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| Implementation of the Optical Beam Profiler System Using LabVIEW | Chế tạo hệ thống xác định biên dạng chùm bằng Web Cam giá thành rẻ và |

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| Software Package and Low-Cost Web Camera | gói phần mềm LabVIEW |
| Abstract - In this paper a realization of the optical beam profiler system based on a low-cost web camera and great capabilities of LabVIEW software package is presented. The system provides possibilities of measuring, capturing, displaying, and recording various parameters of the optical beam, such as spatial profile, beam quality, intensity measurement and so on. Implemented software enables various types of image processing, which makes measuring easier and more accurate. The applications of the developed system include: laser monitoring, nonlinear optics, far-field measurement, education and so on. | Tóm tắt-Trong bài báo này, chúng tôi trình bày cách chế tạo hệ xác định tham số chùm laser bằng web cam giá thành thấp kết hợp với phần mềm LabVIEW. Hệ thống có khả năng đo, thu nhận, hiển thị, và ghi nhận các tham số khác nhau của chùm laser, chẳng hạn như biên dạng, chất lượng chùm, cường độ, v.v…Phần mềm có nhiều kiểu xử lý ảnh khác nhau giúp cho quá trình xử lý dễ dàng và chính xác hơn. Ứng dụng của hệ thống đề xuất bao gồm: giám sát laser, quang phi tuyến, đo trường xa, giáo dục và v.v…. |
| INTRODUCTION<br>In laser applications, the beam profile provides valuable information for the most efficient use of the laser [1] , [2]. For some lasers and applications, monitoring of laser beam profile may only be necessary during the design or fabrication phase of the laser. However, sometimes it is necessary to monitor the laser profile continuously during the laser operation. Some industrial laser applications require periodic beam profile monitoring in order to eliminate producing scrap when the laser degrades. In other applications, such as medical, the practitioner has no capability to tune the laser, and the manufacturers measure the beam profile during design to ensure that | [redacted] |

the laser provides reliable performance at all times. In scientific applications, it is also very important to monitor the beam profile, particularly when examining nonlinear optical properties of the materials. Some materials intend to perform distortion of the laser beam, or act as a lens to focus or scatter the laser beam. In such cases high quality beam profiling is of key importance. A novel z-scan technique for measuring optical non¬linearities based on laser beam radius measurement is reported in [3].

Laser beams produce light with many characteristics that are unique in comparison to other light sources, such as coherence, monochromatic nature, unique spatial power distribution and ability to be focused to extremely small spots. One of the fundamental parameters that indicates how a laser beam will behave in an application is its spatial intensity distribution. As the laser beam propagates, its spatial intensity distribution will change in space and time. Characteristics such as propagation of the beam through space, concentration and collimation of the light are all significantly affected by its spatial intensity distribution. Theory can sometimes predict the behavior of the beam but tolerances in manufacturing of the lenses and mirrors, and ambient conditions, often require an experimental confirmation. Influence of intensity distribution of laser beam

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on the properties of nanoparticles obtained by laser ablation of solids in liquids is reported in [4]. Influence of the spatial laser intensity distribution on laser nitriding of iron is presented in [5].

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In order to select the best optics for a particular laser application, it is important to understand the basic properties of Gaussian beams. A beam quality factor or M2 (also called beam propagation factor) has been defined to describe the deviation of the laser beam from a theoretical Gaussian [6]. An ideal theoretical Gaussian beam has M2=1, whereas for real laser beams M2>1. M2 factor can be calculated from following equation:

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(1)

where 9 is the beam divergence half angle, w0 is the beam waist radius at the 1/e2 times the maximum value point and X is the laser wavelength. The beam propagation factor (M2) is a highly useful parameter for characterizing the optical quality of real laser beams.

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High quality beam profile monitoring is necessary not only in laser applications. Optical fibers are now efficient optical wave guides and are used as transmitting media for the power and information. Transmitted information depends on spatial optical distribution. Fiber output beam shape study using imaging technique is reported in [7]. Beam profile and image transfer study in the

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fiber coupling is reported recently in [8]. The changes in output beam power and intensity profile are investigated in that study and important issues such as the role of the air-gap in fiber coupling and core diameters are described. In [9] source light effects in optical fiber output beam imaging is presented. In addition, the recent rapid development of fiber optic sensors opened another area where observing the optical beam profile at fiber output, is also very important.

Beam profiler device

Figure 1. Typical setup for measurement of the laser beam profile

In this paper an implementation of the optical beam profiler system based on a low-cost web camera and great capabilities of image processing in LabVIEW software package is presented. The system provides possibilities of measuring, capturing, displaying, and recording various parameters of the optical beam, such as spatial profile, beam quality, intensity measurement and so on.

## II. METHODS FOR BEAM PROFILING

Typical setup for measurement of the laser beam profile is given in Fig. 1. When measuring the beam profile of a laser, it is nearly always necessary to attenuate the laser beam, at least to

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| some degree, before measuring the beam with an electronic instrument. There are several ways to do this. The most common way is to use neutral density (ND) filter, either absorptive or reflective. Another way, typically used to attenuate high power laser, is to use optical wedges and reflections from uncoated optical glass surfaces. Whichever technique is applied, it is essential that the attenuator does not introduce any distortion into the laser beam. | [redacted] |
| There are four main types of spatial beam-profiling instrumentation: camera-based systems, pinhole scanners, knife-edge scanners, and slit scanners [10], [11], [12], [13]. Each has specific advantages and disadvantages and measurements that may result in slightly different results. Knife-edge, slit, and pinhole profilers belong to the mechanical scanning devices. These scanners generate a profile by mechanically moving a knife-edge or an aperture (slit or pinhole) across the beam in a plane orthogonal to the optical axis. The light passing through is measured by a detector and correlated with the position of the aperture as it crosses the beam. This method provides an excellent resolution. one of the main advantages of mechanical scanning devices is that they can be used directly with the beam of medium power lasers with little or with no attenuation because only a small part of the laser power reaches the | [redacted]<br>[redacted] |

detector, while the most of it is reflected away from the detector. However, mechanical scanning methods work only on continuous wave (CW) lasers, not on pulsed lasers. Also they have a limited number of axes for measurement, usually only two.

Unlike the mechanical scanners, cameras use two dimensional array pixels as the imaging device. The intensity distribution of a laser or light source is recorded pixel by pixel and displayed as either a topographic or three-dimensional contour plot. The main advantage of such profilers is that they can detect and display any structure that may exist on the profile, and they can be used with both CW and pulsed lasers. Main drawback of this kind of beam profilers is limited resolution to approximately the size of the pixels. Another drawback of camera based systems is extreme sensitivity which requires nearly always attenuation of the laser beam. The two most commonly used cameras are charge-coupled device (CCD) and complementary metal-oxide- semiconductor (CMoS) sensors. Both types of devices convert light into electric charge and process it into electronic signals. In general, CCD cameras have a greater dynamic range and lower noise than CMOS cameras. On the other hand, design of CCD camera itself leads to a disadvantage in comparison with a CMOS camera in the case of beam profiling. Saturation and blooming

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| are related phenomena that occur in all CCD image sensors. A CCD image sensor is an analog device. Charge in every pixel is transferred through a very limited number of output nodes (often just one) to be converted to voltage. In such system when finite charge capacity of individual photodiodes, or the maximum charge transfer capacity of the CCD is reached, saturation occurs which may lead to overflow or blooming. Potentially undesirable effects of blooming may be reflected in the sensor output, ranging from white image streaks and erroneous pixel signal values to complete breakdown at the output amplification stage, producing a dark image. With CMOS sensor situation is different. Each pixel has its own charge-to-voltage conversion, which means that every pixel can be read out individually. Therefore, there are no blooming effects. If a pixel gets saturated, neighboring pixels are not affected. | [redacted]<br>[redacted] |