Optik - International Journal for Light and Electron Optics 185 (2019) 609–613

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.com/locate/ijleo

Original research article

A multi-spot laser system for retinal disorders treatment: Experimental study

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ARTICLE INFO

Keywords:
Multi-spot laser
Retinal disorders
Laser photocoagulation
Liquid crystal display

ABSTRACT

Laser has many uses in ophthalmology depending on its interaction with the different layers of the eye. Laser photocoagulation techniques are used to manage many retinal disorders such as Diabetic Retinopathy by stopping the progress of the disease and prevent blindness through applying small burns on the retina to prevent the severe bleeding of the retinal blood vessels. This treatment procedure requires photocoagulation of the entire peripheral retina in order to save central vision. However, for each eye, it requires several thousands of laser shots that could be achieved in several hours divided over many treatment sessions. Instead, sending a pattern of laser spots could minimize the time required to photocoagulate the retina, hence, the photocoagulation process could be achieved through less treatment sessions, which is needed due to the increasing number of patient and relative shortage of ophthalmologists worldwide. In this work, a technique for multi-spot laser delivery system that can send a desirable pattern of laser spots to the retina in one shot was experimentally implemented and investigated. The optical setup utilized the application of liquid crystal display as a two dimensional array optical switch allowing laser spots to pass through it according to a predetermined pattern providing promising results as a multi-spot laser system to minimize treatment sessions and human errors.

1. Introduction

Laser plays an important role in modern ophthalmology as it is a very good tool for precise surgical procedures of the eye. Laser is not only used to alter human tissue, photocoagulate, cut, remove, shrink and stretch, but also to activate drugs in case of treating ocular diseases. Moreover, it can be utilized in treatment of many ophthalmic diseases such as Diabetic Retinopathy “a chronic disease based on sugar metabolism which can be severe enough to cause vision loss”, Macular Degeneration “a scaring in the macula of the eye due to age”, Glaucoma Trabeculoplasty “a disease that effects the proper drainage function of eye fluids” and Posterior Capsulotomy “a procedure done as a follow-up to cataract surgery in order to restore vision” [1]. Laser photocoagulation can also be employed in the treatment procedures of Retinopathy of Prematurity (ROP). It is an eye disease that may occur in premature babies due to growing abnormal blood vessels in the retina, which can lead to blindness. In this condition, the whole peripheral retina is

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https://doi.org/10.1016/j.ijleo.2019.03.158
Received 6 August 2018; Received in revised form 29 March 2019; Accepted 29 March 2019
0030-4026/

ablated in one session generally under anesthesia in a neonate with abnormal blood vessels growing on the retina.

Among many eye diseases, Diabetic Retinopathy (DR) is the leading cause of blindness for people between 20 and 74 years old. It occurs when high blood glucose damages the smallest blood vessels that supply the retina, causes leakage of small amounts of blood, serum, blood fats and blood proteins. As DR progresses, new abnormal blood vessels may form and proliferate on the surface of the retina and optic nerve (proliferative diabetic retinopathy or PDR). These new vessels break easily and bleed profusely that can lead to vision loss and formation of scar tissue that may tug on the macula or detach the retina from the back wall of the eye that also can cause blindness. Laser photocoagulation uses the heat produced from laser light to seal these abnormal blood vessels in the retina non-invasively [2]. Photocoagulation can be implemented using visible light but laser is more precise, reliable and less painful. Laser also reduces the amount of damage to the adjacent tissue. Laser wavelengths used for retinal photocoagulation range from 400 nm to 800 nm. For many years, the argon blue-green laser (70% blue 488 nm, 30% green 514.5 nm) was the predominated ophthalmic laser, but it became less favourable because of its short wavelength, it scatters more than other colors and therefore requires higher energy level to achieve adequate coagulation [3]. After that the green laser became mostly used in the same applications. Green laser is available in two systems: argon gas (514.5 nm) and solid state frequency doubled Nd.YAG (532 nm) [4,5].

Recently, the high efficiency and good aging properties of the frequency doubled diode pumped Nd.YAG laser which emits at 532 nm made it very popular and much used in the field of ophthalmic photocoagulation. At 532 nm, the absorption by XanthophyII (primarily found in the vicinity of the macula) is much lower than at shorter wavelengths resulting in less heating of the tissue outside the laser spot, therefore, the treatment can be performed with more precision in the proximity of the macula. The vascular leakage on the retina is easier to seal with 532 nm than with the wavelengths of the argon laser, as at 532 nm the absorption by hemoglobin and oxy-hemoglobin is higher than at that of the argon laser [6].

Despite the great changes occurred in the lasers system, the majority of photocoagulation devices are still single-spot or limited multi spots delivery systems, thus, the treatment remains manual, time consuming, boring, and sometimes painful [7]. Patients with progressive proliferative diabetic retinopathy who experience panretinal photocoagulation typically receive between 1200 and 1500 laser spots in two to four sessions of 10–30 minutes per session over the course of 2 weeks to 4 weeks [8,9].

Because the spots are tedious for the patient and physician as well and can be painful especially in the retinal periphery, many efforts toward improvement in retinal photocoagulation systems were principally directed toward fully automated systems with retinal stabilization based on eye tracking and [9,10].

Novel approaches of laser photocoagulation are always being considered, especially, if they significantly reduce the time required for such operation via delivering multi-spots of lasers. An optical mechanism to reduce the treatment time of laser photocoagulation using a micro-lens array and collimating lens was presented by [11], using that system, a single laser beam source divided into four simultaneous laser beams using an optical fiber cable that is constructed of four fibers connected to the laser source via a proximal connector to the slit lamp imaging optics via a distal connector. Although this method of multisport laser delivery helps to reduce the time of treatment to ¼ of single-spot treatment time, the invention still has to be manually aimed by the treating surgeon.

Another mechanism for multi-spot laser delivery system was proposed by [12], the system consists of a rotary disc with edge gearing; this disc is mounted with two prisms or mirrors to deflect an incident laser beam. A micro-motor and shaft gearing coupled with the disc to rotate the system, this results in a ring of laser shots. Although this system helped to reduce the treatment time by delivering a ring of laser spots, but the surgeon has to coordinate the positions of spots in the retina manually. Besides, there is a single pattern spot, which is the ring pattern.

PASCAL (Pattern scan laser, OptiMedica, Santa Clara, California) photocoagulator is a semi-automated system that delivers laser pulses in a rapid, predetermined sequence with a variety of laser spot patterns and sizes resulting in improved precision, safety, patient comfort, and a significant reduction in treatment time compared with single-spot photocoagulation [13]. PASCAL photocoagulator can deliver a series of different pattern arrays and the operator can select the pattern, the number of spots, and the spacing between them. Predetermined pattern include single-spot, square arrays, octants, quadrants, full and modified macular grid, triple arcs, and single-line arc [14]. The main limitation of PASCAL photocoagulator is its retrospective design and lack of randomization [15,16].

Another laser platform, Navilas (Navigated laser, OD-OS, Inc., Teltow, Germany) system has been designed to improve treatment accuracy by integrating imaging and laser delivery into one system. This allows registration of the fluorescein angiogram and surgical plan onto the live retinal image [17]. The Navilas also allows infrared illumination without a need of a contact lens, making the patient's experience more comfortable than standard laser treatment. The surgeon also benefits with improved visualization from the large-field, reflex-free real-time image. The new Navalis laser system allows the clinician to take and view retinal images on a computer screen then plan the area and pattern with which to deliver 532 nm laser pulses. Areas that should not be treated, such as the optic nerve and macula are also demarcated [18]. In fact, the technique of delivering laser spots in NAVILAS system is the same as in PASCAL; consequently, it has the same problems of PASCAL system.

Although laser photocoagulation as a retinal surgery is the best available treatment for such disorders, the current technique of laser photocoagulation is achieved manually over many treatment sessions which can be tedious, time consuming for both doctor and patient, and painful for the patient. In addition to, aiming errors and human errors regarding placing the laser spots on retina during the photocoagulation procedure Therefore, a technique to speed the laser photocoagulation procedure and provide multiple laser applications with a single depression of a foot switch is mostly needed. In this work, a system can send a desirable pattern of laser spots is experimentally implemented and investigated, the system was utilized to send different patterns of laser spots in one shot automatically using the application of liquid crystal display as an optical switch. The system is proposed to minimize the treatment sessions, thus, reduce patient's pain and human errors.

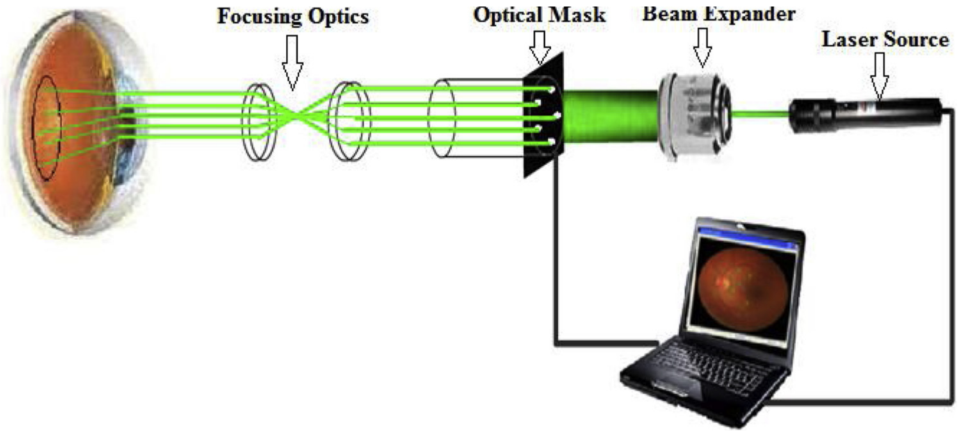

Fig. 1. schematic of the automated laser photocoagulation system.

2. Methods

The implemented system is proposed to solve the problem of manual retinal photocoagulation by sending a pattern of many laser spots in one shoot. The investigated laser delivery optical setup is composed of a beam expander, optical mask and the focusing optics as shown in the schematic diagram in Fig. 1. The laser coming from the source is expanded to cover the desired area on the optical mask. Therefore, some parts from the laser beam will pass and the others will be blocked according to the pattern sent to the optical mask. The small beams coming from the optical mask are then focused to enter the eye through a contact lens to the pupil and finally hit the retina on the intended positions.

The output laser beams from optical mask have been focused and collimated using a focusing lens optics (lenses) to enter the patient's eye through a contact lens which helps the surgeon to observe the different zones of the eye.

In the proposed system is a graphic Liquid Crystal Display "LCD" with dimension of (30 mm × 22 mm), resolution of (84 mm × 48 mm) pixels and module dimension of (38.5 mm × 35 mm) has been utilized as an optical mask [19,20]. The LCD pixel size is (337.302 µm × 493.236 µm) and the space between pixels equals to 19.841 µm. The system has been theoretically proposed in [21] and here is its experimental implantation.

Many modifications have applied on the LCD before being used in our experiments, the metal frame and many layers in addition to reflector layer have been removed to avoid reflection of laser. To overcome the transparency problem of inter-pixels (i.e. the regions between pixels) the front polarizer of LCD has been removed and replaced by one similar to rear polarizer, so, it looked like negative image LCD at the end of the modification. Fig. 2 shows the graphic type LCD before and after modifications and the circuit diagram of the liquid crystal screen driver.

Programming of the LCD is implemented using Microcontroller (At89C52), while the program loaded in microcontroller was written in assembly language and debugged on keil software. The software program used to send the desired pattern from the computer to the LCD screen is written in Matlab using graphical user interface "GUI". Any desirable pattern in an area of 4 × 4 mm of 16 × 16 pixels can be sent to the LCD screen.

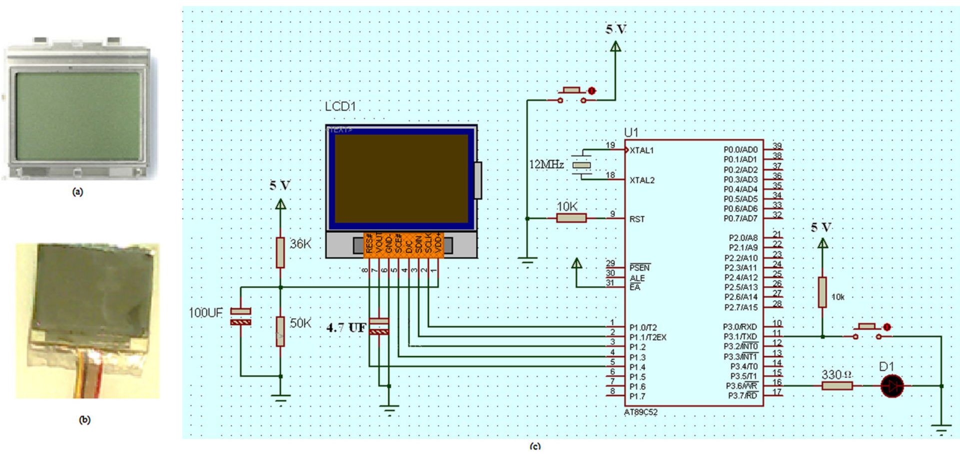

Fig. 2. Philips PCD8544 Graphic LCD (a) before, (b) after modification, (c) Circuit diagram of the microcontroller used to drive the LC screen.

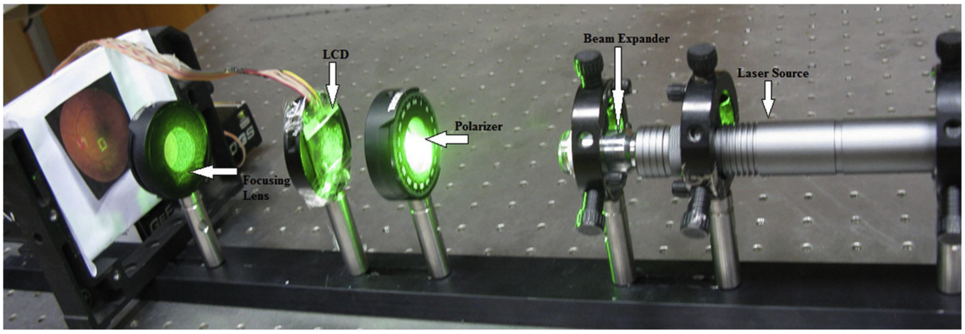

Fig. 3. The Experimental setup.

2.1. Experimental setup

The optical setup consists of a frequency-doubled Nd-YAG laser source 1 W power emits at 532 nm, the laser beam expander 20X to broad the expanded laser beam to cover the active area of the LCD screen, a polarizer, the LCD screen, and a suitable focusing lens as shown in Fig. 3. With this setup we were able to send any arbitrary pattern to the LCD screen and made a laser spots just the same as that pattern.

The polarizer was used to reduce the radiation background and allow the maximum laser intensity to be in the selected pixels on the LCD screen. The desired laser pattern was displayed on a screen with an image of the human retina.

3. Results and discussion

Different patterns of laser spots were projected on a screen with a printed image of a human retina, patterns including square, line, ellipse and triangle-shaped patterns are presented. Any arbitrary patterns can also be made according to the user's need. The pattern is controlled by a Matlab program that enables users to send any desirable pattern to the LCD in its active area as defined in the

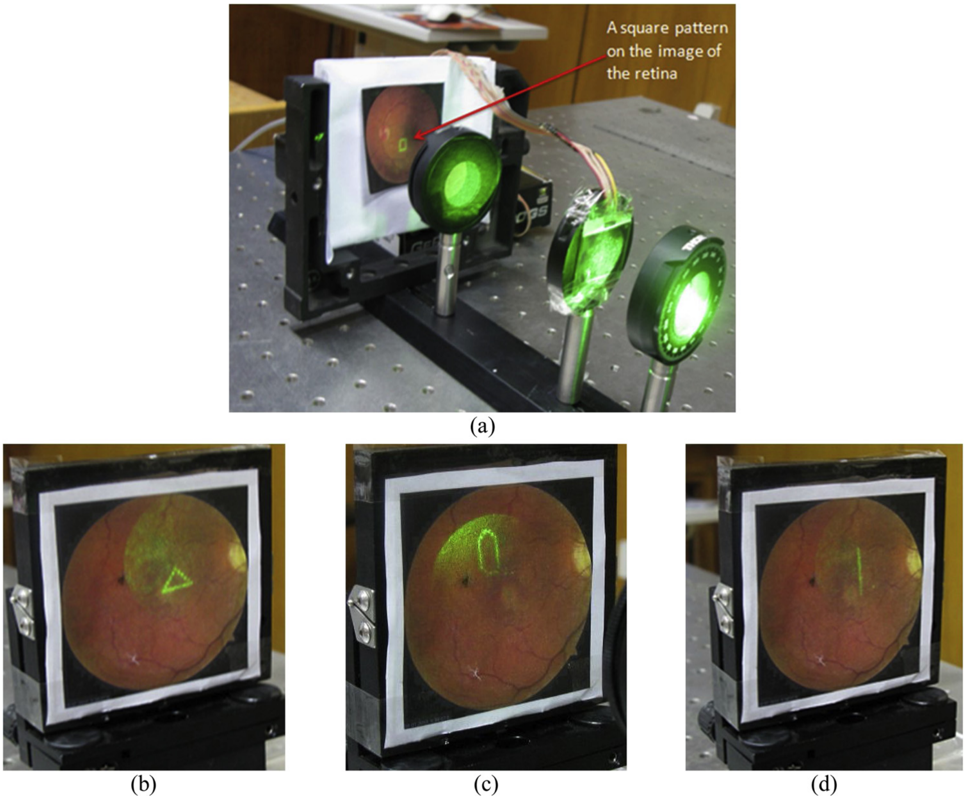

Fig. 4. different patterns of laser spots projected on the printed image of a retina, (a)square pattern, (b) triangle pattern, (c) ellipse pattern (d) line pattern.

program.

Fig. 4 shows the result of sending a different patterns of laser spots and the pattern clearly appears at the printed image of the retina. Although the glow of laser is shown in the image at the output of the laser module, the lenses and the liquid crystal screen but the pattern is precise on the retina. The quality of the image depends mainly on the quality of the LCD screen.

There is a noticeable radiation background in the image rather than the laser spots and this can be due to quality of the LCD and the polarizers as well. Higher quality LCDs may produce more precise results.

Due to the expansion of the laser beam (20X), the power at each point of the wavefront is greatly reduced in addition to the power losses due to the laser propagation through LCD and polarizers, therefore, the average power of the output laser beams was about 14 mW for each laser spot which makes it impossible to photocoagulate the retinal tissue as each spot has to be 1 W to make a desirable photocoagulation. So, usage of a higher power laser source is needed to make the system applicable for retinal laser photocoagulation. However, the proposed system can be used to send almost any arbitrary laser patterns simultaneously unlike PASCAL and NAVILAS systems that depend on scanning constant predefined patterns. In addition, the experimental components of our proposed system are not expensive and the programming software and interface used to send the pattern to the LCD screen is not very complicated.

4. Conclusion

In conclusion, a technique for the delivery of many laser spots arranged in an arbitrary pattern according to the case in one shoot is implemented and investigated. This method is assumed to minimize the number of sessions (nearly one session) required to treat a retina. The obtained results showed the ability of using LCD in laser delivery systems for medical applications, especially in retinal laser photocoagulation through delivery of simultaneous multi-spot of laser rather than scanning and providing any arbitrary pattern of lasers spots rather than a specific pattern. An automatic control was implemented to address the areas of the array of optical switches “LCD” according to the intended pattern. Therefore, the system enables to deliver any arbitrary patterns to retina according to the situation and severity of the disease.

Acknowledgments

The authors would like to thank the EU Egypt Innovation fund, the Research, Development, and Innovation (RDI) program, the ministry of higher education and scientific research, Egypt for funding the initial investigations of the LCD part.

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