

# EFFECTIVE AND INTUITIVE TOOLS FOR OPHTHALMIC DISORDERS

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Indian Institute of Technology-Delhi  
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# EFFECTIVE AND INTUITIVE TOOLS FOR OPHTHALMIC DISORDERS

by

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Submitted

*in fulfillment of the requirements of the degree of Doctor of Philosophy*  
to the



**Indian Institute of Technology-Delhi**

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*Dedicated to*

***My Grandparents***

*“The eye is the lamp of the body; so then if your eye is clear, your whole body will be full of light.”*

*The Bible*

*“The way to get out of the competition trap is actually to be authentic. Find what you know how to do better than anybody because you love to do it and it feels like play.”*

*Naval Ravikant*

*"यथा दृष्टि, तथा सृष्टि!" (As is one's vision, so is their perceptual experience of the world!)*

*The Vedas*

# Certificate

This is to certify that the thesis entitled “**Effective and Intuitive Tools for Ophthalmic Disorders**” being submitted by **Mr. Rijul Saurabh Soans** to the Department of Electrical Engineering, Indian Institute of Technology-Delhi, for the award of the degree of **Doctor of Philosophy** is the record of the bonafide research work carried out by him under our supervision. In our opinion, the thesis has reached the standards fulfilling the requirements of the regulations relating to the degree.

The results contained in this thesis have not been submitted either in part or in full to any other university or institute for the award of any degree or diploma.



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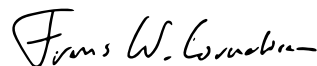
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Rijul Soans

# Abstract

One of the goals in the ophthalmic and vision sciences is to come up with new, easy and sensitive tools to screen for the presence of eye disorders. However, even the latest tools have certain shortcomings in some ophthalmic areas. In this thesis, I focus on two such areas: perimetry and 3D motion perception (3DMP). Even as standard automated perimetry (SAP) to chart the visual field is laborious, requires manual responding and cannot be employed in all patient groups, current clinical depth tests are static in nature and are not reflective of the perceived dynamic 3D world. Therefore, I use eye-tracking and virtual reality (VR) to develop new frameworks to address these issues.

First, I introduce the concept of using eye movements in a continuous tracking paradigm as a natural alternative to the traditional psychophysics used by SAP to screen for the presence of visual field defects. Previously through gaze-contingent simulations of scotomas, it has been shown that there is a direct relationship between visual field loss and the spatio-temporal properties (STP) of eye movements. Here, I show that these properties are altered in patients with glaucomatous and neuro-ophthalmological visual field defects in a specific and measurable way such that the paradigm can be used as a complementary approach to SAP for rapid screening. I find that these properties are stable across control cohorts of two ethnicities.

The thesis then turns towards the creation of a VR-based framework for portable screening of visual field defects. Here, I first illustrate the creation of the modified framework in VR with built-in eye tracking. Next, I describe the procedure to extract

the STP of eye movements of two clinical groups - patients with glaucomatous and neuro-ophthalmic visual field defects and healthy controls in this VR setting. Subsequently, I compare the performance of the VR framework to that of the screen-based eye tracker setup in terms of separation of the clinical groups. I find that the two frameworks perform similarly even though the latter framework is considered to be research-grade. I also show that patients prefer this adapted VR version of the framework across all dimensions of user experience over the less portable screen-based eye-tracker version and the standard SAP.

In the latter part of the thesis, I extend this framework to the detection and continuous evaluation of 3DMP in a VR environment with built-in eye tracking. I briefly describe how eye movements and their associated extra-retinal binocular cues can be used to measure 3DMP. Through experiments on visually healthy volunteers, I illustrate that the framework agrees well with prior retino-centric 3DMP studies. Lastly, I show that the measurement of 3DMP is reasonably robust in the presence of systematic and variable errors in the VR eye-tracking data.

In summary, these frameworks pave the way to not only create new screening tools for ophthalmologists and vision scientists but also advance our understanding of oculomotor behavior in relevant clinical and healthy populations.

## सार

नेत्र विकारों की उपस्थिति स्क्रीन करने के लिए नए, आसान और संवेदनशील उपकरणों का अविष्कार करना नेत्र और दृष्टि विज्ञान के लक्ष्यों में से एक है। हालांकि, नेत्र क्षेत्रों में नवीनतम उपकरणों में भी कुछ कमियां हैं – इसलिए इस थीसिस में, मैं दो ऐसे क्षेत्रों पर ध्यान केंद्रित करता हूँ जिनका नाम है : परिमेट्री और 3 डी मोशन परसेप्शन (3 डी.एम.पी)। यहां तक कि दृश्य क्षेत्र को चार्ट करने के लिए स्टैंडर्ड ऑटोमेटेड परिमेट्री (एस.ए.पी) श्रमसाध्य है और इसके लिए मैन्युअल प्रतिक्रिया की आवश्यकता होती है। इसके अतिरिक्त, ये सभी रोगी समूहों में नियोजित नहीं किया जा सकता है। वर्तमान नैदानिक डेपथ-परसेप्शन परीक्षण प्रकृति में स्थिर हैं और यह 3 डी दुनिया (3 डी मोशन परसेप्शन) को प्रतिबिंबित नहीं करते हैं। इसलिए, इन मुद्दों को हल करने के लिए मैं आई-ट्रैकिंग और वर्चुअल रियलिटी (वी.आर) का प्रयोग करके नए परीक्षण को विकसित करता हूँ।

सबसे पहले, मैं दृश्य क्षेत्र दोषों की उपस्थिति पता लगाने के लिए एस.ए.पी द्वारा उपयोग किए जाने वाले पारंपरिक मनोभौतिकी के स्थान पर नेत्र गति की निरंतर ट्रैकिंग करने की अवधारणा का परिचय देता हूँ। पहले, स्कोटोमा के गेज-कंटिजेंट सिमुलेशन के माध्यम से, मैं यह दिखाता हूँ कि – दृश्य क्षेत्र के दोषों और आंखों की गति का स्पेशियल-टेम्पोरल प्रॉपर्टीज (एस. टी. पी) के साथ सीधा संबंध है। यहां, मैं दिखाता हूँ कि ग्लूकोमाटस और न्यूरो-ओफ्थल्मोलॉजिकल संबंधी मरीजों में एस. टी. पी विशिष्ट रूप से बदल जाती हैं जिन्हे नापा जा सकता है। मैंने यह स्थापित किया है की ये प्रॉपर्टीज दो विभिन्न प्रजातियों में स्थायी हैं।

इसके बाद थीसिस में, मैं पोर्टेबल स्क्रीनिंग के लिए वी.आर-आधारित फ्रेमवर्क के निर्माण के बारे में बताता हूँ। यहां, मैं पहले वी.आर में बिल्ट-इन आई ट्रैकिंग के साथ संशोधित फ्रेमवर्क के निर्माण का वर्णन करता हूँ। इसके बाद, मैं दो नैदानिक समूहों के आंखों की गति का एस.टी.पी निकालने की प्रक्रिया का वर्णन करता हूँ। इस वी.आर सेटिंग में, मैं ग्लूकोमाटस और न्यूरो-ओफ्थल्मोलॉजिकल रोगी और स्वस्थ नियंत्रण वाले लोगों में परीक्षण करता हूँ। इसके बाद, मैं वी.आर फ्रेमवर्क के प्रदर्शन की तुलना स्क्रीन-आधारित आई ट्रैकर सेटअप से करता हूँ। हालांकि स्क्रीन-आधारित आई ट्रैकर फ्रेमवर्क को शोध-ग्रेड माना जाता है, मैंने

यह स्थापित किया है कि दोनों फ्रेमवर्क समान रूप से प्रदर्शन करते हैं। मैं यह भी दिखाता हूँ कि मरीज़ एस.ए.पी और कम-पोर्टेबल स्क्रीन-आधारित आईट्रैकर के मुकाबले में वीआर संस्करण को पसंद करते हैं।

थीसिस के अंतिम भाग में, मैं इस बिल्ट-इन आई ट्रैकिंग वाले वी.आर वातावरण में 3 डी.एम.पी का निरंतर मूल्यांकन करता हूँ। मैं संक्षेप में वर्णन करता हूँ कि 3 डी.एम.पी को मापने के लिए आंखों की गति और उनसे जुड़े अतिरिक्त-रेटिनल संकेतों का उपयोग किस प्रकार किया जा सकता है। मैं स्वस्थ नियंत्रण वाले लोगो में परिक्षण के द्वारा स्पष्ट करता हूँ कि यह फ्रेमवर्क पूर्व रेटिनो-केंद्रित 3 डी.एम.पी अध्ययनों के साथ अच्छी तरह सहमत है। अंत में, मैं दिखाता हूँ कि वी.आर के द्वारा परिवर्तनशील त्रुटियों की उपस्थिति में 3 डी.एम.पी का माप काफी मजबूत है।

संक्षेप में, ये फ्रेमवर्क न केवल नेत्र रोग विशेषज्ञों और दृष्टि वैज्ञानिकों के लिए प्रभावी और सहज स्क्रीनिंग टूल हैं, बल्कि प्रासंगिक नैदानिक और स्वस्थ लोगो में ऑकुलोमोटर व्यवहार की हमारी समझ को भी आगे बढ़ाता है।

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# Abbreviations

3DMP	3-Dimensional Motion Perception
AIIMS	All India Institute of Medical Sciences
BCVA	Best Corrected Visual Acuity
CCG	Cross Correlogram
CDOT	Changing Disparity Over Time
DLS	Differential Light Sensitivity
DOF	Degrees of Freedom
DT	Decision Tree
EM	Eye Movements
EMC	Eye Movement Correlogram
FDT	Frequency Doubling Technique
FOV	Field of View
GON	Glaucomatous Optic Neuropathy
GDI	Gini's Diversity Index
GEQ	Game Experience Questionnaire
HCI	Human-Computer Interaction
HFA	Humphrey Field Analyzer
HMD	Head Mounted Device
IIH	Idiopathic Intracranial Hypertension
IITD	Indian Institute of Technology-Delhi
IMU	Inertial Measurement Unit
IOVD	Inter Ocular Velocity Differences
JOAG	Juvenile Open-Angle Glaucoma

LHON	Leber's Optic Neuropathy
MAD	Median Absolute Deviation
MST	Medial Superior Temporal
MT	Middle Temporal
MTD	Motion-through-depth
NAION	Nonarteritic Anterior Ischemic Optic Neuropathy
NPV	Negative Predictive Value
POAG	Primary Open Angle Glaucoma
PACG	Primary Angle Closure Glaucoma
PCA	Principal Component Analysis
PPV	Positive Predictive Value
PVFL	Peripheral Visual Field Loss
ROI	Regions of Interest
SAP	Standard Automated Perimetry
STP	Spatio Temporal Properties
SITA	Swedish Interactive Thresholding Algorithm
SVOP	Saccadic Vector Optokinetic Perimetry
TON	Toxic Optic Neuropathy
TONP	Temporal Optic Nerve Pallor
TPR	True Positive Rate
TNR	True Negative Rate
VFD	Visual Field Defects
VR	Virtual Reality
UEQ	User Experience Questionnaire
UX	User Experience
XAI	Explainable Artificial Intelligence