A new screening system for the estimation of ocular anterior chamber angle width

Davide Cassanelli[a], Giovanni Gibertoni[a], Stefano Cattini[a], Luciano Quaranta[b], Ivano Riva[b], Carlo Bruttini[b], Giovanni De Angelis[b], and Luigi Rovati[a]

[a]Dip. di Ingegneria "'Enzo Ferrari"', Univ. di Modena e Reggio Emilia, Via Vivarelli 10 - 41125 Modena (Italy)
[b]Fondazione IRCCS Policlinico San Matteo, Piazzale Golgi, 19, 27100, Pavia (Italy)

ABSTRACT

Primary Angle Closure Glaucoma occurs more frequently in people with a narrower limbal anterior chamber depth (LACD) condition. Nowadays, clinical gold standard as an assessment technique, i.e. gonioscopy, is invasive and complex, whereas Van Herick (VH) technique is non-invasive, but subjective. The instrument, we propose, can automatically performs the VH procedure using a blue laser line, a piezo-actuator, and an image recognition algorithm embedded on a Raspberry Pi board. Preliminary measurements have been carried out on volunteers, and the results proved the feasibility of our approach. The final instrument unveils a high potential for early-stage diagnosis and screening applications.

Keywords: Van Herick, Primary Angle Closure Glaucoma, Anterior Chamber Angle measurements, Automatic Instrument, Optical measurement methods

1. INTRODUCTION

Primary angle-closure glaucoma (PACG) is a common cause of bilateral blindness worldwide, that might become preventable if dedicated diagnostic strategies would allow identifying subjects more likely to benefit from prophylactic treatments in the early stages of the disease.[1] Prevention of PACG starts assessing limbal anterior chamber depth (LACD).At present, gonioscopy remains the most widespread diagnostic method for assessing LACD. However, this technique requires suitably trained healthcare professionals, is highly subjective, and the findings may vary with the amount of light or the mechanical compression during the eye examination. Quantitative information might be obtained also with other techniques, such as Ultrasound BioMicroscopy (UBM) and anterior segment OCT (AS-OCT).[2] Unfortunately, mainly due to the costs but also to the skills required for their use, these techniques are not suitable for large scale population-based studies or screening in routine clinical practice for PACG. Another interesting diagnostic approach is the LACD estimation by the van Herick (VH) technique. This non-contact approach allows classifying the LACD into 4 grades.[2] The working principle of the VH technique is based on the visual comparison between the peripheral anterior chamber depth and the thickness of the cornea. Such information can be obtained with a slit-lamp biomicroscope: a narrow slit of light is projected onto the peripheral cornea at an angle of 60° as close as possible to the limbus. The resulting image is a slit projected onto the surface of the cornea, its width is used as a reference for the grading of the angle. The width of the angle is graded by the distance (AC) between the corneal slit image (C) and the slit image on the iris. The anterior chamber drainage angle, and so the LACD, is evaluated as the ratio (AC/C) between the peripheral anterior chamber depth and the limbal-corneal thickness, as observed in the microscope section. As reported in Table 1, when the Van Herick grading is expressed as a ratio, for recording the measured AC/C ratio, four grades from "1" (closed-angle) to "4" (angle wide open and incapable of closure) are originally used.[3,4] The VH technique is a quick and easy way to estimate anterior chamber depth, but has some drawbacks that could affect the grading: (i) uncertainty in finding the exact position of the limbus, (ii) uncertainty on optical triangulation configuration, and (iii) uncertainty in the visual estimation of the ratio AC/C.[5] Therefore, the measurement for the VH test can be carried out only by suitably trained and skilled healthcare professionals or

e.mail corresponding author: davide.cassanelli@unimore.it

GRADE	AC/C	CLOSURE RISK
4	>0.75	Closure impossible
3	0.75 - 0.45	Closure unlikely
2	0.45 - 0.25	Closure possible
1	<0.25	Closure likely

Table 1. Van Herick grading scheme.

technicians.
In this paper, we briefly present a portable instrument able to automatically execute the VH exam and perform a preliminary VH grading estimation.

2. SYSTEM DESCRIPTION AND MEASUREMENT PROCEDURE

2.1 System prototype

To realize a portable and easy-to-use the device, the design of the instrument's optics is based on a modified virtual reality viewer. The right viewer display was removed and a high-resolution camera was placed onto the same plane to capture the eye image. As shown in Figure 1.(b), also the left display was removed and onto the same plane a red LED was positioned on the optical axis. Exploiting the consistency of focus, this fixation LED helps the patient to keep his gaze forward during the measurement. The viewer optics allows the operator to easily keep the eye image in focus during the measurement by compensating for head movements. A blue light laser equipped with a cylindrical lens replaces the slit-lamp light. A rigid support, made with additive manufacturing technology, houses a piezo-translator on which the laser is fixed. As shown in Figure 1, this housing is fixed to the viewer ensuring the projection of the laser line at 60° with respect to the camera-eye axis thus replicating the classic optical configuration set by the ophthalmologist during the VH exam.
The measurement is performed by scanning the eye with the laser line in the temporal-nasal direction. Synchronously with the scanning process, the images of the eye are acquired by the camera and processed by a RaspberryPi board. The same board is used also to control all the system components: the piezo-translator, the laser intensity, and the fixation LED. A diagram of the instrument optical scheme is shown in Figure 1.(a) while Figure 1.(b) shows a picture of the prototype, in which the mechanical eye model used to align the system is visible.

2.2 Measurement Procedure

The measurement procedure takes several steps. First, after asking the patient to wear the modified viewer and stare at the fixation LED, an image of the eye was acquired and the position of the cornea border, i.e. the limbus, was roughly estimated by an image analysis algorithm. Afterwards, the laser was turned on and, both the laser line scan and image acquisition. The images were analyzed in real-time to monitor the laser beam position on the eye and to discard frames not of interest to save memory. When the laser line was in the proximity of the previously identified cornea border position, the system saved 20 images; to minimize the measuring time, these images were processed at the end of the eye scanning. Using an image recognition algorithm, the contours of the laser beam projections on the anterior cornea, posterior cornea, and iris were identified. The extracted contours were then fitted by second-degree polynomial curves. This step allowed us estimating the corneal thickness (C) and anterior chamber depth (AC), so measuring the LACD. The measurement cycle result was calculated as the average of the estimated LACD from the 20 images. The entire measurement procedure lasted 20 seconds.
Figure 2 shows a typical output of the described image processing job. From the left to the right, there are the two contours of the projection of the laser line on the cornea and the respective polynomial fit curves (blue and pink curves) are well visible. The last contour and its fit curve (green curve) define the anterior chamber depth.

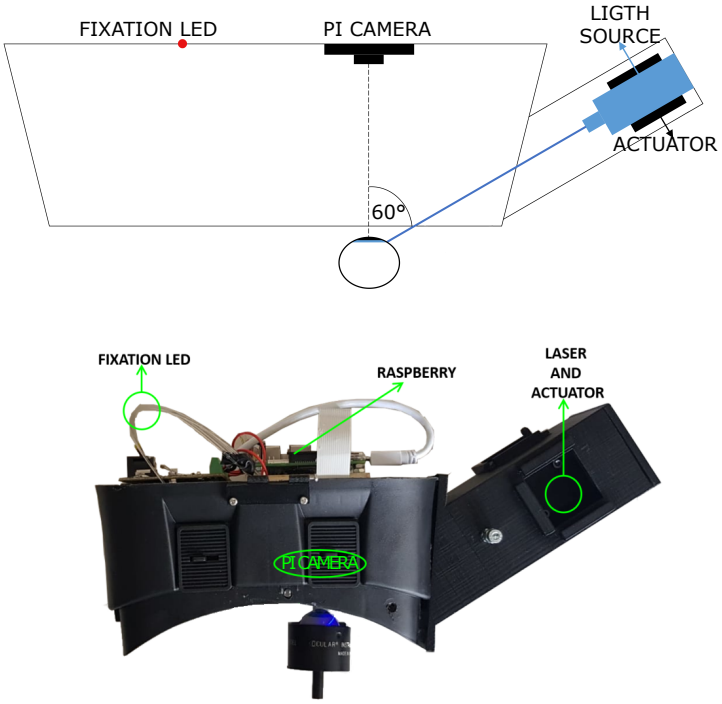

Figure 1. (a): Diagram of the instrument optical scheme, with the 60° angle laser projection is schematically represented by the blue solid line (laser) and the dashed black line (camera/eye optical axis). (b): Picture of the prototype and the mechanical eye model used in the system alignment procedure.

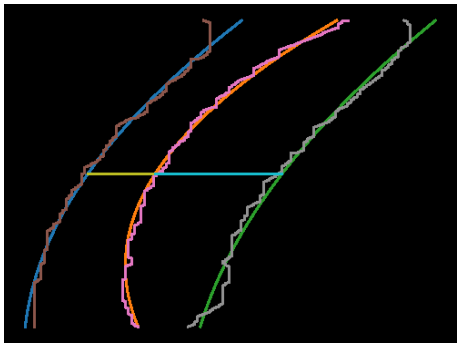

Figure 2. Contours of the laser beam projections on the anterior cornea, posterior cornea, and iris. From the left to the right, the two contours of the projection of the laser line on the cornea and the respective polynomial fit curves (blue and pink curves) are well visible. The last contour and its fit curve (green curve) define the depth of the anterior chamber.

3. RESULTS

All the electronic/optical components and the entire system prototype were characterized and tested in operation. The laser optical power was measured, through a calibrated optical power meter to confirm, in agreement with the design specifications, that the optical power impinging on the patient eye was lower than the maximum exposure recommended by the ANSI standards.[6,7] Great attention was paid to the assessment of the the spatial resolution of the scan, mainly related to the thickness of the projected laser line on the target. To quantify this parameter, the image of the laser line was acquired during a projection on the patient's sclera. The intensity levels of the image on the horizontal axis passing through the eye center of the eye were then analyzed. The normalized intensity levels are shown in the Figure 3. According to the Gaussian fitting shown in the figure,

FWHM of the laser line thickness is about 400 μm. The functional test of the instrument was performed on

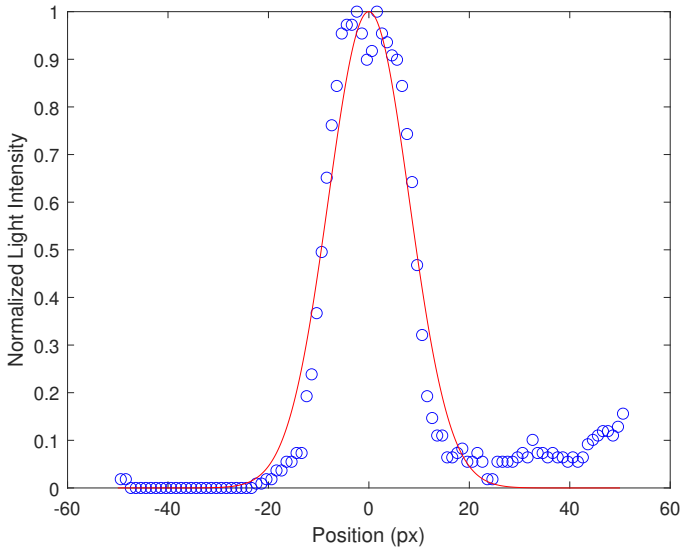

Figure 3. Light Source thickness on a human eye. • laser intensity profile; • Normalized intensity levels of the projected laser line. According to the Gaussian fitting shown in the figure (red line), the laser line FWHM thickness is about 400 μm.

healthy volunteers, with different iris colour, i.e. brown, black and light blue. The age of volunteers ranges from 24 to 27 years. Good image contrast and sharpness were observed, regardless of the iris colour. As shown in Figure 4, some small differences were observed on the brightness of the image in the case of slightly pigmented iris (a), and heavily pigmented iris (b). Nevertheless, in both images, the laser lines projections on the cornea and iris are well visible and sharp and well detectable.
Preliminary repeatability tests were performed on three healthy volunteers aged 24 to 27. Each subject was tested five times in five different days under the same conditions (ambient lighting, position of the subject and instrument, time). The measured mean AC/C ratios and their standard deviations are given in Table 2.

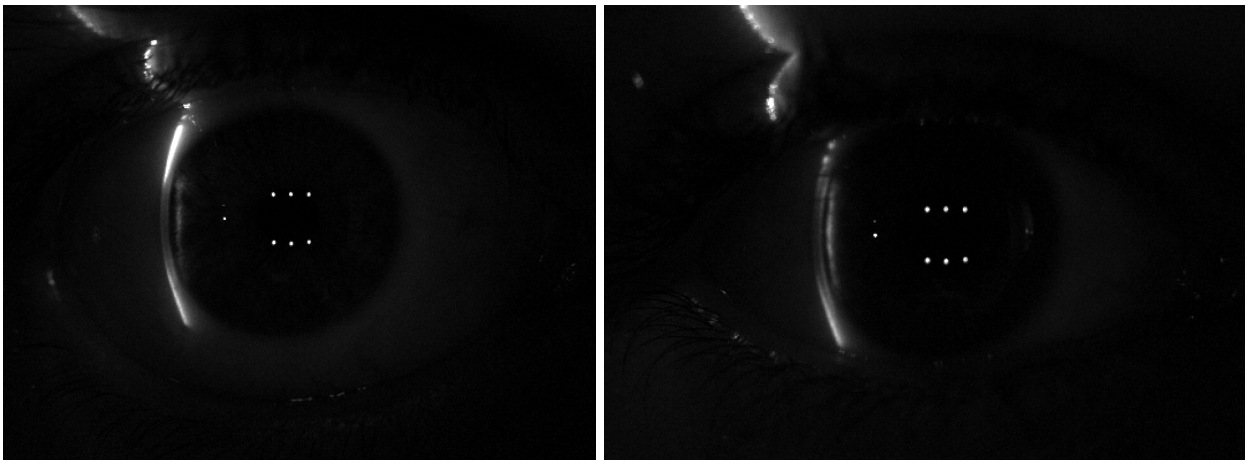

Figure 4. Preliminary measurements have been performed on two volunteers, with different iris colour. Slight (a) and heavy pigmented (b) iris.

PATIENT	MEAN AC/CT	STD
1	0.99	0.123
2	1.10	0.075
3	1.11	0.054

Table 2. Repeatability measurements results.

4. CONCLUSION

In this paper, the preliminary results for an innovative portable instrument prototype, able to perform the VH test automatically, and to estimate the LACD from acquired images, are presented. This characterization demonstrated shows the applicability of the approach and evidenced the preliminary instrument performances, both in terms of scanning precision and of image quality and sharpness. The development activity is in progress; future developments are focus on both hardware and software fine tuning. Moreover, an artificial intelligence algorithm will be implemented to automatically classify the VH grading.

This preliminary research is our first step towards the realization of an ophthalmic tool for large scale population-based studies and/or screening in routine clinical practice, so allowing for early diagnosis and treatment to decrease the number of persons affected by PACG, minimize long, complex, costly, and invasive therapies, and prevent permanent vision loss.

REFERENCES

[1] Tham, Y.-C., Li, X, W. T. Y., Quigley, H. A., Aung, T., and Cheng, C.-Y., "Global prevalence of glaucoma and projections of glaucoma burden through 2040: a systematic review and meta-analysis," *Ophthalmology* **121(11)**, 2081–2090 (Nov 2014).

[2] Riva, I., Micheletti, E., Oddone, F., Bruttini, C., Montescani, S., De Angelis, G., Rovati, L., Weinreb, R. N., and Quaranta, L., "Anterior chamber angle assessment techniques: A review," *J Clin Med* **9**, 3814 (Nov 2020).

[3] Van Herick, W., Shaffer, R. N., and Schwartz, A., "Estimation of width of angle of anterior chamber. incidence and significance of the narrow angle. incidence and significance of the narrow angle," *Am J Ophthalmol.* **68(4)**, 626–629 (Oct 1969).

[4] Foster, P. J., Devereux, J. G., Alsbirk, P. H., Lee, P. S., Uranchimeg, D., Machin, D., Johnson, G. J., and Baasanhu, J., "Detection of gonioscopically occludable angles and primary angle closure glaucoma by estimation of limbal chamber depth in Asians: modified grading scheme," *Br J Ophthalmol.* **84 (2)**, 186–192 (Feb. 2000).

[5] Leung, M., Kang, S. S. O., Turuwhenua, J., and Jacobs, R., "Effects of illumination and observation angle on the Van Herick procedure," *Clin Exp Optom.* **95(1)**, 72–77 (Jan 2012).

[6] American National Standards Institute (ANSI), New York, NY, *American National Standard for Safe Use of Lasers* (Dec. 2013). ANSI, Z136.1-2014.

[7] American National Standards Institute (ANSI), New York, NY, *American National Standard for Safe Use of Lasers in Health Care.* (May 2018). ANSI, Z136.3-2018.