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# Design and Construct A beam Profile of Near IR Laser Based on CCD Camera

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## Abstract

One of many applications of Lasers is the beam profile. For some Lasers and applications this may only be necessary during the design and fabrication phase of the Laser. The aim of the research is to design and construct a Laser beam profile based on CCD camera. The system have been constructed on analyzing in the near infrared (NIR) Laser beams as the CCD silicon chip can be exploited in this region of the electromagnetic spectrum. The results show the successfulness of the profile in displaying proper Laser images. Also, care must be taken to avoid over exposing the CCD camera. Finally, stability of the imaging system is of great important.

## Introduction

There are many applications of lasers in which the beam profile is of critical importance. It is usually necessary to be measured to insure that the proper profile exists. For some lasers and applications this may only be necessary during the design or fabrication phase of the laser. In other cases, it is necessary to monitor the laser profile continuously during the laser operation. For example scientific applications of lasers often push the laser to its operational limits and continuous or periodic measurement of the beam profile is necessary to insure that the laser is still operating as expected. Some industrial laser applications require periodic beam profile monitoring to eliminate scrap produced when the laser degrades. In other applications, such as some medical uses of laser, the practitioner has no capability to tune the laser, and the manufacturers measure the beam profile in design to ensure that the laser provides reliable performance at all times [1].

In general, the analysis of laser beam is based on energy measurement, the intensity distribution of the laser beam, beam divergence, waist parameter, number of modes …, etc. Usually the above parameters are measured individually by using separate setting. The most common type of camera used for laser beam diagnostic incorporates a silicon-based sensor. These cameras consist of two types, charge injection devices, CID, and charge coupled devices, CCD. Silicon based cameras convert the wavelength range from 190 nm to 1.1 μm, when the normal glass window is removed, which would otherwise attenuate the UV. Cameras have been interfaced to digitizers to connect the signal into a computer. Current computer software provide very illuminating 2D and 3D beam displays. They also provide very sophisticated numerical analysis on the beam profile [1]. The Aim of The Present Research is to design and construct a laser beam profiler based on CCD camera. The work is concentrated on analyzing near infrared (NIR) laser beams as the CCD silicon chip can be exploited in this region of the electromagnetic spectrum.

## System Consideration

In many laboratories, industrial and medical applications, it is not often sufficient to measure the power or energy of a laser, it is necessary to measure the beam shape and intensity profile, and how these change as the beam propagates. Also changes of wavelength and modal structure may change the effectiveness of the laser beam.

As laser beam propagates, its width and spatial intensity change in space and time due to changes in the laser cavity, divergence and interactions with optical elements. Spatial intensity distribution is one of the fundamental parameters that indicate how a laser beam will behave in an application. Theory can sometimes predict the behavior of a beam, but tolerance ranges in mirrors and lenses, and ambient conditions affecting the laser cavity and beam delivery necessitate verification [2].

An added system feature for precision measurements is a qualitative real-time visual display of the laser-beam intensity profile A pseudo color gray scale algorithm encodes the laser beam intensity pattern, and the TV monitor displays a colored image representing the intensity distribution for the laser beam. Recent advances in the development of video graphic display systems using two-dimensional CCD arrays have made it possible to use such equipment for viewing and analyzing laser-beam profiles. Indeed, lasers are becoming of increasingly high quality. To a large extent this is due to the availability of electronic beam profile instruments. These instruments provide a real time view of the laser. The laser beam profile that provides infinity greater intention to enable laser optimization. Also, electronic laser beam profilers produce much more accurate quantification of laser beam properties. The accuracy of these measurements enables scientists to fine-tune the laser properties to a greater extent than previously possible [3]. This work describes the design and performance of a video graphics system that gives a two-dimensional image and an energy profile of the output laser on a continuous wave (or quasi-continuous) basis.

The system under consideration is a CCD-based beam diagnostic system creates a pseudo color representation of the intensity distribution for the full beam. A standard video camera (CAM 3500 of FAIRCHILD) is incorporated into the system [3]. Because the camera is sensitive in the visible and near infrared lasers with wavelengths in this region (He-Ne laser, laser diode, Nd: YAG laser) can be characterized.

The system includes analog-to-digital converter from which digital data is transferred to a computer memory of a microprocessor, the microprocessor coupled to the computer memory for retrieving and processing data, a display unit for determining the total energy, divergence and position of an applied laser beam, and optical accessories.

## System Description

Fig.(1) shows An arrangement of the equipment under consideration. The system consists of the following units.

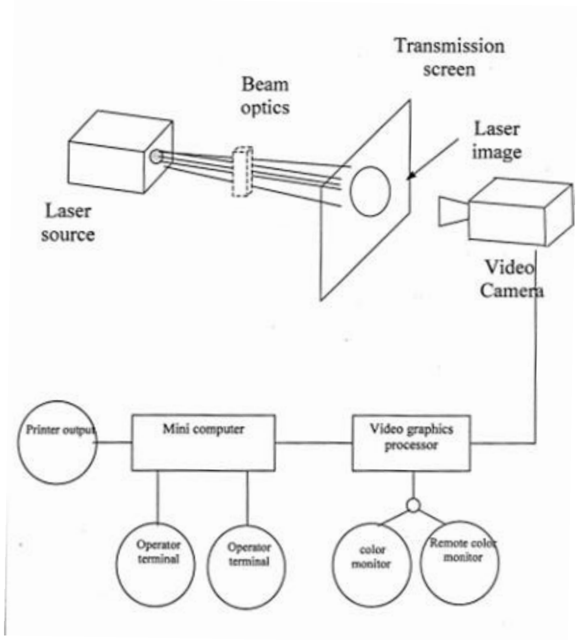


*Fig. (1) The Block diagram of Laser beam profile.*

## Experimental Work

CCD camera is the most common type of cameras used in beam profile analysis. Therefore, it is necessary to determine some of the CCD imaging parameters. Imaging parameters such as focal-ratio, wavelength responsively, and accepted incident intensity range and magnification correction factor are the most useful parameters regarding the present work. Thus, the above parameters are considered. To provide beam profile analysis facility a computer program has been developed. The program measures beam diameter, beam divergence and display intensity beam profile. Visible and near infrared lasers were imaged and analyzed.

## Determination of Some of CCD Imaging Parameters

Before starting the laser beam imaging and analyzing functions, the following steps must be considered. For the sake of obtaining proper images and avoiding damaging the CCD chip, attenuators and spectral filters have to be used. The former limits the laser intensity level impinging upon the CCD while the latter allowing only the desired wavelength to pass through. Furthermore, for implementing the required calculations, linear magnification correction factor has to be determined. The following measurements will be carried out, however.

**ICCD Camera Responsively and Laser Attenuators**

Fig.(2) illustrates typical relative spectral responsively curve of a CCD video camera. The peak sensitivity is at the wavelength 0.57 µm. A typical camera can detect flux as low as 0.3 lux. Hence even low power lasers may affect the CCD chip. It is therefore decided to determine the laser power threshold at which images of good definition may be obtained. To implement this attenuators are used.

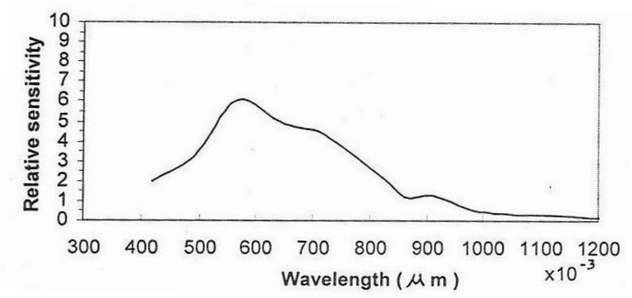


***Fig. (2) Typical relative spectral response of a silicon array.***

As an example, Table (1) summarizes the results that are obtained when a He-Ne laser (2.86 mW, λ=0.632µm) is attenuated using circular type attenuator. It is important to mention here that in most laser systems, especially in diode lasers, the desired emission is associated with unwanted ones. To get rid of this, filters, preferably interference filters, of known transmission, must be used.

***Table (1)***
***Acceptable input power values for clear images.***

| *Rotation angle (Degree)* | *Transmission T%* | *Transmitted beam power µW* | *Image quality* |
|---|---|---|---|
| 255 | 2.1 | 0.06 | Bright |
| 270 | 1.7 | 0.05 | Clear |
| 285 | 1 | 0.03 | Clear |
| 300 | 1 | 0.03 | Clear |
| 315 | 0.7 | 0.02 | Clear |
| 330 | 0.7 | 0.02 | Clear |

**Developing of a Computer Program**

For the purpose of evaluating and determining the laser beam characteristics a computer program has been developed, utilizing the MATLAB software facilities. A dialogue is established between the user and the computer, enabling the user to follow the required imaging and measuring procedure. The functional steps of the program will be described below.

First program informs the user what type of CCD camera and objective and other accessories, such as attenuators, filters or transmission screen, he has to employ that match the program nature. After the laser beam spot is imaged (the receiving transparent screen is located at a proper distance, from the CCD camera), the user is asked to input the power (or the intensity) of the laser and also asked if the beam divergence is to be evaluated. If the answer is yes, then the user is asked to take a second image of the laser beam but this time the source has to be moved away from the screen, almost twice the distance of the first case. In any case, the program will measure the diameter of the given image and displays its intensity profile.

**Laser Beam Analysis**

Visible and near infrared continuous wave lasers were imaged and analyzed. High repetition rate NIR pulsed diode laser was also examined. The following cases were dealt with where concentration was made on revealing detailed intensity information across laser beams:

A 30 mW CW collimated laser (λ=0.675µm) was imaged and analyzed. Fig. (3) illustrates the analysis of this laser.

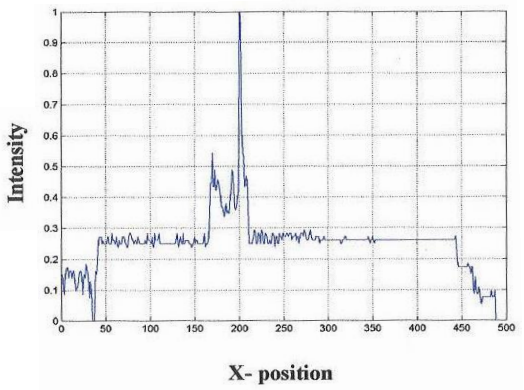


***Fig. (3) A CW collimated diode laser λ=0.675μm Intensity profile of the beam.***

A continuous wave 30 mW NIR (λ=0.83μm) diode laser was imaged and analyzed as shown in Fig.(4). In this case the micro lens was removed from the laser housing.

The same CW diode laser (λ=0.83μm) was re-imaged but this time the micro lens is used. Fig. (5) demonstrates this case.

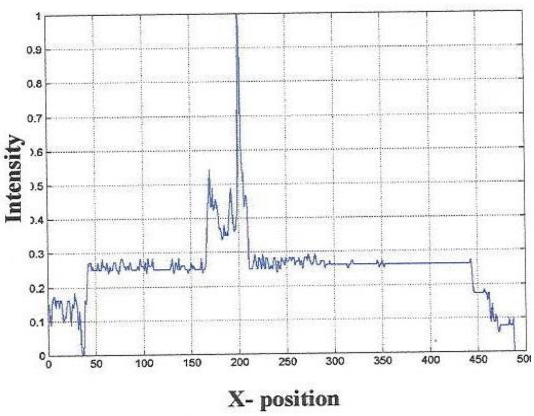


***Fig. (4) A CW diode laser λ=0.83μm Intensity profile of the beam, without micro lens.***

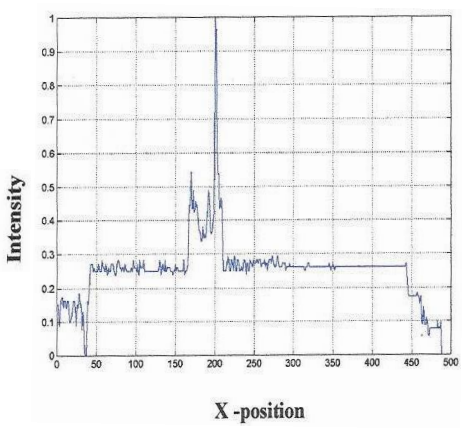


***Fig. (5) A CW collimated diode laser λ=0.83μm Intensity profile of the beam with micro lens.***

Again the CW diode laser (λ=0.83μm) was imaged. This time the micro lens was replaced by a lens of focal length =3cm and the image is focused on the transmission screen, Fig. (6).

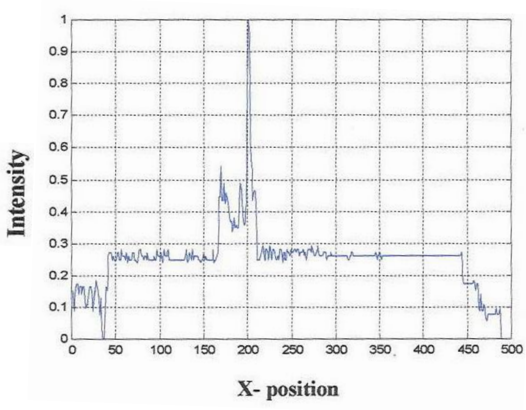


***Fig. (6) A CW collimated diode laser λ=0.83μm Intensity profile of the beam with a lens of focal length 3 cm.***

The analysis of the NIR diode laser (λ=0.83μm) in 2D and 3D was carried out and presented in Fig. (7).

(λ=1.062μm) and peak power ≥ 1250 W (P=30Mw) and repetition rate of 20 kHz with pulse width of 2 ns was imaged and analyzed as shown in Fig. (8). This time the source-screen distance was 1 meter.

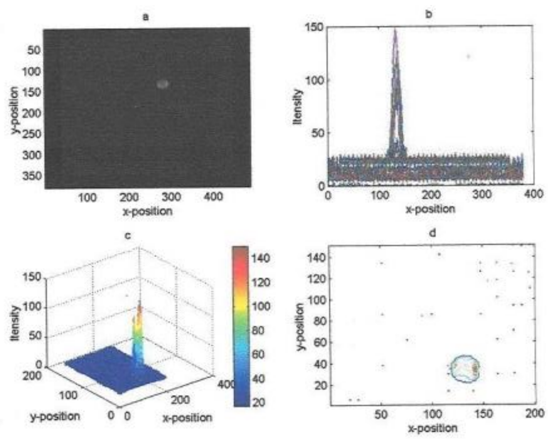


***Fig. (7) Analysis of NIR CW diode laser of λ=0.83 μm and p=30 mW***
***a- Image of the laser beam.***
***b-2D Intensity distribution along x-axis.***
***c- 3D intensity distribution.***
***d- Laser spot contour.***

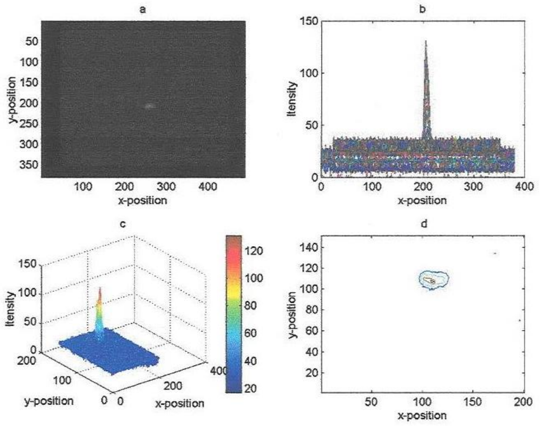


*Fig. (8) Analysis of diode pulse laser of λ=1.062(source-screen=1meter)*
*a- Image of the laser beam.*
*b- 2D Intensity distribution along x-axis.*
*c- 3D intensity distribution.*
*d- Laser spot contour.*

The pulsed diode laser (λ=1.062μm) was re-imaged but this time the source-screen is increased to 15 meter. Fig. (9) illustrates the case where more details are revealed and the noise, which is accompanied with the desired signal, is clearly seen

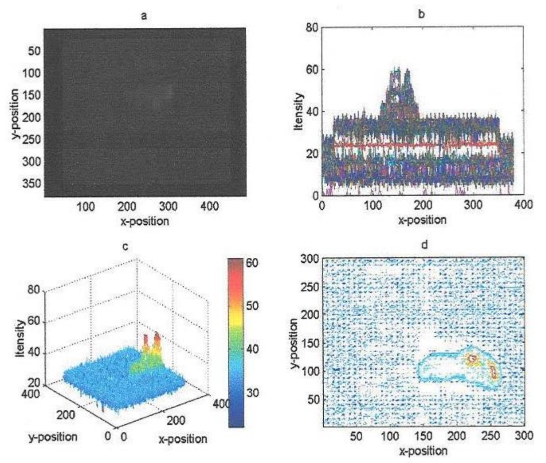


*Fig. (9) Analysis of pulse laser of λ=1.062 μm (source-screen=15 meter)*
*a- Image of the laser beam.*
*b- 2D Intensity distribution along x-axis.*
*c- 3D intensity distribution.*
*d- Laser spot contour.*

**Photometric beam profile measurement**

It is interesting to compare between laser beam profile obtained by using conventional photometric beam profile method with that implemented by using modern laser beam imaging method. Hence it is decided to carry out photometric measurements for determining the intensity distribution across a pulsed laser beam of wavelength 1.062 μm and its divergence. The following experimental steps are followed: A silicon detector of area 10×10 mm is allowed to receive laser signals emitted by a pulsed transmitter located at 35 m from the detector plane as shown in Fig. (10).

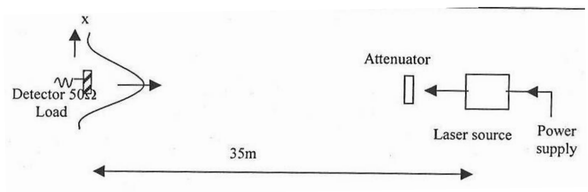


*Fig. (10) Experimental setup for photometric measurement.*

Using a special mounting and scanning mechanical arrangement, the detector is moved in steps, each of 5mm, across the ± X and ± Y directions and the detector circuit output voltages Vxs and Vys are recorded.

To ensure linear readings the laser is attenuated (0.01 transmission) using neutral density attenuator and step 2 is repeated.

Vxs and Vys are drawn as functions of directions X and Y respectively. Figs. (11) and (12) indicate that the beam profile for each direction is nearly Gaussian. Using these curves the diameter of the laser spot at $1/e^2$ points is measured to be 52mm for both directions. It is deduced that the divergence of the laser is 1.5 mrad.

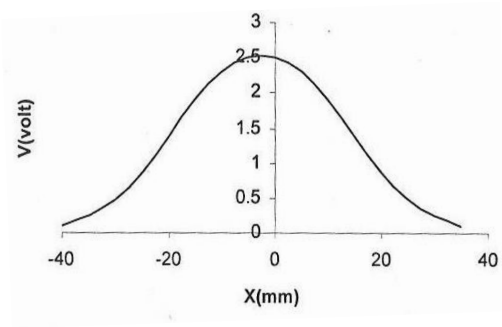


*Fig. (11) The Laser beam profile along x-direction.*

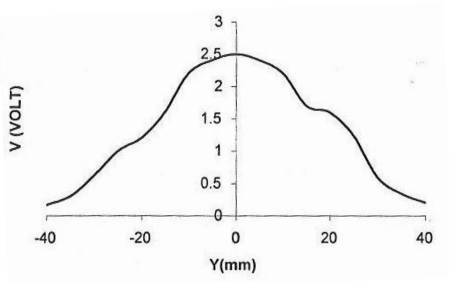


***Fig. (12) The Laser beam profile along y-direction.***

**Divergence measurement of a laser beam**

An important practical feature of a laser beam is its divergence. The significance of this feature is appreciated in long-range laser projection applications, when accuracy is desperately required. Thus the importance of carrying out an adequate measurement becomes a crucial factor. The system under consideration is thought to be a useful tool for such measurement. From many different approaches that can be followed in determining the beam divergence, the most common and acceptable one, that depends on the $1/e^2$ points in measuring the beam diameter, is used here. Although quick evaluation can be made to determine the divergence, simply by measuring the radius of the spot at $1/e^2$ and dividing it by the distance from the laser source, more elaborate work may be needed to give the matter its merit. Accordingly, it is decided to use the following procedure:

First, the spot of a laser beam is received on a transparent screen, located at an appreciable distance from the source. This spot is CCD imaged and the spot diameter $D_1$ is measured by computer. Next, the source is moved almost twice the distance $Z_1$ away from the screen (or vice versa) and the diameter of the second imaged spot $D_2$ is determined.

The full angle divergence may then be calculated by using the following relation see Fig.(6).

$$\theta = \left( \frac{D_2 - D_1}{Z_2 - Z_1} \right) \times 1000$$

Where: $\theta$ in milliard D’s and Z’s are measured in the same appropriate units.

A practical example of determining a beam divergence is the following:

In certain guidance application, it is required to direct a CW 30 mW near infrared (NIR) diode laser beam of wavelength of 830 nm at a distant target so that the beam divergence would be no more than 0.1. For this purpose and in accordance to Rayleigh resolution equation, a converging lens of focal length 3cm and of effective aperture of 1cm, fair enough to collect most of the diverging output laser, is employed. The laser emitting port is located near the focal point of the lens than the distance is finely adjusted to get, with the aid of IR to VIS converter a clear diffraction pattern at a distance 15m far away from the source. Fig.(7) demonstrates the function of the collimating lens.

To measure the divergence, this diffraction pattern together with another pattern at a distance 30 m are imaged. The computer program is then used to calculate the divergence.

**Results and Conclusions**

The laser beam diagnosing and analyzing system designed and constructed in this research has been used to analyze visible and NIR laser beams. Results have indicated the successfulness of the profiler under investigation in displaying proper laser images and encourage us to develop upon. The CCD CAM3500 camera employs conventional CCD chip type of spectral range 0.4 to 1.1μm of peak responsively at λ=0.57μm hence showed adequate performance over the NIR range. During the experimental work several facts have come out. These facts must be considered in order to achieve proper imaging. They are:

Care must be taken to avoid over exposing the CCD camera, therefore attenuators have to be employed. Unwanted visible and NIR signals accompanied with the signals under examination must be removed in order to record true information Misleading information may result in to false analysis. Thus, spectral filters, preferably interference filters, have to be incorporated with the imaging system. Stability and good fixation of the imaging system components and the laser source under test are of great importance if successful well-defined image ought to be

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taken. Employing high resolution CCD camera may reveal more detailed information that result in to reliable beam analysis. Image taken by using transmission screen have showed clarity and contain adequate information while those taken by projecting beams on wall or white screen were of less quality. Trials were made to image laser beams by letting them to fall directly on the CCD chip (the objective of the camera being removed). The obtained images were of less quality than those taken by the aid of the transmission screen. Accuracy of the results depends upon what was mentioned above and adequacy of the formulae that are adopted by the developed software.

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## الخلاصة

تم في هذا البحث تصميم وبناء منظومة تشخيص وتحليل حزمة ليزرية والتي تتالف بشكل رئيسي من كاميرة CCD وكارت إلكتروني للتعشيق بين الكاميرة والحاسبة. وتم بناء برامجيات خاصة لتحليل الحزم الليزرية وعرض نتائج التحليل على شكل صور ثنائية وثلاثية الأبعاد. وتم أستخدام مكونات بصرية وميكانيكية مثل الموهنات والمرشحات الطيفية والحوامل وذلك لضمان تحقيق نظام تصوير مناسب. وتم التركيز على تصوير إشعاعات ليزرية مستمرة 0.83 μm بطول موجي منبعثة من دايود ليزري وإشعاعات نبضية بطول موجي 1.062 μm منبعثة من ليزر نبضي. أكدت الدراسة إمكانية إستخدام كاميرات فيديوية تقليدية من نوع CCD لتصوير ليزرات الأشعة تحت الحمراء القريبة وتحقيق وضوح وتفاصيل مقبولة للصورة الملتقطة والتي تساعد في أستخدامها لإغراض مراقبة أشعة الليزر وتحليل الأشكال الجانبية لحزمة الليزر.