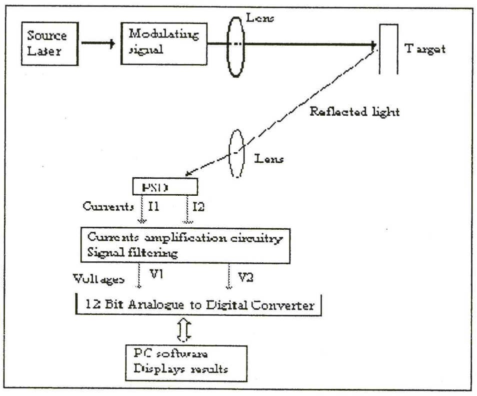

***Fig.** 7 Block diagram of red range finder.*

The irradiance H available on the PSD surface, is the incident radiant power per unit area and is obtained by multiplying the intensity of the source in watts per steradian by the solid angle subtended by the unit area. Thus the irradiance is given by [7]:

$$H = \frac{A\,P\cos q}{2\,pR^2} \qquad (3)$$

Where θ is the angle between a small incremental area of the source and the normal to the surface of the target.

The next point considered regarding the received light power was how much light power the receiving lens would collect. This was proportional to the area A of the lens.

Laser driver circuit

As lasers are dependent on current for their operation, a driver circuit was incorporated into the design. Therefore, the next major part of the electronics to be designed was the laser driving circuit.

Timing circuit

As the laser needs to be modulated at 1 KHz, some form of time driver was required. The simplest known device was a 555 monolithic timing circuit [8]. See Fig. 8a, 8b y 8c, for the implementation of this laser driver.

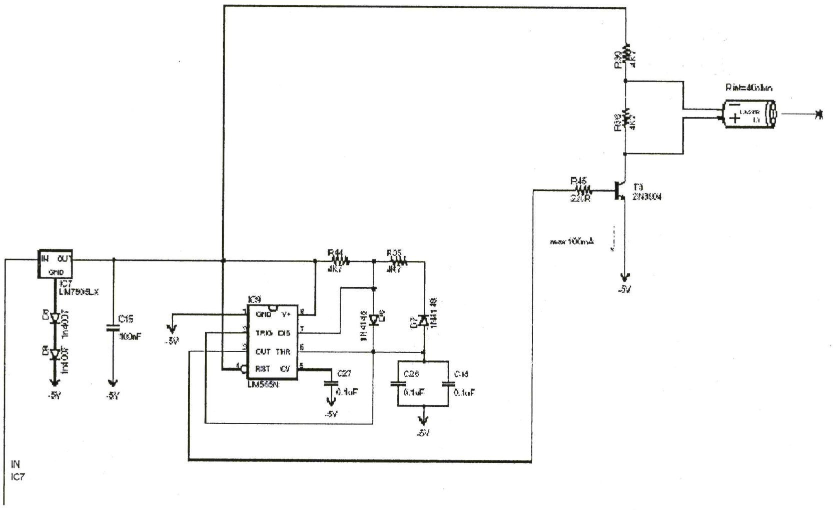

***Fig.** 8a Source laser driver circuitry.*

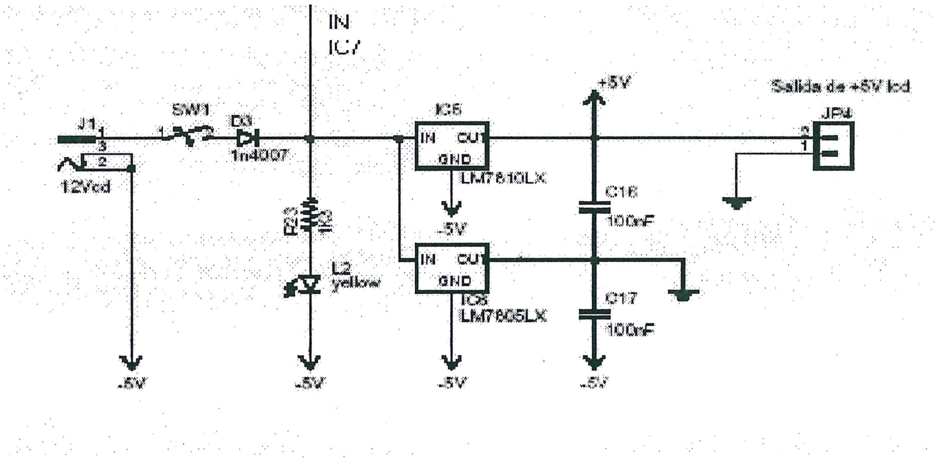

Fig. 8b Source laser driver circuitry.

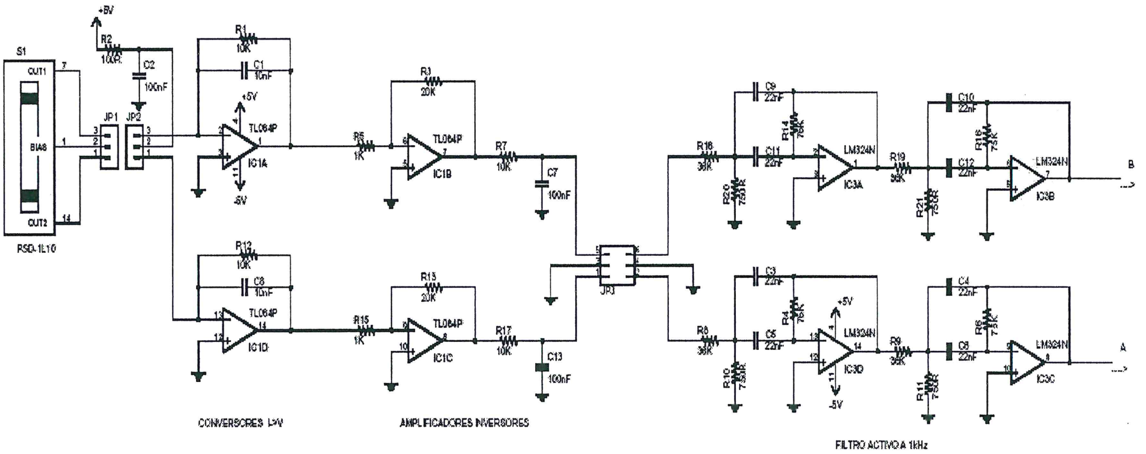

Fig. 8c Amplifier and filter driver circuitry.

Optical system

A target were also placed on a rail at adjustable lengths. The lens was used to collimate the beam from the laser onto the target positioned a short distance away. A piece of aluminium was used as the target. Its dull, non-uniform surface ensured that small quantities of red light would be reflected back.

As the target was mounted on the rail, it could be easily moved back and forth to allow the system to measure different ranges.

The PSD, mounted on a piece of veriboard, was in turn mounted onto an aluminium mount plate, this mount plate was then in turn, mounted to a XYZ-position mount, which was mounted on the optics board. This XYZ-position mount was used to position the PSD precisely in all three axes, in relation to the receiving lens.

The receiving lens for the system was a plano-convex lens. This lens was placed on the board so that it was exactly in line with the transmitting lens. The distance between the centres of these lenses was 80 mm. The PSD was mounted approximately 75 mm behind this, and the XYZ-position mount was used to get the exact focal length.

All the components within the system were set so that their centres were all at the same height. The PSD was positioned at the correct height by way of the XYZ-position mount.

The target was then set at a range of 50 cm in front of the lenses. The centre of the PSD was then set using the XYZ-position mount to be at the point where the red light was focused. This made 50 cm the mid-range of the range finder.

See Fig. 9 and 10 for photographs of this system.

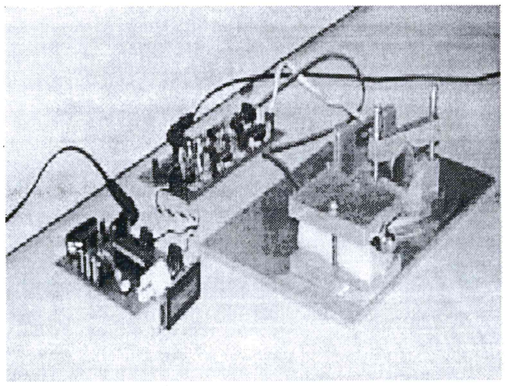

Fig. 9 *View of the range finder components.*

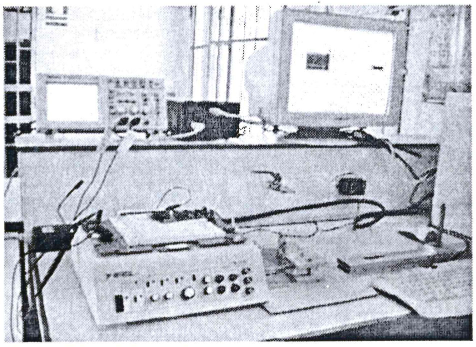

Fig. 10 *Complete view of the range finder in operation.*

Once the optical components were set up, and the electronic sections were built and tested, the two sections were tested together using an oscilloscope.

This enabled the fine-tuning of the position of the PSD using the XYZ-position mount. The oscilloscope was able to determine that the two signals of the PSD did indeed change their amplitude as the target was moved closer and further away. The band pass filter was removing the natural light and fluorescent light components as well. At this point, it was time to set up the PC and the I/O card.

PC SET UP WITH DAQ I/O CARD AND LAB VIEW

Software design

The output of the electronics section needed to interface with the PC. The National Instruments Multifunction Data Acquisition Card was used as the interface [9]. This I/O card came with a small plug in board (they are joined by a ribbon cable) to allow easy access to the various channels available on the card. See Fig. 10 for a picture of this plug in board.

The two signal outputs and ground of the signal processing PCB were fed into to two analogue input channels and ground of the I/O card. The input mode for these was referenced single-ended. The analogue input channels use 12- bit analogue to digital converters. The channels used are analogue channel 0 (left) and analogue channel 1 (right). These channels were then fed into Lab View virtual channels. The minimum and maximum input ranges can be set in these virtual channels. In this design, the range -1V to +1V was used. The *Lab View* software then used this range to set the gain of the channels to 100. This allowed the precision of the channels to be 5mV. In effect, these virtual channels were able to use the full 12-bit resolution of the ADC, leading to increased accuracy. The reading of these two signals was then displayed on the oscilloscope.

The only method available in *Lab View* to measure the amplitude of the signals was by the root mean square (RMS) method. Therefore, the two signals then had their amplitudes determined by a Basic averaged DC-RMS virtual instrument. This virtual instrument takes a signal in, applies a window to the signal, and averages the DC and RMS values calculated from the windowed signal with the previous DC and RMS values. Once the RMS values are known, they can be manipulated as in equation 2.

The equation was "graphically" implemented in *Lab View*. The output of this was the position on the PSD. The next step was to determine the range to the target based on the position of the light spot on the PSD. The light spot moving off the end of the PSD determined the usable range of the range finder set-up. This was determined by the signals approaching zero. At the nearest range, this occurred at 20 cm, and at the furthest range, this occurred at 80 cm. As the PSD is a linear device, the data pairs were used to calculate the slope of the line and the y intercept. These values were then used to convert the PSD reading into a range. This process was verified to be correct as the y intercept (at 0 cm) was calculated to be the same as the separation distance of the transmitting and receiving lenses. The graphical programming can be seen in Fig. 11.

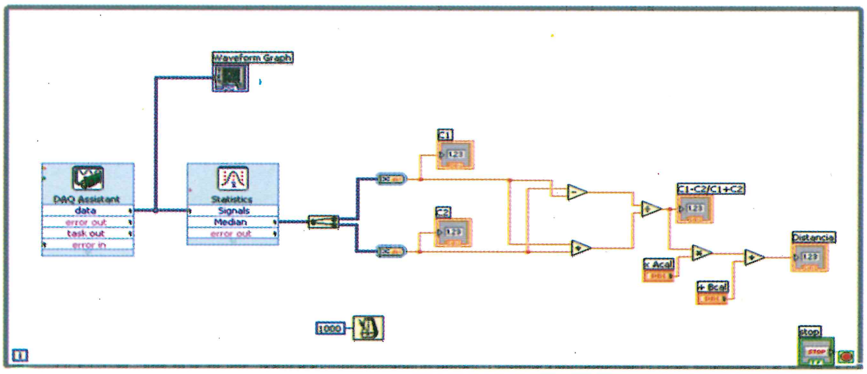

Fig. 11 *Lab View graphical programming.*

The range finder was successfully implemented using the PSD as the basis for its functionality. Modulated red light from a laser was collimated by a X10 microscope objective lens. This light was aimed at a target that reflected some of this light. Some of the reflected light was passed through a lens and was focused onto the active surface of the PSD. The PSD converted this red light into two currents, by which the position on the PSD could be determined. These two currents were converted two voltages by two transimpedance amplifiers. The signals were then passed through a band pass filter to remove noise from natural and artificial light. These conditioned signals were passed to a National Instruments DAQ I/O card that reads in the signals via a 12-bit ADC. These signals were then passed to the Lab View range finder virtual instrument, running on a PC, and the position the light spot on the PSD was determined and hence the range to the target. Also, the range finder responded to changes in the range to the target instantly. The range finder prototype had a working range of 20 to 80 cm. Figure 12 shows the range finder responded to changes in the position of target.

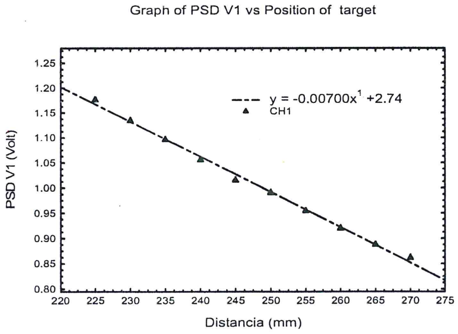

Fig. 12 *Show the linear respost of PSD, these values were then used to convert the PSD reading into a range.*

DATA ANALYSIS AND CONCLUSIONS

From graphs of the position the light spot on the PSD vs the position of target, was determined the range to the device. it was seen that the red range finder based on the PSD was a viable product. Its accuracy was around 1%.

It has been demonstrated in this work that a position sensitive detector is a viable basis for a range finder using red laser light. The red laser used in the thesis uses low power.

The range of the system is 20 -80 cm. The range finder designed in the prototype had very good accuracy (1%).

This range finder responded to changes in the range to the target instantly. It could be used in real time applications where rapid range measurement is required. Also, a series of measurements could be used to determine the velocity or acceleration of a target, demonstrating the versatility of this system.

As this range finder uses a PC as part of its design, its readings could be used as a data logger to keep a record of the range of a target over time.

The range of the system is 20 - 80 cm. Changing two parameters of the system could modify this range. The first is the lens separation distance. If this were reduced, the longer range of the system would improve, as the focused light spot would not go beyond the end of the PSD at greater distances.

The second parameter is the focal length of the lens. If a different lens with a shorter focal length were used, near range could be improved by reducing the light spot movement on the PSD as the target is moved closer.

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