Journal of Electronics and Informatics (ISSN: 2582-3825)
www.irojournals.com/iroei/

Filtering of Corneal Images using Hybrid Wavelet Transform in the Cases of Keratoconus

K. R. N. Aswini[1], S. Vijaya Raghavan[2]

[1]Ph. D Scholar, Department of ECE, SCSVMV Deemed University, Kanchipuram, Chennai, India
[2]Assistant Professor, Department of ECE, SCSVMV Deemed University, Kanchipuram, Chennai, India

E-mail: [1]krnaswini@gmail.com, [2]professorvijayece@gmail.com

Abstract

One of the most prevalent, bilateral, asymmetric, and progressive corneal diseases, keratoconus can have a slight to severe impact on vision. Early on, the condition is frequently misdiagnosed as irregular astigmatism, delaying diagnosis. Although we have cutting-edge diagnostic techniques, the results are insufficient to fully assess the corneal health at different areas, making it challenging to plan additional treatment programmes. Here, image pre-processing techniques using a Hybrid Wavelet Transform of Discrete Wavelet Transform (DWT) and Stationary Wavelet Transform (SWT), followed by soft and/or hard thresholding and Inverse Wavelet Transform, are proposed in order to achieve early and accurate diagnosis and assess the health of the cornea. The qualitative and quantitative metrics are reached by taking into account the several Electronic Corneal Topography picture modes, which would be useful to an ophthalmologist in moving on with therapy. This approach has been proven to have greater promise than the ones currently in use, particularly in relation to corneal diseases like keratoconus. Additionally, this approach aids in more accurate keratoconus stage determination.

Keywords: Hybrid wavelet transforms, stationary wavelet transform, thresholding, corneal topographer, keratoconus, and corneal health

1. Introduction

The front-based simple layer of the eye, the cornea, undergoes reformist thinning in keratoconus, a degenerative eye disease. Kéras, which in Greek means "cornea," and Cnus, which in Latin means "cone," are the roots of the word "keratoconus." In this disease, the

DOI: https://doi.org/10.36548/jei.2022.2.005
Received: 24.05.2022, received in revised form: 01 .07.2022, accepted: 15.07.2022, published: 25.07.2022

cornea's thickness gradually decreases and assumes a conical form. Vision is obstructed by a cornea that has a cone shape, and light and glare may also be an issue. Low quality of life conditions such as blurry vision, double vision, partial blindness, unexpected astigmatism, and light sensitivity may result from this. In more severe situations, the cornea may reveal a scarring or a circle. As the cornea changes from its normal form of a circle to one of a cone, the eyesight becomes increasingly worse. [1] [2]

1.1 Symptoms & Signs – Prevalence

The main signs and symptoms include problems driving, Fleischer rings, double and distorted vision, astigmatism, difficulty seeing in low light, myopia, photophobia, sensitivity to glare, etc. The majority of the time, men and women experience the symptoms throughout puberty or the early adolescent years. This visual abnormality is bilateral and asymmetrical. Although the aetiology is unknown, it is generally agreed that a combination of inherited, environmental, and hormonal variables have a role [3].

A familial history of the illness runs in about 7% of individuals affected. The proposed ecological aspects include allergies and eye cleaning. the covert component entails shaping the cornea into a cone. About 1 in 2,000 people are affected by keratoconus. It typically occurs in late adolescence or early adulthood. Although it occurs in all populations, it may occur more frequently in some ethnic groups, such as those of Asian heritage [29].

1.2 Modern Diagnostic Tools

The diagnosis of keratoconus frequently begins with an evaluation of the patient's clinical history by an ophthalmologist or optometrist, focusing on the primary complaint and other visual manifestations, the presence of any set of experiences of visual illness or injury that may affect vision, and the presence of any family history of visual infection. The person's visual acuity is then assessed using an eye graph, such as a typical Snellen outline of gradually smaller letters. A manual keratometer may be used to measure the cornea's constrained bend, with the presence of random astigmatism signalling a potential keratoconus condition. The estimation capability of the device may be exceeded in serious instances. Retinoscopy, in which a light shaft is centred around the person's retina and the reflection, or reflex, is viewed as the inspector tilts the light source to and fro, can provide an additional sign. One ocular disorder, keratoconus, exhibits a scissor reflex, where two groups push toward and away from one another like the cutting edges of a pair of scissors [4] [5].

If keratoconus is suspected, the ophthalmologist or optometrist will examine the cornea using techniques for cut light assessment in order to seek for other telltale signs of the disease. When a situation is serious, it is usually immediately visible to the analyst and can support a clear decision before additional particular testing. When examined closely, a Fleischer ring of yellowish-earthy to olive-green pigmentation can be seen. ring can be seen in about 50% of eyes with keratoconus. The Fleischer ring, which is caused by the iron oxide hemosiderin stating inside the corneal epithelium, is undetectable and may not always be immediately apparent, but it becomes more noticeable when viewed through a cobalt blue filter. Similar to Vogt's striae, which are minute pressure lines inside the cornea caused by extending and thinning, roughly half of the participants have them. Inadvertently, the striae disappear when a little pressure is put on the eyeball. In Munson's sign, a profoundly articulated cone might create a V-shaped space in the lower eyelid when the person's gaze is directed downward. Even though Munson's sign is an outstanding marker of the disease, other clinical signs of keratoconus will typically have developed long before Munson's sign is visible. As a result, despite being a clinically significant finding, this finding is not usually important for making a case [6] [7] [8].

By predicting a sequence of concentric rings of light onto the cornea, a handheld keratoscope, sometimes referred to as "Placido's Circle," can provide an easy non-invasive portrayal of the outside of the cornea. Using corneal topography, a mechanised instrument extends the slit-up design onto the cornea and determines its geography by examining the advanced picture, a more definitive result may be obtained. The geology map shows any scarring or mutilations in the cornea, and keratoconus is revealed by a distinctive steepening of bend that is typically below the centre of the eye. As a benchmark for measuring its rate of movement, the strategy can capture an early indication of the severity and extent of the disfigurement. It is particularly helpful in identifying the issue when it is still in its early stages and there are few telltale indicators [9].

1.3 Perception of Light in Case of Keratoconus

Monocular polyopia, or the perception of many "phantom" images, is the most typical Keratoconus symptom. This effect is most clearly seen in high differentiation fields, such as a state of light on a dark background. An individual with keratoconus sees many images of the point, spread out in a clamorous example, as opposed to seeing just one point. Except for the fact that it frequently adopts new structures over time, this sample doesn't alter significantly from day to day. Around light sources, people frequently see streaking and exploding distortion. Some people have even reported seeing the images move in relation to one another in rhythm with their heartbeat. In keratoconus, coma is the transcendent optical distortion of the eye. Two factors, including scarring that develops on the cornea's exposed highpoints and periodic misshaping of the cornea's exterior, are to blame for the person's sense of visual distortion. These components show how to map different regions of the retina to frame areas on the cornea. Low-light situations can exacerbate the effect as the dull-adjusted pupil opens to reveal more of the cornea's uncertain surface [10].

2. Literature Survey and Outcomes

[11] emphasised the necessity of identifying the biomechanical characteristics of the cornea in order to locate disorders that impact the cornea, such as keratoconus and the harmful effects of electromagnetic and UV rays. In order to reconstruct and recover corneal structures after surgery, the findings of the assessment of biomechanical properties are beneficial, which creates a demand for the estimation of stiff, non-invasive, and high-resolution structures for the diagnosis of ophthalmic illnesses. A technique to measure corneal sclerosis by Dual Frequency Confocal Transducer-Based High Resolution Imaging was also proposed. In order to evaluate the relative stiffness map, use acoustic radiation force impulse imaging. To cause interior tissue movement, a 48 MHz monitoring element and an 11 MHz pushing element are utilised. Mechanical B/D scans are used to determine the stiffness distribution over the tiny sections of cornea since the elastic characteristics of ocular tissues and tissue movements or displacements are directly correlated. By simulating tissue phantoms, the suggested system is tested in various stages and geometrical configurations. Fresh pig eyeballs are taken into consideration for ex vivo corneal investigations. Artificially, the corneas with sclerosis were manufactured by injecting Formalin solution. Experimental evidence has shown that one of the best methods for determining the distribution of stiffness over the cornea at various phantoms is ARFI imaging. The lateral and axial resolutions are calculated to be 177 and 153 m, respectively. The results of ARFI Imaging ex vivo tests can also be used to identify small and insignificant parts of the cornea that have sclerosis, and are therefore important in the diagnosis of Corneal sclerosis, a serious corneal illness similar to Keratoconus.

[12] As a progressive ophthalmic condition, keratoconus would require surgical treatment to prevent a significant loss in visual acuity. Correcting the corneal irregularities aids in maintaining vision. Cross-Linking (CXL), a surgery that is frequently advised for this

ISSN: 2582-3825

problem, allows for the indirect assessment of success by determining the presence and depth of the stromal demarcation line. Hazy cornea, which is located far from the demarcation line and represents the opacity of the cornea, is one of the major noteworthy problems following surgery. When the cornea loses its transparency, vision impairment results. Slit lamps are used to measure the aforementioned direct and indirect metrics.

Optical Coherence Tomography (OCT) or a biomicroscope are employed. The depth of the demarcation line (if present) and the stage of the hazy cornea are measured and analysed, but this takes a lot of time and is not always accurate or user-friendly. Here is a method that has been suggested, using machine learning and imaging techniques to automatically detect, analyse, and determine corneal haze, the presence of a demarcation line, and its depth in OCT images. By using this technique, the observer can learn about the haze, visual annotation, structure, region, and demarcation line in the cornea, among other things. This method is demonstrated to be effective and efficient through experimental analysis, and the results can be obtained more quickly in a repeatable and reproducible manner.

[13] Due to structural abnormalities, irregularities, and decreased corneal thickness in Keratoconus cases, the focus of light rays on the retina is distorted. Visual impairment is caused by this incorrect focus. They are frequently confused because they are similar to those that can be seen in the early stages of astigmatism. In order to distinguish between and classify the conditions Keratoconus and Astigmatism using axial topographic images, a shape recognition-based algorithm has been proposed.

[14] have highlighted the challenges brought on by the delay in diagnosing Keratoconus, which is one of the main causes of corneal transplantation because it interferes with the focus of light rays on the retina due to the irregular and conical structure of the cornea. In order to better observe the structural organisation of Sutural Lamellae, which are found in Keratoconus Corneas, Second Harmonic Generation (SHG) microscopy techniques are applied in this paper. These techniques are in line with the assessment techniques used by clinicians. The same outcomes are contrasted with corneas in good health. Specifically, statistical differences between healthy and keratoconus sutural lamellae in the pattern of orientation and distribution Utilizing 3D correlation of SHG image stacks, the corneas are shown, and as a result, are discovered to be a better option for the early diagnosis of Keratoconus.

[15] As the most important sense in humans, vision can be affected by a variety of diseases and conditions, some of which may even be inherited, leading to a high prevalence of people with low vision and other visual impairments. Most situations can be resolved using conventional techniques, but only if a reasonable control could be avoided and up until the early detection of various problems affecting visual acuity and visual field. The corneal ectasia, also known as keratoconus, is one of the introduced visual problems, and its early detection isn't all that difficult to determine, especially in the early stages of development. For clarification, the reproduction and demonstration of the natural eye in the current study serve as a tool for early detection by determining the level of keratoconus contribution. Presumptive conclusion tools for professionals, enabling them to take the necessary actions to control this ailment. Through sophisticated preparation made possible by free programming, images of the natural eye are used to examine the various stages of keratoconus.

The goal of this investigation, according to [19], was to characterise a different characterization strategy for differentiating keratoconus based on factual investigation and to comprehend the forecast of these arranged information with clever frameworks. For this analysis, 301 eyes from 159 patients and 394 eyes from 265 refractive surgery newcomers were used as the benchmark group. Factor analysis is a multivariate technique. The majority of the time, measurable methodologies have been employed to find more meaningful, simple, among the others, and free factors. After that, a different arrangement strategy was constructed using bunching examination techniques on these variables, and it was then evaluated using fictitious neural networks and support vector machines.

[20] In this study, a novel method for predicting astigmatism in keratoconus (KC) patients following ring implantation is proposed. KC is a gradual, non-inflammatory corneal thinning condition that causes protrusion, myopia, and uneven astigmatism. Without a corneal transplant, the intracorneal ring implantation operation has emerged as a viable method to treat keratoconus. In this work, two machine learning (ML) classifiers based on a decision tree and an artificial neural network were used. Artificial neural networks outperformed decision trees, attaining an absolute mean error in a validation data set of less than 2 dioptres. The most important features underwent investigation as well.

[21] Another hereditary calculation based on distinct information kinds is suggested in this paper for assurance that coefficients can alter with the developmental cycle while taking into account a few measurements setup for keratoconus patient's borders from the Ocular Response Analyzer. It is anticipated that, similar to the classifier, it would

demonstrate the productivity of hereditary computation based on distinctive information types in the portrayal of a connected solution for challenging streamlining problems.

3. Block Diagram of Proposed Methodology

The Corneal Topography images of Patients with keratoconus are divided based on the degree of corneal thinning. Mild, Medium, and Severe are the three levels that are recognised. In order to efficiently pre-process and investigate the characteristics using wavelet transforms, the input images are taken in a variety of modes including Axial - Absolute, Axial - Numeric, 3D Cornea, Axial - Absolute and Axial - Absolute with Rings and Pupil. The block diagram lists the numerous procedures that go into pre-processing the cornea using input photos of the corneal topography.

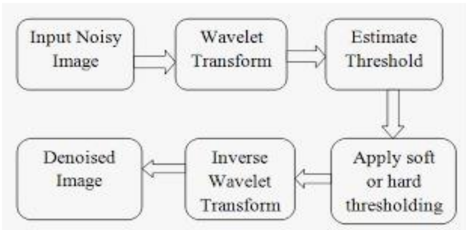

Figure 1. Block Diagram of Proposed Methodology

The application of Discrete Sampling of Wavelets for improved mathematical and functional analysis is specific to the discrete wavelet transformations (DWT). In comparison to the Fourier transform, the DWT has the ability to achieve temporal resolution by obtaining both frequency and location with respect to time [23].

Here, the Stationary Wavelet Transform is suggested in order to close the translation variance gap between the processed image and the Discrete Wavelet Transform. Up sampling and Down sampling from DWT are eliminated, and filter coefficients are then up sampled by a factor of 2 (i-1) to achieve Translation Variance. The number of samples in the output is the same as the number in the input, making it a redundant transform at first. The same number of duplications or redundancies occur with the same number of wavelet coefficients when the levels are decomposed. Quasi-continuous wavelet transforms and redundant wavelet transforms are other names for the stationary wavelet transform. Wavelet transforms with translation invariance, shift invariance, cycle spinning, and maximal overlap (MODWT), Undecimated wavelet transform (UWT) [24].

4. Proposed Instruments for Research

A non-intrusive clinical imaging technique called corneal topography, also known as photokeratoscopy or videokeratography, is used to plan the surface ebb and flow of the cornea, the eye's outer structure. Since the cornea typically accounts for around 70% of the eye's refractive force, its topography is fundamentally important in determining both vision quality and corneal health. The three-dimensional guide is thus a crucial tool for the eye doctor or ophthalmologist, as it can help with the diagnosis and treatment of a variety of conditions, the planning of cataract surgery and intraocular lens implantation (plano or toric IOLs), the planning and evaluation of refractive surgery, such as LASIK, and the attack of contact focal points. As a development of keratoscopy, corneal topography increases the estimating range from the four focuses that keratometry provides, which are spaced a few millimetres apart, to a system of thousands of focuses encompassing the entire cornea. [25] The process is quick and simple to do. The Corneal Topographer is the name of the device. Here, the corneal structures were observed using the Corneal Topographer CT 1000 from Shin - Nippon and its accessories [26].

The Electronic Corneal Topographer is a diagnostic tool. For instance, the KISA percent file (keratometry, I-S, slant rate, astigmatism) is used to show up at a determination of keratoconus, to screen the suspect Keratoconus patients, and to examine the level of corneal steepness changes in sound relatives. It is actually one of the tests the patients must undergo before the Cross-connecting and the Mini Asymmetric Radial Keratotomy (M.A.R.K [27]. In every way, topography is a measure of the most important intellectual.

The tear film on the eye's surface doesn't provide any further information beyond the arch-communicated status of this layer. Since keratoconus is a case of the entire cornea, any estimation that focuses only on one layer is usually insufficient for a cutting-edge conclusion. If refractive surgery is being contemplated, it is important to note that a simple geological estimation may overlook particularly early cases of keratoconus. The estimation is also susceptible to thin tear coatings. Additionally, the estimation's layout can be challenging, particularly for eyes with Keratoconus, severe astigmatism, or occasionally after refractive surgery.

Reproduced keratometry (SimK), a measurement made by Corneal Topography equipment, is a close approximation of the exemplary measurement made by the commonly used keratometer. CorT, which has been shown to assess refractive astigmatism more precisely than SimK and other techniques, is another amazing application of corneal geographic information. Contrasted with SimK, which is dependent on just one ring, CorT uses data from every Placido ring over the cornea. While corneal topography relies on reflected light from the cornea's front (foremost), a technique known as corneal tomography also provides a portion of the cornea's back (inner) state. This additional corneal information is incorporated into a measurement known as CorT absolute, which more accurately measures refraction when compared to SimK, regular CorT, and other methods [28].

4.1 Sample Corneal Topography Images – Keratoconus

The accompanying photos, which were captured in the Axial-Absolute Mode, Axial-Numeric, Axial- bsolute with Rings and Pupil, and 3D Cornea modes, respectively, concern diverse states such as Normal, Mild, Moderate, and Severe Keratoconus.

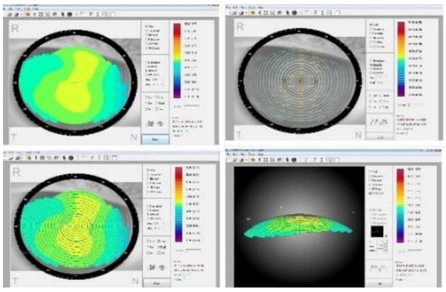

Figure 2. Normal Cornea

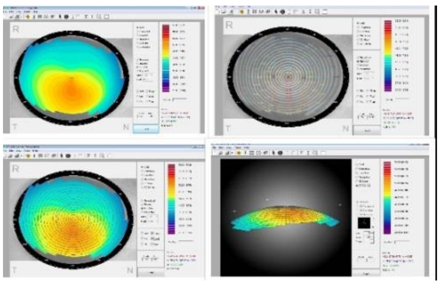

Figure 3. Mild Keratoconus

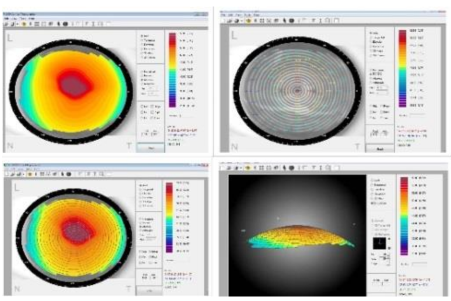

Figure 4. Moderate Keratoconus

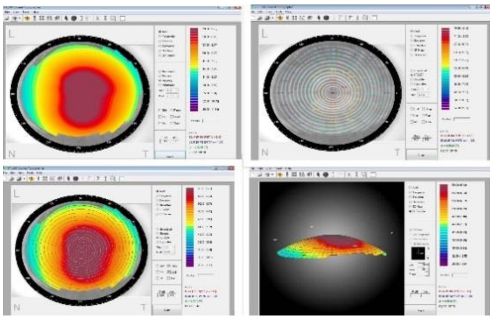

Figure 5. Severe Keratoconus

5. Conclusion

The qualitative and quantitative properties of Corneal Topography images are obtained by applying Hybrid Wavelet Transform of DWT and SWT, followed by soft and/or hard thresholding and Inverse Wavelet Transform, with optimal decimation in DWT and Non-decimation in SWT. The noise factor is significantly filtered, which will aid the ophthalmologist in making an early Keratoconus diagnosis. High resolution and improved image compression are both made possible by DWT. Hybrid Wavelet Transform is considered to have potential in the field of biomedical image processing, particularly for images of the corneal topography in Keratoconus patients, as SWT aids in obtaining the shift variance.

Acknowledgements

With the utmost respect and gratitude, I would like to humbly express my gratitude to the management, senior physicians, doctors, optometry division, IT office, and clinical research and development teams at Koothattukulam, Kerala's Sreedhareeyam Ayurvedic Research and Development Institute and Sreedhareeyam Ayurvedic Eye Hospital and Research Centre. Additionally, we would like to express our gratitude to the respected members of the institutional ethics committee as well as the knowledgeable experts for their acknowledgement and valuable suggestions, which enabled us to continue and calibrate our research in accordance with the demands and trends of the time.

Availability of Data and Material

The data used is authentic and have attained the Institutional Ethics Committee Clearance for this Research Work from Sreedhareeyam Ayurvedic Research & Development Institute, Koothattukulam.

References

[1] H. Kandel, K. Pesudovs, and S. L. Watson, "Measurement of Quality of Life in Keratoconus," Cornea, 2020, doi: 10.1097/ICO.0000000000002170.

[2] M. Romero-Jiménez, J. Santodomingo-Rubido, and J. S. Wolffsohn, "Keratoconus: A review," Contact Lens and Anterior Eye. 2010, doi: 10.1016/j.clae.2010.04.006.

[3] A. B. Epstein, "Keratoconus and related disorders," PDF) North Shore Contact Lens. Retrieved Sept., vol. 8, p. 2007, 2000.

[4] S. Pantanelli, S. MacRae, T. M. Jeong, and G. Yoon, "Characterizing the Wave Aberration in Eyes with Keratoconus or Penetrating Keratoplasty Using a High-Dynamic Range Wavefront Sensor," Ophthalmology, 2007, doi: 10.1016/j.ophtha.2007.01.008.

[5] T. Nakagawa et al., "Higher-order aberrations due to the posterior corneal surface in patients with keratoconus," Investig. Ophthalmol. Vis. Sci., 2009, doi: 10.1167/iovs.08-2754.

[6] L. T. Nordan, "Keratoconus: Diagnosis and treatment," International Ophthalmology Clinics. 1997, doi: 10.1097/00004397-199703710-00005.

[7] P. Padmanabhan and S. Badrinath, "Ectatic Disorders of the Cornea," in Sankara Nethralaya Clinical Practice Patterns in Ophthalmology, 2004.

[8] J. H. Krachmer, R. S. Feder, and M. W. Belin, "Keratoconus and related noninflammatory corneal thinning disorders," Survey of Ophthalmology. 1984, doi: 10.1016/0039-6257(84)90094-8.

[9] T. B. Edrington, K. Zadnik, and J. T. Barr, "Keratoconus.," Optometry clinics : the official publication of the Prentice Society. 1995.

[10] L. J. Maguire and W. M. Bourne, "Corneal topography of early keratoconus," Am. J. Ophthalmol., 1989, doi: 10.1016/0002-9394(89)90001-9.

[11] T. Zhang et al., "High-resolution acoustic-radiation-force-impulse imaging for assessing corneal sclerosis," IEEE Trans. Med. Imaging, vol. 49, no. 12, pp. 2463–2473, 2018, doi: 10.1109/TMI.2013.2256794.

[12] A. R. Dhaini, M. Chokr, S. M. El-Oud, M. A. Fattah, and S. Awwad, "Automated detection and measurement of corneal haze and demarcation line in spectral-domain optical coherence tomography images," IEEE Access, 2018, doi: 10.1109/ACCESS.2018.2789526.

[13] S. A. Hasan and M. Singh, "An algorithm to differentiate astigmatism from Keratoconus in Axial Topgraphic images," 2015, doi: 10.1109/IIC.2015.7150918.

[14] R. Mercatelli et al., "Morphological characterizazion of human keratoconic corneas by SHG microscopy," 2016, doi: 10.1049/cp.2016.0943.

[15] E. Pinos-Vélez, M. Baculima-Pintado, M. Cruz-Cabrera, and L. Serpa-Andrade, "Modeling of the human eye as a tool to determine the degree of involvement of keratoconus using the image processing," 2017, doi: 10.1109/SysEng.2017.8088267.

[16] X. Qian et al., "Ultrasonic Microelastography to Assess Biomechanical Properties of the Cornea," IEEE Trans. Biomed. Eng., 2019, doi: 10.1109/TBME.2018.2853571.

[17] D. Rohrbach, H. O. Lloyd, R. H. Silverman, R. Urs, and J. Mamou, "Improved High-Frequency ultrasound corneal biometric accuracyacoustic-property maps of the cornea for," Transl. Vis. Sci. Technol., 2018.

[18] D. Rohrbach, H. O. Lloyd, R. H. Silverman, R. Urs, and J. Mamou, "Acoustic-property maps of the cornea for improved high-frequency ultrasound corneal biometric accuracy," 2015, doi: 10.1109/ULTSYM.2015.0149.

[19] M. Singh et al., "Noncontact Elastic Wave Imaging Optical Coherence Elastography for Evaluating Changes in Corneal Elasticity Due to Crosslinking," IEEE J. Sel. Top. Quantum Electron., 2016, doi: 10.1109/JSTQE.2015.2510293.

[20] M. Ucar, B. Sen, and H. B. Cakmak, "A novel classification and estimation approach for detecting keratoconus disease with intelligent systems," 2013, doi: 10.1109/eleco.2013.6713897.

[21] M. A. Valdes-Mas, J. D. Martin, M. J. Ruperez, C. Peris, and C. Monserrat, "Machine learning for predicting astigmatism in patients with keratoconus after intracorneal ring implantation," 2014, doi: 10.1109/BHI.2014.6864474.

[22] V. W. Ramos et al., "An application of algorithm based on abstract data types to the keratoconus diagnosis," 2013, doi: 10.1109/ANTHOLOGY.2013.6784907.

[23] D. Barina, "Real-time wavelet transform for infinite image strips," J. Real-Time Image Process., 2020, doi: 10.1007/s11554-020-00995-8.

[24] S. A. Broughton and K. Bryan, Discrete fourier analysis and wavelets: Applications to signal and image processing: Second edition. 2018.

[25] N. Alpins, J. K. Y. Ong, and G. Stamatelatos, "Corneal topographic astigmatism (CorT) to quantify total corneal astigmatism," J. Refract. Surg., 2015, doi: 10.3928/1081597X-20150224-02.

[26] R. Fan, T. C. Y. Chan, G. Prakash, and V. Jhanji, "Applications of corneal topography and tomography: a review," Clin. Exp. Ophthalmol., vol. 46, no. 2, pp. 133–146, 2018, doi: 10.1111/ceo.13136.

[27] N. Alpins, J. K. Y. Ong, and G. Stamatelatos, "New method of quantifying corneal topographic astigmatism that corresponds with manifest refractive cylinder.," J. Cataract Refract. Surg., 2012, doi: 10.1016/j.jcrs.2012.07.026.

[28] https://en.wikipedia.org/wiki/Corneal_topography

[29] www.cornea.org