IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received December 3, 2021, accepted December 19, 2021, date of publication December 24, 2021,
date of current version January 20, 2022.

Digital Object Identifier 10.1109/ACCESS.2021.3138522

Development of Prototype to Measure Intraocular Pressure of Eye Along With Gonioscopy

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ABSTRACT Tonometry, a procedure of glaucoma investigation is carried out effectively in all eye care clinics. The other testing method namely gonioscopy requires professional expertise and experience due to which optometrists/ophthalmologists avoid this test. Hence the proposed technology would let these two important glaucoma testing procedures be performed simultaneously with a common instrument ''Tonogoniometry'' and making detection easier, time-saving, and lowering uneasiness to the patient. Tonometry is implemented by embedding a vibration sensor on the 3-mirror goniolens. The experiment is performed on goat eyes and the data collected is statistically analyzed. The relation between the Intraocular pressure (IOP) of the eye and the sensor output is derived and is implemented in LabVIEW. During tonometry, the sensor output captured by the NI data acquisition card is fed to the LabVIEW platform which will display the evaluated IOP of the eye on the computer screen. Meanwhile, there is no obstruction to the light path through the goniolens to visualize the anterior chamber angle to perform gonioscopy. The experimental results epitomized that the rise in IOP of the eye will increase the intensity of vibration of the sensor and the sensor output will have a higher magnitude.

INDEX TERMS Anterior chamber angle, glaucoma, gonioscopy, IOP, LabVIEW, NI data acquisition card, tonometer, vibration sensor.

I. INTRODUCTION

Glaucoma is a common and widely spread eye defect in animals and humans. It damages the optic nerve which happens mainly in people over the age of forty [1]. Glaucoma is the second leading cause of blindness and around 79.6 million are suffering from Glaucoma and 2.8 billion are at risk category population, over 3.2 billion screenings are required per year [2]. With the aging population globally other clinical conditions such as hypertension and myopia are also growing rapidly, which significantly increases the risk of Glaucoma. Diagnosis of glaucoma in its early stage is very important since it cannot be cured but it can be prolonged or its growth can be diminished [3]. Elevated intraocular pressure (IOP) is one of the primary risk factors and only modifiable factor in glaucoma and clinicians use this as an important clinical measure in the treatment of glaucoma. A tonometer is a standard device used to measure the IOP of the eye.

The associate editor coordinating the review of this manuscript and approving it for publication was Gautam Srivastava.

Glaucoma can be mainly classified as open-angle glaucoma (POAG) and acute angle glaucoma (PACG). PACG is more common in Asia, whereas POAG is evenly distributed around the world. 75% to 95% of glaucoma cases in the United States, Australia, and Europe are POAG, whereas 70% to 90% of glaucoma cases in India and China are PACG [4]. This could be best detected if proper gonioscopy is performed. Gonioscopy is the most common method performed as part of slitlamp biomicroscopy for examination of the anterior chamber angle, peripheral iris, and differentiation between angle-closure, secondary and occludable glaucoma. It is an optical instrument used to view the anatomical angle between the eye's cornea and iris to determine if it is open or closed and also to find abnormal blood vessels and adhesions. Hence, to diagnose glaucoma, tonometry along with gonioscopy will validate glaucoma and its form precisely [5].

Health care providers administer these assessments independently, which is usually time-consuming and causes discomfort for both patients and physicians.

The screening methods that are in use are not sufficient in the rural settings, as they are not portable and need slitlamp biomicroscope to understand the type of Glaucoma and plan a proper treatment or assist for further referral. Around 905 Million population in India reside in the rural side, where there is a lack of proper screening tools and limited access to eye care facilities. Most often rural glaucoma patients have moderate or severe stages of glaucoma by the time they are diagnosed and provided appropriate care.

Though tonometry is performed by eye care professionals, gonioscopy is not as regularly performed in clinical care [6]. This may be due to a lack of amicable technology, lack of interest, and clinical competency. The survey was carried out by [7] on 147 glaucoma specialists regarding their prevailing practice and has found that 82.6% reported doing gonioscopy in all patients with glaucoma or those with suspects. The remaining 14.4% perform gonioscopy only when IOP is high or peripheral anterior chamber depth was shallow or may not perform the test at all. Thus leading to misdiagnosis of glaucoma and resulting in different clinical management approaches.

To address these problems an innovative Tonogoniometry is proposed to measure IOP along with gonioscopy procedure in a single instrument. The current innovation will be cost-effective, time-saving, less discomfort, portable, and thereby add value to the field of glaucoma.

Researchers [8] introduce a tonometric method to measure IOP by indenting the cornea using an indenting element with a predetermined force. The indentation device is placed in contact with the cornea consists of a rigid annular member with a hole at its center and a movable annular member allowed to slide within the hole in the rigid annular member. The actuation apparatus projects the movable central piece against the cornea beyond flattening of the cornea using a predetermined amount of force. The IOP is calculated based on the distance traveled by the movable central piece. Icare tonometer [9] consists of a probe base with the probe inside which will contact the surface of the cornea. The probe is of magnetic material and is placed within the base during which no measurement is taken and will be released to contact with the cornea during the measurement. The IOP is derived based on the variations in the velocity of the probe before and after the contact of the probe with the cornea or, in other words, based on the amount of kinetic energy lost or gained in the rebound of the probe. Sensimed Triggerfish [10] introduces a portable and continuous recording tonometer system on a contact lens. A pressure sensor is united with a contact lens in the form of an active strain gauge, passive strain gauge, and a rigid element and they are placed at a distance from the center of the contact lens. Thus, the variation of the intraocular pressure is determined by the subtraction of the measured variation of the electrical resistance of passive strain gauge from the measured variation of electrical resistance of active strain gauge. The active strain gauge will measure the deformation of the eyeball and hence determine the variations in the IOP. The passive strain gauge is insensitive to eyeball movements and indicates the variations due to environmental factors. Meanwhile, the rigid element acts as an antenna for recording purposes. The present innovation [11] records the diurnal variations in the IOP of the eye since the extent of fluctuation in the eye pressure is more in glaucoma patients than in healthy persons. The tonometer system includes two individual transducer devices to detect the displacement of the first and second plunger members respectively. Here, two individual pressure applicators will applanate two separate locations on the eyelid. The applanation pressure applied by the plunger is measured by the sensing device within the pressure applicator. The calibration device receives an electrical pressure signal from the sensor. The calibration device is scaled during the calibration of the tonometer to ensure that the applied pressure measured by the second pressure sensing device corresponds to the actual IOP of the eye. The Mackay Marg tonometer [12] consists of a plunger of 1.5mm diameter with a flat footplate. The tip of the plunger is covered by a thin disposable rubber membrane. The cornea will flatten as the tonometer touches the surface of the cornea and plunger displacement rises to its peak due to the intraocular pressure along with the bending force of the cornea. Further bending of the cornea beyond the surface of the transducer will spread towards its surrounding annular area and hence the curve descends to form a trough. The height of the trough above the baseline is an indicator of the IOP of the eye. The applanation tonometer system [13] comprises an applanator comprising of fiber optics array, to applanate the surface of the cornea. A force sensor is coupled to the applanator to measure the force applied by the applanator on the eye. An image sensor is used to record the images of the deformed cornea and hence is used to calculate the area of the applanated portion of the eye. The slope of the line relating the force and the area of applanation is used to estimate the IOP of the eye. Frequent monitoring and timely treatment to lower the IOP of the eye are very important for glaucoma patients. Hence, the author [14] introduces an IOP monitoring implant for real-time tracking using an artificial neural network (ANN). When broadband light is focused on the implant, the pressure-dependent optical spectrum will be reflected and the ANN converts it into IOP levels. The ANN regression has been used for demodulating the optical signal reflected from the implant to perform a non-linear mapping between the optical spectra and its corresponding IOP. A smartphone-based tonometer system is introduced by [15] to the market which uses machine learning and its results are validated with golden standard Goldmann applanation tonometer. A mobile applanation tonometer system is introduced by [16] makes use of an applanator, image sensor, and a mobile processor. Force is applied on the surface of the cornea such that the flat tip of the applanator produces an applanated zone in the eye. Images of the applanated zone are captured by the image sensor kept in the mobile computing device. Memory in the processor stores the lookup table containing the IOP values corresponding to the diameter of the applanated zone measured from the captured images of the applanated zone.

Dynamic contour tonometry is introduced by [17], where direct transcorneal intraocular pressure measurement is carried out. A sensor is integrated into the concave contact surface with a 10.5mm radius of curvature will measure the IOP of the eye, when the central contour matching area of the tip of the tonometer matches with the cornea. The device [18] measures IOP by actuating the movable central piece which moves in response to the magnetic field. The magnetic field is produced by the flow of current through the coil. The progressive increase in current will increase the repulsion force between the actuation apparatus and movable central piece and hence greater force is applied on the cornea until a predetermined amount of applanation is reached. As the force on the cornea is proportional to the IOP of the eye, the amount of current through the coil is proportional to the IOP of the eye. The conversion unit will convert the current value into equivalent eye pressure. The tonometer [19] includes a pair of arms pivotally connected at proximal ends and a contact member is connected at the distal end of one of the arms. A pressure transducer is in contact with the contact member is pressed against the closed eyelid. The electrical signal measured by the pressure transducer is proportional to the deflection of the contact member and hence is dependent upon the IOP of the eye. The device may also include a memory unit along with the display unit to display the eye pressure.

The proposed device offers benefits to the patients as well as clinicians as they would not have to perform two different examinations to diagnose glaucoma and the amount of uneasiness is significantly reduced by combining the contact procedures into a single step. This innovation is not much explored by researchers as well as commercial eye care device manufacturers. The proposed innovative tonogoniometer would help to measure IOP and view the angle structures in a single instrument.

II. METHODOLOGY

Normally anterior chamber angle cannot be directly visualized by the conventional examination tools (using slitlamp biomicroscopy) because light from the angle undergoes total internal reflection. To overcome this a lens is placed over the eye. Goldmann single, two, three, or four mirror gonioprisms involve lenses inclined at a definite angle. The proposed method involves the use of 3 mirror goniolens, where the optical component needs to be retained. Thus, the proposed technology is implemented by embedding a vibration sensor on the existing 3 mirror goniolens in a particular position such that the optical path to view the anterior chamber angle structure is not obscured while performing gonioscopy. The sensor output is utilized to measure quantity equivalent to IOP of the eye and hence attain the objective to develop a tonometer. To accomplish the need, experimentation is carried out on the animal model eye with varying pressure. The block diagram in Fig. 1, explains the methodology implemented to explore the relation between the vibration sensor voltage output and the IOP of the eye. Initially, the sensor embedded on goniolens is placed over the surface of the eye. A known pressure is built within the eye using a standard manometer. Force is applied such that the surface of the cornea is deformed. The sensor output is recorded when the surface of the eye bounces back after the force on the eye is released. The peak to peak voltage output of the sensor corresponding to a particular IOP of the eye is then amplified by a suitable amplifier and is then recorded in LabVIEW.

The details of the experimental set-up along with the procedure carried out to derive the relation between the IOP of the eye and the sensor output are described below.

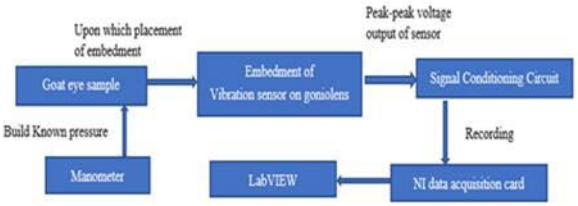

FIGURE 1. Steps followed to obtain the relation between IOP of eye and sensor output.

A. SELECTION OF SENSOR AND EMBEDMENT OF SENSOR ON GONIOLENS

Selection of appropriate sensor and placement of the sensor on the 3 mirror goniolens of 12 mm diameter corneal contact is the major challenge for the measurement of intraocular pressure of eye along with gonioscopy. The force or pressure sensor cannot be placed in contact with the eye to measure IOP, since the goniolens situated on the eye to view the anterior structure of the eye cannot be disturbed. Hence, the main constraint of placement of the sensor is overcome by embedding the vibration sensor over the surface of the goniolens. The Minisense 100 piezo vibration sensor has high voltage sensitivity up to 1V/g, low cost, and is highly linear with cantilever-type horizontal mounting shielded construction [20]. The tip of the horizontal beam in the sensor is loaded by a mass to offer high sensitivity. The acceleration in the vertical plane creates bending in the beam and hence piezoelectric response created by the sensor will be detected as the voltage output at the electrodes of the sensor. The sensor output is around 50Hz and has sinusoidal output. The top view of the vibration sensor with its dimensions is indicated in Fig.4.

A supporting structure is designed to mount the sensor on goniolens. The supporting structure is composed of two parts to provide an option for the goniolens to be cleansed at regular intervals. Both these structures are screwed, one of them from the outside and another from inside to form a tight supporting structure on the goniolens to hold the vibration sensor. The material used for the supporting structure to place the sensor at the anterior side is aluminium and its dimensions are expressed in Fig.5. The shape of the aluminium structure shown in Fig. 5, is designed concerning the shape of Goniolens. Meanwhile, acrylic is used on the posterior side of the embedment and the inner and outer diameter of the spherical structure of the acrylic structure are detailed

in Fig.6. Fig. 5 is the side view of the aluminium holder and Fig. 6 is the rear view of the acrylic holder. The image of the tonogoniometer is shown in Fig. 2 and the single line diagram of the tonogoniometer indicating the height of different parts is shown in Fig. 3. These attachments to the goniolens for the embedment of the sensor will create more distance between the free end of the sensor and the surface of goniolens in contact with the eye and hence will in-turn provide more comfort to the patient undergoing the procedure.

FIGURE 2. Embedment of vibration sensor on goniolens.

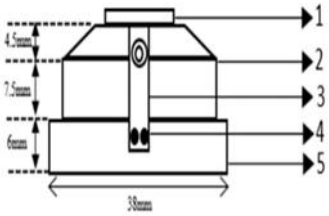

FIGURE 3. Single line diagram of tonogoniometry with actual dimensions.

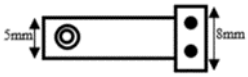

FIGURE 4. Top view of the sensor.

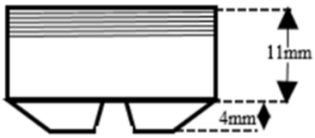

FIGURE 5. Side view of the aluminium holder.

B. DESIGN OF SIGNAL CONDITIONING CIRCUIT

The output of the sensor is a sine wave of low amplitude (few millivolts) and hence the presence of even little noise will also distort the signal leading to ambiguous results. An instrumentation amplifier is a differential amplifier with high input impedance, low output impedance, and low common-mode rejection ratio [21]. It provides proper impedance matching and eliminates noise common to inputs [22], [23]. Thus, the output of the sensor is fed to the instrumentation amplifier and the peak-peak voltage output of the sensor is recorded in the LabVIEW platform. The voltage gain of the amplifier is estimated from equation (1). Fig. 7 is the circuit diagram of the instrumentation amplifier.

The gain for the amplifier is given as follows:

$$A_v = \frac{V_0}{V_2 - V_1} = 1 + \left(\frac{2R_1}{R_{gain}}\right) * \frac{R_3}{R_2} \qquad (1)$$

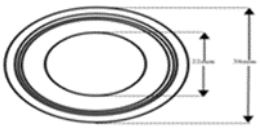

FIGURE 6. Rear view of the acrylic holder.

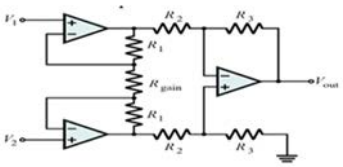

FIGURE 7. Design of Instrumentation amplifier.

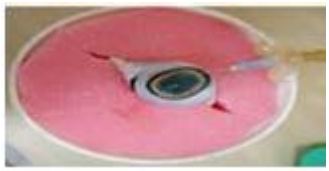

FIGURE 8. Insertion of the syringe into the cornea.

The values of the circuit employed are

$$R_1 = R_2 = R_3 = 1\text{K}\Omega, \quad R_{gain} = 5\text{K}\Omega potentiometer$$
$$A_v = 2.2$$

C. MANOMETER SETUP

The process of manometer calibration is as follows:

i. A transparent PVC water column manometer was used in this current study.
ii. Calibration of this manometer has been carried out using a pressure calibrator.
iii. Using a pressure pump a range of air pressure (10mmHg to 50mmHg/ 1.33322 KPa to 6.66612KPa) was supplied to the calibrator and the manometer.
iv. Based on the calibrator readings, the manometer scales have been defined.
v. This process has been repeated to ensure the accuracy of the readings.

The manometer calibration has been revalidated using the number of goat eye samples as explained below:

i. Fresh goat eye has been cannulated as shown in Fig. 8 and the pressure on the cornea has been measured using an Icare tonometer.
ii. The Experiment has been repeated for 30 numbers of fresh goat eyes with a pressure range from 10mmHg to 50mmHg. The manometer scales have been redefined.
iii. The results of the Icare tonometer are found linear as compared to the manometer reading as shown in the graph Fig. 9.

D. PNEUMATIC ARRANGEMENT

Constant force must be applied on all the samples of goat eyes during the experimentation to nullify the effect of varying force. Hence, a pneumatic system is employed which makes

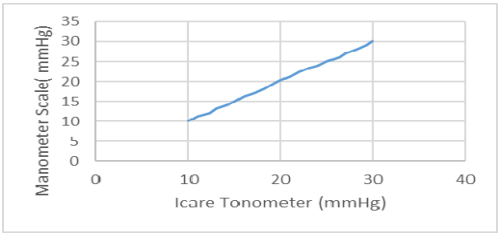

FIGURE 9. Comparison of Manometer scale with Icare tonometer.

use of pressurized air or gas to move the piston. The pneumatic system mainly consists of a 3/2 push-button, one-way flow control valve, and a quick exhaust valve and is connected to a cylinder or single-acting cylinder. Fig. 10 is the circuit diagram of the pneumatic system. Push-button when pressed releases the pressurized air onto the cylinder and hence due to the pressure of the air, the cylinder moves down. When the button is released, the cylinder moves back to its original position. A flow control valve is used to control the flow of air in the system and its force is used to move the cylinder up and down. The tonometer readings from the sensor are noted during the bouncing back action of the eye or in other words after the force on the cornea is released. To ascertain that the bouncing action of the eye is only due to the intraocular pressure of the eye, the controlled air must rapidly exhaust. Hence, a quick exhaust valve is used to rapidly exhaust the controlled air and is placed after the control valve. The quick exhaust valve ascertains that the bouncing back action of the eye after the force on the eye is suddenly released will be mainly due to the IOP of the eye.

E. DESIGN OF GONIOLENS HOLDER

The placement of the goat eye and also the positioning of embedment on the eye is arranged such that during the force of applanation, the eye should be held in its fixed position, and the cornea of the eye should be allowed to deform and bounce back. Thus, the goat eye sample is allowed to move only in a vertical direction otherwise will introduce an error in sensor output.

The sketch of the goniolens holder set-up designed for the placement of the tonogoniometer on the eye sample is shown in Fig. 12 and the snapshot of the goniolens holder is presented in Fig. 11. It consists of a plywood base with its center marked for positioning the goat eye. Support is designed to place the goniolens on the eye which consists of a white acrylic sheet with a hole at its center and is supported on the four corners by bolts and nuts. The measurement of the bolts is 8mm * 50mm. The acrylic sheet touches only the corners of the eye and rests on the four nuts. The thickness of the acrylic sheet is 4mm. Two screws are fixed on the acrylic sheet on 2 opposite sides near the holes. Two handles are welded to the 2 edges of the goniolens which in turn is supported by 2 screws to keep the goniolens on the eye. An acrylic cap, a goniolens guide, and an eye clamp are included in the holder for proper positioning of the tonogoniometer on the eye and are displayed in Fig. 12. Hence

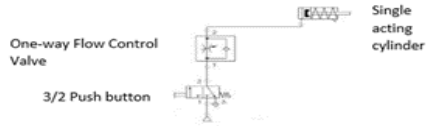

FIGURE 10. Pneumatic system.

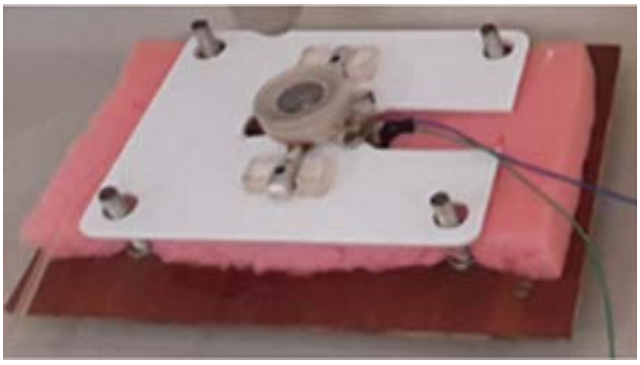

FIGURE 11. Snapshot of goniolens holder.

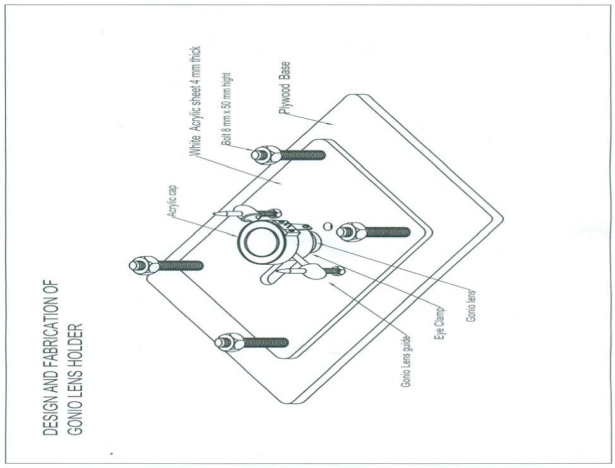

FIGURE 12. Isometric view of goniolens holder.

during experimentation tonogoniometer kept on the eye will not displace from its position during the experimentation.

F. EXPERIMENTATION WITH GOAT EYE

The experiments are carried out on goat eyes to find the influence of the IOP of the eye with the vibration sensor output. Fig. 13, is the image of the experimental set-up established to derive the relation between the IOP of the eye and the sensor output. The different parts of the experimental set-up are the pneumatic system, Signal conditioning circuit, Electronic device installed with LabVIEW, Goniolens holder along with eye sample, tonogoniometer, and manometer set-up and are marked in the image Fig. 13. A predetermined pressure is developed in the goat eye using a standardized manometer set-up as indicated in part (5) in Fig. 13. The manometric examination was carried out by [24] on bovine, ovine, and caprine freshly enucleated eyes after 6 hours of storage in 0.9% NaCl. The study [25] explains about inflation rig is an ex-vivo method to control the eye pressure of cadaver eyes

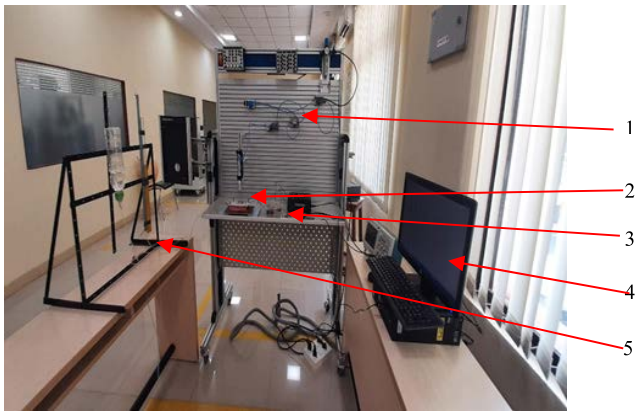

FIGURE 13. Experimental set-up.

during post mortem. During experimentation, the eye sample is covered with an acrylic plate such that the goniolens embedded with a sensor, are held fixed in their place and are indicated as part (2) in Fig. 13. A fixed force is applied to the eye using a pneumatic arrangement indicated as part (1) in Fig. 13, which will deform the surface of the cornea. After the force is released, the elastic property of the eye will tend the deformed surface of the eye to revert to its original position immediately. This action is called bouncing of the eye, which depends on the amount of pressure in the eye. Hence, the reading of the vibration sensor after the release of force from the embedment which is dependent on the IOP of the goat eye is utilized to measure the IOP of the eye. The amplitude of bouncing back is tapped at the terminals of the sensor and is amplified by an instrumentation amplifier indicated as part (3) in Fig. 13. The peak to peak voltage output of the amplifier is transferred through National Instruments (NI) data acquisition card and hence is recorded by an electronic device installed with LabVIEW indicated as part (4) in Fig. 13. The results and analysis have been discussed thoroughly in the results and discussion section.

III. RESULTS AND DISCUSSION

Each goat eye sample was applied with 10mmHg, 12 mmHg, 16 mmHg, and 20 mmHg, and the sensor output was noted. Meanwhile, to procure the exact relation between the IOP of the eye and the sensor output, experimentation was carried out with 30 goat eye samples. The results of experimentation with goat eye samples were recorded and statistical analysis is further carried out on the experimental results.

Statistical analysis is carried out by [26] on the cancer data set and hence box plot and whiskers plot has been used to find the relationship between the attributes. It proved that people who smoke will have higher chances of getting affected by cancer. The experimental results on goat eye to explore the relation between IOP of eye and vibration sensor output are recorded in the box plot shown in Fig. 14. The box plot infers that as the pressure applied to the goat eye sample is increased the deformation of the cornea decreases which results in a high magnitude of sensor output. The above plot

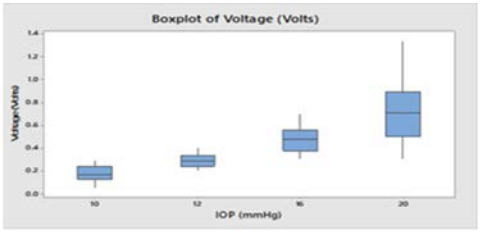

FIGURE 14. Box plot representation of goat eye experimental results.

also summarises that for a particular pressure there is a range of voltage output of the sensor. This may be due to the change in shape, age, size, and condition of the goat eye sample and also due to the variations in surrounding atmospheric conditions. But for every pressure, the range of voltage output is very small and hence the sensor output is repeated for constant IOP of the eye, or the repeatability rate of the sensor output is high in the experimentation process.

The outcome of the boxplot is illustrated in Table 1. In Table 1, Q1 and Q3 refer to the maximum and minimum values of data which are closely packed for every change in IOP of the eye. Whiskers refer to random values that are crept in due to measurement error and hence have not been considered in the calculations. IQ range is the difference between Q1 and Q3. The strength of the relationship between the variables in the model is described by the R square value and its value for the experimental data is 75.97%. It signifies that a good relationship exists between the independent and dependent variables in the current testing method. S is the standard error of the regression defined as the average distance of the observed values from the regression line and is 1.97594. The prediction interval corresponding to the S value is 95% and hence the results are considered precise.

The experimental results in the boxplot are validated by the patent [5], which summarises that the IOP of the eye is inversely proportional to the distance of travel of the cornea. In the current research, the lower amplitude of deformation of the cornea at higher IOP produces a larger amplitude of vibrations in the sensor output during bouncing back action of cornea and hence higher magnitude of sensor output. Therefore, the principle of the higher amplitude of sensor output for increased IOP of the eye is experimentally validated (Fig. 14).

Further, the regression method was applied to establish the exact relationship between sensor output and IOP of the eye [27] and is expressed in Equation (2).

$$P = 5.887 + 30.65V - 18.33V^2 + 2.126V^3 \qquad (2)$$

where V is the peak to peak voltage output of the sensor (mV)and P is the IOP of the eye (mmHg).

Further, equation (2) is executed in an application software LabVIEW will result in an exe file. The data acquisition system (e.g., NI DAQ card) reads the sensor output voltage and feeds the voltage to equation (2) will evaluate the IOP of the eye. Thus, the IOP of the eye (P) will be displayed on the front panel of the LabVIEW.

TABLE 1. Analysis of box plot representation.

IOP (mmHg)	Q1	Q3	Median	IQ range	Whiskers
10	0.12584	0.24245	0.16922	0.11661	0.04729, 0.29469
12	0.2389	0.335355	0.28115	0.096455	0.2031, 0.39855
16	0.372865	0.557262	0.4711	0.184398	0.30632, 0.69459
20	0.49726	0.890143	0.70677	0.392883	0.30177, 1.33517

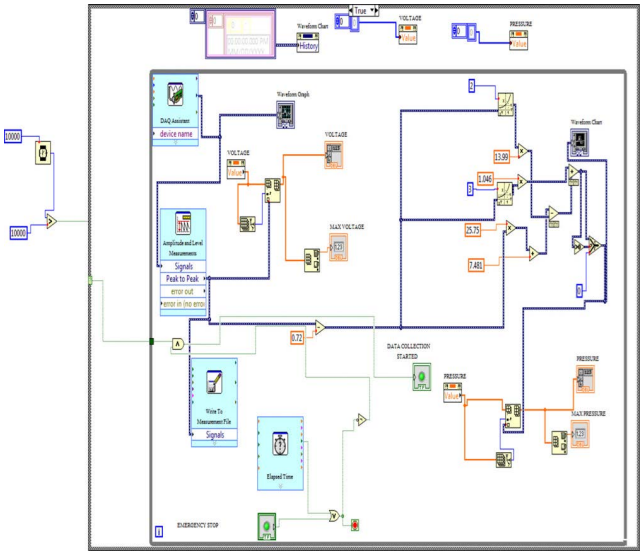

FIGURE 15. Block diagram window of LabVIEW during the true condition.

But, the equation should be executed only during the bouncing back of the eye or when force from the eye is suddenly removed. Hence, the case structure is being used in LabVIEW to provide 10 seconds delay such that the evaluation of IOP is carried out only when force from the cornea is suddenly released. Hence, during false conditions, a provision is made to provide 10 seconds delay for the optometrist to apply force on the eye and deform the cornea. Hence no operation is carried out in the software during the false condition. After 10 seconds delay, the true condition shown in Fig. 15, is executed to evaluate the IOP of the eye. The program will start recording the data from the sensor and determine the IOP of the eye by executing the equation (2) and the IOP is displayed on the front panel window of LabVIEW.

Fig. 16 display the front panel window of the LabVIEW. It displays two arrays that show the peak-peak voltage output of the sensor and the corresponding pressure according to the derived equation. Two numeric indicators indicate the maximum voltage and the corresponding maximum pressure (which is the desired output) respectively. The front panel window of LabVIEW also includes a green LED indicator and the LED glows when the data from the sensor starts recording during true case structure. This action will report

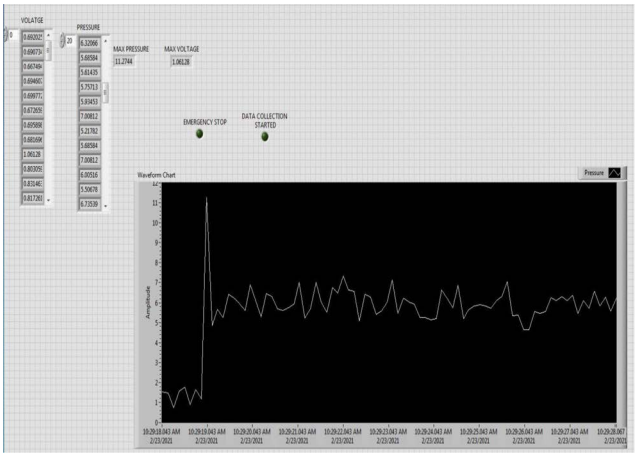

FIGURE 16. Snapshot of front panel window of LabVIEW.

to the doctor that the data recording from the sensor into LabVIEW has been initiated and evaluation of IOP is in progress. The front panel display also has an emergency stop button to stop the process of evaluating IOP at any instant of time. The main part of the front panel window is the waveform chart, which displays the pressure against the time. Every evaluated pressure on the graph are corresponding to the sensor output. In Fig. 16, as visible, the maximum pressure is 20.3 and occurs during bouncing back action of the eye and is considered as the IOP of the eye. The result obtained is considered fairly accurate as using the manometer set-up, the goat eye was developed with 20mmHg of pressure. The experiment is repeated for different values of IOP and different samples of the eye and similar results are obtained and hence the technology is validated.

Thus, a tonogoniometer will evaluate the IOP of the eye along with gonioscopy. The prototype requires an anesthetic drop to be instilled into the eye to numb the eye and also for accurate estimation tonometry needs to be performed first followed by gonioscopy as this contact procedure can vary or change the aqueous humor dynamics.

Fig. 17 explains the working principle of the tonogiometer. Tonometry is carried out by placing the tonogoniometer on the surface of an eye sample. The ophthalmologist/optometrist will applanate the surface of the cornea using the embedment and simultaneously start LabVIEW recordings. Buffering time of 10 seconds is allotted till the surface of the cornea is deformed by the clinician, during which false case structure is implemented, where no recording takes place. After 10 seconds delay, the true case structure is implemented as shown in Fig. 15 and hence sensor output and the corresponding pressure will display in two arrays placed on the front panel window of LabVIEW as shown in Fig. 16. Meanwhile, the force on the cornea is released and hence the deformed cornea will bounce back immediately. This results in the maximum voltage output of the sensor and the corresponding maximum pressure. This maximum pressure during the bouncing back action of the eye corresponds to the IOP of the eye. The values of pressure recorded in the

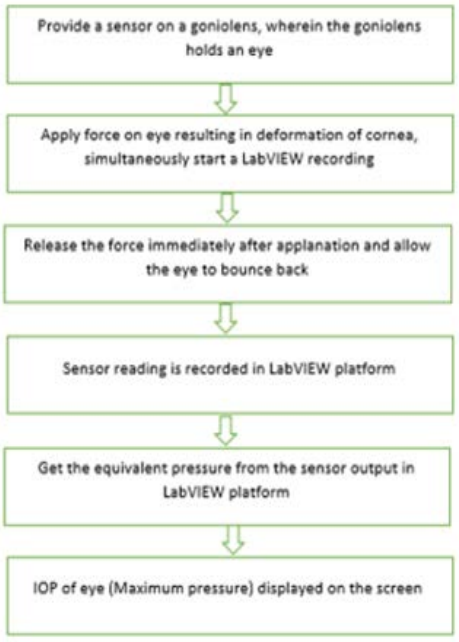

FIGURE 17. Steps illustrating the operation of tonometry using Tonogoniometry.

array are displayed on the waveform chart against time on the X-axis as shown in Fig. 16. The maximum pressure recorded in the waveform chart also corresponds to the IOP of the eye.

Further, gonioscopy is carried out by passing the light into the eye through the tonogoniometer. This enables the optometrists to view the anterior chamber angle as well as visualize the internal structure of the eye. However, the uneasiness caused to the patients during testing cannot be avoided as tonogoniometry needs the device to touch the eye.

IV. CONCLUSION

The developed prototype ''Tonogoniometry'' offers patients a momentary advantage as they do not need to undergo several examinations to diagnose glaucoma. Hence the amount of uneasiness is reduced by combining two contact procedures into one. This innovation is not addressed in clinical as well as at industrial side. But separate devices exist to perform tonometry and gonioscopy. The operating parameters of the developed prototype ''tonogoniometry,'' may not alter during testing with the patient's eye, as the usage of goniolens is not altered and the tonometry utilizes sensor, amplifier, and exe file, whose output may not get affected due to the environmental conditions, amount of usage as well as the place where testing is carried out. Hence the principle is validated and a more detailed experimental study will be performed in the future in terms of mould design, positioning the sensor, and accuracy of the output. It would need to go through a series of tests, validations, and quality checks. Further experimentation will be carried out on live rabbit eyes and human beings after getting the ethical clearance. The goat eye samples have been collected, preserved and all experiments have been performed within 2 hours of the removal. Though the experiments were performed within 2 hours, the corneal and the ocular structure degenerative changes might influence the IOP measurements, this is the limitation of the current study. The amount of corneal biomechanical changes recorded by the vibration sensor will be measured as future scope of the work by the use of high-resolution ultrasound imaging method and also use of noncontact imaging methods. Meanwhile, during animal experimentation, better preservative techniques (cornisol) will be indulged to preserve the elastic properties of the cornea and hence increase the accuracy of data recording.

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