Development of 3D Laser Profilometer Monitored by CMOS Camera and Computer Software

Juan Ignacio Escorza Chávez, José Luis Jiménez-Pérez, Zormy Nacary Correa-Pacheco

***Abstract*— In this work a cheap digital 2D and 3D laser profilometer was developed. To monitor the laser beam, a CMOS camera is mounted to sense the laser spot and through a computer script developed in MATLAB ™, the profile and properties of the beam are monitored. In this work, the most important laser properties are its beam width and shape. The profilometer is able to profile a Gaussian distribution laser, where the coordinate of the point of maximum intensity, standard deviation, width and waist of the laser are obtained through treatment of the images acquired by the sensor and adjusting the beam distribution. As an application of this work, profiles in 2D and 3D of a He-Ne laser was studied and compared with a knife-edge technique for its use in photothermal techniques experiments such as thermal lens spectrometry and Z-scan.**

***Index Terms*— Laser profilometer, 2D, 3D, CMOS camera, MATLAB ™**

I. INTRODUCTION

The laser profilometer is used to analyze the spatial intensity profile of the beam on the sensor surface. The profilers are able to measure the width of the beam quality and intensity profile. Despite new technologies and advances in the development of next-generation lasers that reach femtosecond pulses [1], [2], the characterization is an element present in all lasers with applications in the research field. This paper presents a CMOS sensor that was developed, which in comparison to CCD sensors is present in a greater number of products. This project offers the facility to use any sensor of a conventional camera possessing sufficient resolution for imaging area resolution. The current manufacturing technology CMOS sensors provides us with pixel sizes of units of micrometers, which gives us the right resolution to perform the analysis laser with a linewidth from 50 microns to ensure the appropriate number of pixels contribute to the measurement.

The instruments and techniques that have been developed to obtain the features mentioned above include [3]:

- Techniques for camera: Use a square or rectangular two-dimensional array of pixels that scanned the image or the laser light received. The intensity distribution is recorded pixel by pixel and displayed as image or a 3D topographic contour graph. This project is based on this technique.
- Knife edge: A knife or holes cut the laser before detection by a power meter that measures the power versus time that are integrated to get the full profile.
- Phase detection: a beam is passed through a small 2D lens arrangement in a Shack-Hartmann sensor. Each lens re-routed a portion of the laser to later rebuild the profile.
- Traditional techniques: These include the use of photographic plates and burning papers where the profile is obtained through the hole or stop mark on the material.

The main advantage of profilometers by camera lies in the ability to detect and display any structure having the profile and can be used both, in continuous beam (CW) and pulsed [4],[7], which can even be used concave mirrors or lenses depending on the application [14], regardless of the method of transmission such as gas, diode, semiconductor, free electrons [10], with particular attention to the laser diode due to its tendency to produce lasers with elliptical shape [11],[12].
Camera sensors most commonly used are the charge coupled devices or CCD (Charge-Coupled Device) or Complementary Metal-Oxide-Semiconductor or CMOS. Each one has advantages and disadvantages depending on the application. Both convert light into electric charge for processing electronic signals. In a CCD sensor, each pixel charge is transferred through a limited number of output nodes to be converted into voltage, stored and sent to a chip as analog signals. Effects such as saturation or "ghosts" are related to all the images obtained through such sensors.

In a CMOS sensor, each pixel has its own conversion system load voltage and often have amplifiers, reducing noise and digitization circuits to send the image as digital bits. With respect to bandwidth, for an order of 190 to 1100 nm, the CCD and CMOS sensors are suitable for work [4].
To obtain the beam width, a definition commonly used is when the beam intensity has fallen to $1 / e^2$ (13.5%) of its peak value. This is derived from the spread of a Gaussian beam lasers and is suitable for working in a TEM_{00} fundamental mode or close to this mode.

The current limitations of the project lie in the failure to identify fundamental modes different to TEM_{00} and nearest ones, as well as the correction angle of the image profiles with elliptical geometries.

For the project, a script in MATLAB ™ and Graphical User Interface (GUI) for easy use of the profiler (see Fig. 1) was developed.

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Fig. 1: Front Panel of GUI profiler.

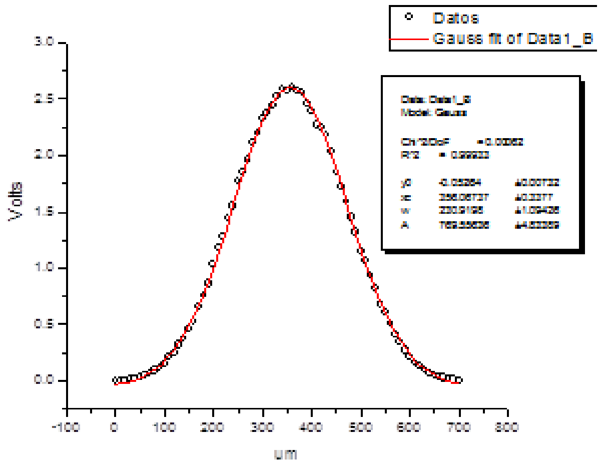

Fig. 2: Gaussian beam profile obtained by the profile of a knife profile. The laser waist was obtained from the adjustment where its value turned out to be w = 231 microns.

The program has two main functions, video and testing. The first, shows real-time images issued by the sensor used for the correct positioning of the sensor in front of the beam to be measured. The GUI presents a single button with which you can measure, for the video mode is used to start or stop image transmission.

Test mode modifies the legend button to start test and enables the options menu. If there have been no previous tests, the menu will only allow loading external images previously captured for processing for which a window will open. In this window, you can choose the image, or to obtain the profile through the sensor. Once the test starts without loading the image, a preview of the current profile status is displayed for 5 seconds, then a picture is captured and adjustments and measurements can be made.

To carry out the measurement, a Gaussian fit was used for each of the elements of the columns of the image obtained in greyscale. The adjustment result is stored again in a 2D matrix for the presentation of the results, the accuracy and the coefficients.

II. RESULTS AND DISCUSSION

First, the waist of the laser was measured. A He-Ne laser of 632 nm (Uniphase) with power of 1 mW with constant power by the knife edge technique was used. These measurements are made by placing a micrometric hole in the photodiode sensor and a micrometer by scanning the laser Gaussian profile. In Figure 2 the experimental data adjusted to theoretical Gaussian curve is shown:

$$f(x) = a\, e^{\left[-\frac{(x-b)^2}{2c^2}\right]} \qquad (1)$$

where $a = \frac{1}{\sigma\sqrt{2\pi}}$ is the amplitude, $b = \mu$ is the centroid position, $c = \sigma$ is related with peak width. For the He-Ne laser, a diameter of 231 µm was obtained.

After the adjustment, as a second step, the system was used for shaping the laser beam and in the main window of the menu, the results are displayed. In Fig.3, the original image of the laser spot He-Ne with which you work for measurements is shown. This is obtained through the camera sensor.

In Fig. 4, the curves of the intensity distribution level of the laser beam in two dimensions is shown.

The original profile of the 3D laser sensor obtained through the sensor before making the adjustment is displayed as observed in Fig. 5.

In Fig. 6 profile of the 3D laser after the adjustment on the image is displayed.

At the point of maximum intensity setting, the 2D profile obtained from the sensor (red) and Gaussian (blue) adjustment are compared as seen in Fig. 7.

One can observe the colors from warmer to cold showing the variation of the Gaussian laser intensity.

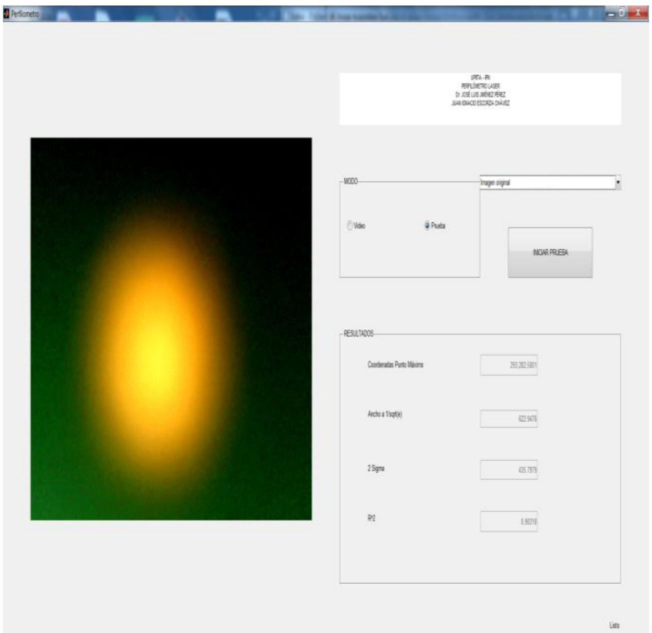

Fig. 3: Original image of the spot laser He-Ne.

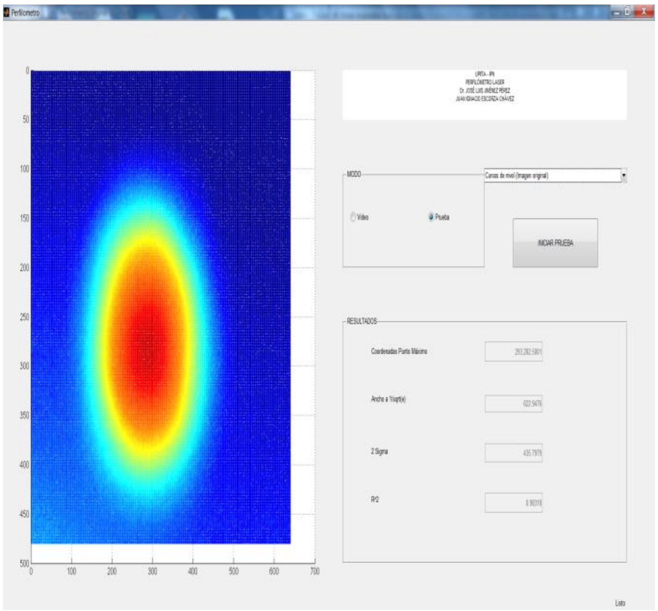

Fig. 4: Contours (Original image).

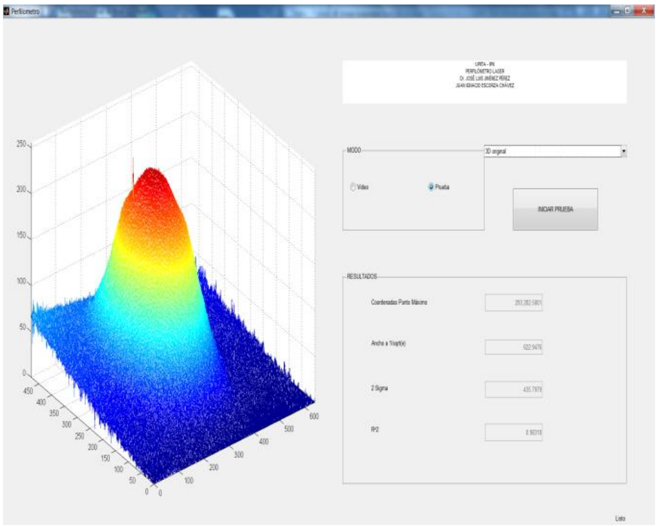

Fig. 5: 3D original.

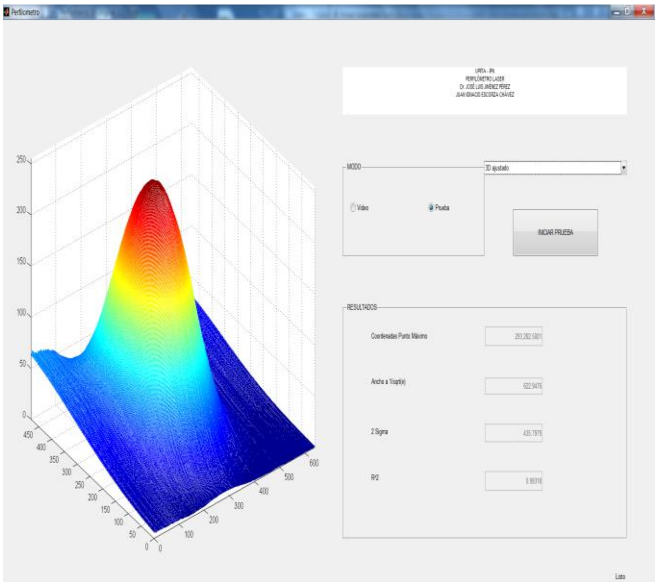

Fig. 6: 3D Adjusted.

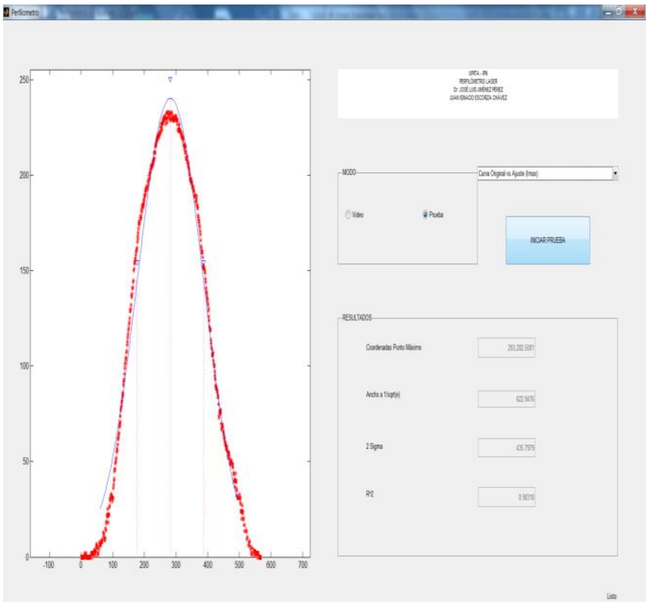

Fig. 7: Original curve vs. Adjustment (Imax).

In Fig. 8 the results of the adjustment made as the coordinates of the point of maximum intensity (Imax), and the beam width are shown $Imax\frac{1}{\sqrt{e}}$, 2 times the standard deviation Sigma [3] and ω for a Gaussian equation of the type

$$y = Imax * e^{\left[-\left(\frac{x-x_c}{2\omega}\right)^2\right]} \quad (2)$$

and the determination coefficient R^2 that determines the quality of the model.

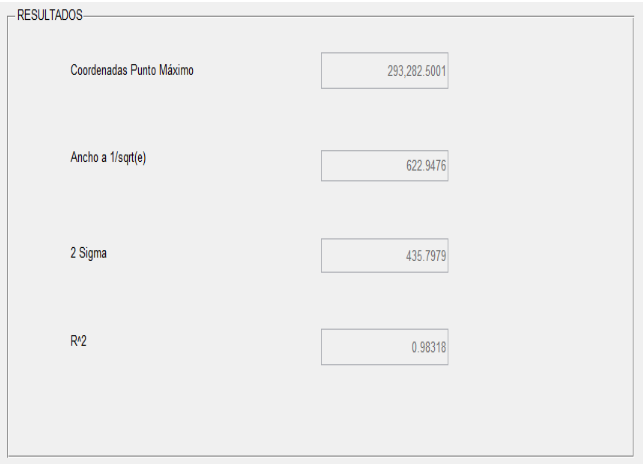

Fig. 8: Results.

The results obtained $\left(w = \frac{2\,Sigma}{2} = \frac{435.7979\mu m}{2} = 217.8989\right)$ were compared with the knife edge method $(231\ \mu m)$ having and excellent aproximation coefficient with a variation of 5.67%.

III. Conclusion

In this work, satisfactory results in the development and measurements obtained from an inexpensive 2D and 3D digital laser profilometer were obtained. As an application of this work, 2D and 3D profiles of a He-Ne laser were studied and compared with the technique of knife edge for use in experiments related to photothermal techniques such as spectroscopy, photothermal deflection or optothermal spectroscopy [9] and Z-scan. The shape and width of the laser beam of this work are comparable with commercial measurement equipment that cost $ 4,000 USD and for our equipment the cost was only $ 15 USD.

The profilometer can be adapted to any conventional camera connected via USB to a much lower cost than those available in the market of foreign origin greatly contributing to research in Mexico and to our university.

The profile of a laser beam and its characterization in a fundamental aspect in different areas, where applications of this work are wide from research in physics, and medicine for the diagnosis of eye by laser and the detection and treatment of cancer [9] and industry [4] as laser cutters assisted gas [8], combustion processes [9], and research as Raman spectroscopy, for modeling studies and simulation of carbon nanotubes [12] where the optimal characterization of materials and work equipment are important to achieve good quality products, measurements and implementations.

In the future, this project will included the removal of existing limitations and implementation of ISO 11146 [6] for processing and obtaining results as well as the development of a faster algorithm.

ACKNOWLEDGMENT

We would like to thank to the National Polytechnic Institute through its BEIFI program for the great support and trust deposited in the realization of this project.

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