A webcam in Bayer-mode as a light beam profiler for the near infra-red	Webcam ở chế độ Bayer đóng vai trò là bộ xác định tham số chùm trong vùng

	hồng ngoại gần.
Beam profiles are commonly measured with complementary metal oxide semiconductors (CMOS) or charge coupled devices (CCD). The devices are fast and reliable but expensive. By making use of the fact that the Bayer-filter in commercial webcams is transparent in the near infra-red (> 800 nm) and their CCD chips are sensitive up to about 1100 nm, we demonstrate a cheap and simple way to measure laser beam profiles with a resolution down to around + 1 mm, which is close to the resolution of the knife- edge technique.	Tham số chùm thường được đo bằng các thiết bị CMOS (Bán Dẫn Bổ Sung Oxit kim loại) hoặc thiết bị tích điện kép (CCD). Những thiết bị này nhanh và đáng tin cậy nhưng giá thành cao. Bên cạnh đó chúng ta lại thấy bộ lọc Bayer trong các webcam thương mại trong suốt trong vùng hồng ngoại gần (> 800 nm) và các chip CCD của chúng có độ nhạy đến bước sóng 1100 nm, chúng tôi đưa ra một phương pháp đơn giản để đo tham số chùm laser với độ phân giải nhỏ đến + 1 mm, gần bằng với độ phân giải của kỹ thuật mép dao.
1. Introduction Measuring the beam profile of a laser beam is an important and common task for researchers or engineers dealing with lasers. In addition to laser power and pulse duration, only the knowledge of the exact diameter and beam profile allows for the determination of the local laser power on a sample or work piece. Especially in material processing and in medical applications it is crucial to have a well defined focused laser spot [1-4]. For determination of the beam profile and diameter several methods exist. A simple and cheap method is the exposure of thermal or photo paper. For pulsed high power lasers the ablation of photo-paper, thermally induced phase changes [5], or the generation of ultrasound by the photoacoustic effect [6] can be used. However, their applicability for the analysis of a focused laser beam is limited. The use of thermal or photo paper suffers from a low dynamic	[redacted]

range (DR) and from the fact that the measured beam profile does strongly depend on the exposure time [4]. Thermally induced ablation or phase changes are affected from the so called heat affected zone (HAZ) [7], which does strongly depend on the substrate material and the pulse duration. For crystalline silicon and pulse-durations of 20 ns the HAZ may exceed 2 mm. The methods based on ablation or phase changes suffer from a poor dynamic range, i.e. an area is either ablated or not. Furthermore, the plasma plume, generated during ablation might partially shield the laser beam which may cause artifacts in the measured beam profile. The resolution of the photoacoustic method is limited to several mm [6]. Thus, these methods are unsuited for a beam analysis of tightly focused laser beams.

For laser spots with a beam width > 10 mm one can use commercial CCD cameras, which have pixel sizes between 4.4 and 7 mm see e.g. [8-10]. The drawbacks of the commercial CCD or CMOS beam-profiling cameras are that they are rather expensive (> 1000 EUR) while only providing relative low resolution. Smaller focused spots with diameters in the mm range can be analyzed by means of the scanning knife edge technique [11]. Here, one measures the power of the laser beam with a photo diode while moving a sharp edge through the laser spot. The resolution of the knife edge technique lies in the order of 1 mm, limited by diffraction at the edge [4]. The knife

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edge technique has two major drawbacks. First, the technique is rather slow. Thus, for example, analyzing single laser pulses is not possible. Second, no spatial resolution is provided, unless one does acquire multiple-knife edge beam profiles at different angles and subsequently calculates the beam profile. This, however, slows down the measurements even more.

A relatively simple and low cost way to measure laser beam profiles is the utilization of a webcam as demonstrated in [12]. With this method beam-profiling of pulses from a Nd:YAG laser with a wavelength of 1064 nm was demonstrated. In [12] the native resolution (about 9 mm pixel size) of the webcam was used, limiting the technique to relatively large spots.

Webcams usually are designed to record color-images. For this purpose they have color filters in front of each single CCD element. Such a single CCD element is called sub-pixel in the following. In most cases one color-pixel consists of four sub-pixels with separate color filters: one sub-pixel with a red color filter, two sub-pixels with a green color filter, and one sub-pixel with a blue color filter. These color filters are called Bayer-filter. In the EEPROM of the webcam the information from four sub-pixels is processed and the resulting RGB value for the combined pixel is returned. Before returning the RGB value further

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calculations are made on the webcam's EEPROM in order to improve the image quality, e.g. to correct the white balance. However, by using special software it is possible to access every sub-pixel element. In this mode the webcam is said to be in Bayer-mode.

In this paper we used a low-cost webcam for beam-profiling; whereupon we improved the resolution by making use of the Bayer-mode and using the property of the Bayer-color-filters to be transparent in the near infra-red region. The size of one subpixel was about 2.8 mm, which is about a factor of 2 smaller than the pixel size of nowadays commercial available CCD beam profilers. Depending on the wavelength of the examined laser the transmittance of the Bayer-filters was corrected by software. We demonstrated the capability of the technique by measuring the beam profile of a focused laser spot of a Nd:YAG laser at its fundamental wavelength of 1064 nm and by analyzing the Gaussian beam shape of a Ti:sapphire laser in the focal zone.

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