# Towards Resilient Ocular Anomaly Detection for Health Monitoring

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**Abstract**

This paper introduces Optover-AI, a research project aimed at developing a resilient system for early detection of health conditions through ocular analysis. Leveraging an extensive dataset of over 280,000 pupillary response videos collected from more than 10,000 individuals, Optover-AI integrates innovative artificial intelligence solutions from the FAIR project (Future Artificial Intelligence Research) to extend the capabilities of existing ocular monitoring technologies. The proposed system aims to eliminate the need for user-specific baselines and enable detection of a broader range of visual anomalies by analyzing various ocular components, including iris and sclera. Through the implementation of advanced machine learning techniques, particularly the RAZOR method (Refining Accuracy by Zeroing Out Redundancies), Optover-AI seeks to organize unstructured data and identify anomaly patterns that might indicate not only neurocognitive alterations but also systemic diseases. This study, conducted by the innovative start-up SOBEREYE in collaboration with the University of Naples Federico II, within the framework of Italy's National Recovery and Resilience Plan, represents a significant evolution in health monitoring and workplace safety, proposing an innovative, non-invasive, accessible, and user-friendly diagnostic tool with potential impacts on public health costs reduction and improvement of quality of life.

**Keywords**

AI for Health and Medicine, eHealth, ocular analysis, pupillometry, resilient AI, health monitoring, anomaly detection, clustering

## 1. Introduction and Project Background

The global healthcare landscape has undergone a profound transformation over the past decade, with digital health technologies revolutionizing traditional approaches to patient monitoring and disease detection [1, 2]. E-health monitoring systems have emerged as critical tools in modern healthcare frameworks, offering continuous, real-time assessment of physiological parameters without the constraints of clinical settings [3, 4]. These technologies have demonstrated particular value in environments where traditional medical supervision is impractical or intermittent, enabling early intervention strategies that significantly improve health outcomes [5]. Recent advancements in wearable technology, computer vision, and artificial intelligence have accelerated the development of non-invasive monitoring solutions that can detect subtle physiological changes indicative of emerging health concerns [6]. Among these innovations, ocular biomarkers have gained significant attention due to their unique position as accessible windows into both neurological function and systemic health conditions [7].

The human eye offers rich diagnostic information through various measurable parameters, including pupil dynamics, ocular motility, and corneal integrity [7]. Of particular diagnostic value is the Pupillary Light Reflex (PLR), a neurological mechanism whereby the pupil constricts in response to light stimulation and dilates in darkness [8]. This reflex is governed by complex neural pathways involving both sympathetic and parasympathetic nervous systems, making it a valuable indicator of autonomic

*Ital-IA 2025: 5th National Conference on Artificial Intelligence, organized by CINI, June 23-24, 2025, Trieste, Italy*
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CEUR Workshop Proceedings ceur-ws.org ISSN 1613-0073
published 2025-12-07
CEUR-WS.org/Vol-4121/Ital-IA_2025_paper_50.pdf

nervous system function [9]. Research has established that alterations in PLR metrics, including latency, constriction velocity, maximum constriction amplitude, and redilation time, correlate strongly with various neurological and physiological states, including fatigue, cognitive load, substance influence, and neurological disorders [10, 11, 12]. The temporal dynamics of the PLR can reveal subtle impairments in neural processing that precede clinical manifestation of various conditions, offering a potential avenue for early detection [13].

Optover-AI emerges as a research initiative in the health and well-being domain, aiming to evaluate the feasibility of an advanced system for early diagnosis and continuous monitoring of health conditions through ocular analysis. This initiative builds upon the established foundations of SOBEREYE, a company that has been at the forefront of workplace accident prevention for several years [14, 15], developing and patenting an intelligent, automated pupillary analysis technology [13, 16, 17]. Their current system, named Optovera [14], assesses an individual's neurocognitive state in real time by analyzing the subject's PLR, captured using low-cost devices such as smartphones, identifying signals of fatigue, reduced attention, or other neurocognitive alterations caused by external factors. While SOBEREYE's technology has proven effective in identifying neurocognitive alterations across hundreds of global implementations, its current requirement for user-specific pupillary response baselines presents a significant constraint. This individualized calibration process, requiring initial video data collection and analysis for each user, creates a substantial barrier to broader adoption in clinical disease detection scenarios where immediate assessment without prior baseline data is often necessary.

The Optover-AI project aims to extend Optovera's capabilities by applying Knowledge Discovery from Data (KDD) approaches [18] on the massive dataset of over 280,000 pupillary videos and images collected from more than 10,000 individuals throughout years of operation. This unprecedented volume of ocular data will be the foundation for incorporating resilient AI solutions developed within the FAIR project (Spoke 3 - Resilient AI), specifically focusing on eliminating the need for user-specific baselines and enabling detection of a wider range of ocular anomalies potentially linked to more complex conditions beyond neurocognitive states. By utilizing this extensive repository of pupillary measurements, Optover-AI will develop population-based normative models and integrate advanced machine learning techniques for anomaly detection, creating a more versatile, accessible platform for health monitoring through ocular assessment. The project addresses critical challenges in current ocular monitoring systems, including individual variability in pupillary responses, environmental confounders, and the need for robust, generalizable detection algorithms that maintain performance across diverse populations. The resulting technology, built upon years of accumulated data, has potential applications spanning occupational safety, neurological screening, and general population health monitoring, representing a significant advancement in non-invasive diagnostic capabilities.

The remainder of this paper is organized as follows. In Section 2 an overview of the project's goals and methodology is provided. The innovative aspects of Optover-AI are highlighted in Section 3, and its expected outcomes and impact are discussed in Section 4. Last, ethical and privacy considerations are discussed in Section 5, and final remarks and directions for future work are provided in Section 6.

## 2. Methodological Framework and System Implementation

The Optover-AI initiative aims to establish a comprehensive framework for advancing ocular-based health monitoring. To this end, three key interconnected objectives have been defined:

1. **Applying unsupervised learning techniques to organize data and identify anomaly patterns.** The project will implement advanced clustering algorithms and dimensionality reduction methods to analyze the extensive pupillary database without relying on predefined classifications. This approach will enable the discovery of natural groupings within the data and the identification of outlier patterns that may indicate previously unrecognized health conditions or subtypes of known disorders.

2. **Leveraging the pupillary database and ground truth to train new deep learning systems**

**capable of generalizing across different subjects.** By utilizing SOBEREYE's unparalleled dataset of 280,000+ pupillary recordings from over 10,000 individuals, OPTOVER-AI will develop cross-subject generalization models that overcome the limitations of current user-specific baseline requirements. These models will incorporate transfer learning techniques to adapt to individual variations while maintaining diagnostic accuracy across diverse populations.

3. **Training convolutional neural networks (CNNs) to detect anomalies from single images, eliminating the current requirement for dynamic data like pupillary response videos.** This objective represents a significant paradigm shift in ocular diagnostics, moving from temporal analysis to spatial pattern recognition [19]. By training specialized CNN architectures [20] on static pupillary images, the project aims to enable rapid screening without the need for extended recording sessions, dramatically increasing accessibility and deployment potential across various healthcare contexts.

The methodology incorporates the RAZOR method (Refining Accuracy by Zeroing Out Redundancies) [21] for data organization and anomaly pattern identification. This approach systematically eliminates redundant or non-informative features while preserving diagnostically relevant signals, enhancing both computational efficiency and anomaly detection precision. The RAZOR method employs iterative feature importance evaluation combined with domain-specific knowledge to optimize the signal-to-noise ratio in the final models. Initial validation will utilize existing ground truth labels in SOBEREYE's database, comprising thousands of annotated cases with verified neurocognitive states. This validation framework will be potentially supplemented by domain expert evaluations to identify subtler health anomalies related to ocular examination that may not be explicitly labeled in the current dataset. A multi-tier validation protocol will assess both technical performance metrics (sensitivity, specificity, AUC-ROC) and clinical utility measures through collaborations with healthcare professionals.

The implementation of OPTOVER-AI will proceed through two primary phases. The initial phase involves a comprehensive analysis of the state of the art and system architecture design. This includes conducting a systematic literature review examining recent advancements in ocular biomarkers, pupillary response analytics, and AI applications in diagnostic medicine, with particular attention to resilient AI methodologies. The research team will consult with stakeholders across multiple domains to establish clear performance targets for accuracy, speed, and usability. The architectural design will incorporate both on-device processing components and cloud-based infrastructure [22] with scalable computing resources for handling large-scale data processing tasks. The subsequent development and validation phase will focus on implementing the designed architecture, preparing data, integrating AI methodologies, and conducting rigorous system testing. A comprehensive MLOps framework [23] will be employed, incorporating automated model versioning, continuous integration pipelines, and non-regression tests [24]. The validation strategy will include unit tests [25] for individual components, integration tests for subsystem interactions, and end-to-end [26] system validation using holdout datasets. This approach ensures that iterative improvements in specific modules translate to overall system performance gains without compromising existing capabilities.

## 3. Innovative Aspects

OPTOVER-AI introduces several key innovations to the field of health monitoring. First, the integration of resilient AI techniques with ocular analysis enables the detection of not only neurocognitive states but also potentially systemic diseases. By expanding beyond pupillary reflex analysis to include other ocular components such as the iris and sclera, the system can detect a wider range of visual anomalies that might indicate more complex health conditions.

The elimination of user-specific baselines represents an additional significant advancement over existing technology, making the system more versatile and applicable across diverse populations without requiring lengthy individualized calibration. Furthermore, the potential ability to detect anomalies from single images rather than dynamic video data would significantly reduce computational requirements and increase accessibility of this technology [27].

Last, the non-invasive nature of the technology, coupled with its integration into common devices like smartphones, makes it an accessible and user-friendly solution for continuous health monitoring [1]. This facilitates both workplace safety applications and personal health management.

## 4. Expected Outcomes and Impact

OPTOVER-AI is expected to yield a modular and scalable architecture capable of identifying early alterations in health conditions through ocular image analysis. The project aims to produce a functional prototype incorporating machine learning algorithms for precise detection of visual anomalies associated with neurocognitive and systemic conditions.

The potential impact spans multiple domains. At the *individual* level, the technology promises improved workplace safety and quality of life through proactive, possibly remote, health monitoring. At the *societal* level, it may contribute to public health improvement and healthcare cost reduction through early detection and prevention.

The project aligns with the FAIR program objectives, particularly in Spoke 3 focusing on Resilient AI. By integrating advanced machine learning technologies applied to ocular analysis, OPTOVER-AI contributes to early detection of health alterations, thus improving well-being and public health. Moreover, the project will provide new benchmarks for testing and validating models developed within the FAIR project, contributing to enhancing the resilience and effectiveness of AI algorithms.

## 5. Ethical and Privacy Considerations

OPTOVER-AI adheres strictly to GDPR compliance, ensuring anonymity of collected and analyzed data. No clinical trials will be conducted during the project, and the existing SOBEREYE dataset does not include any personal identifiers. The non-invasive nature of ocular monitoring avoids risks to users' health, promoting well-being through early prevention of potential issues. Additionally, the project follows the Do No Significant Harm (DNSH) principle, ensuring environmental sustainability through the use of low-energy consumption devices and resource-efficient software architectures [28, 29].

## 6. Conclusions and Future Perspectives

OPTOVER-AI represents a significant step forward in ocular-based health monitoring technology, with potential applications in workplace safety, public health, and personal wellness. By leveraging artificial intelligence techniques with an extensive dataset of ocular measurements, the project aims to create a resilient system capable of detecting subtle changes that might indicate developing health issues. Future research directions could include the expansion of detectable conditions, integration with other health monitoring systems, and development of personalized intervention strategies based on detected anomalies. As the technology matures, it could become an integral component of preventive healthcare, contributing to earlier intervention and improved health outcomes across various populations. The project, currently at TRL 2 (*Technology Readiness Level 2: Concept and application formulation*), aims to reach TRL 3 (*Analytical experimentation and concept testing*) by its conclusion, setting the foundation for further development towards a commercial product that could significantly impact health monitoring practices globally.

## Acknowledgements

OPTOVER-AI is funded under Italy's National Recovery and Resilience Plan, Mission 4 "Education and Research" - Component 2 "From Research to Business" - Investment 1.3, financed by the European Union - NextGenerationEU - Code PE00000013_2.
This work has been partially supported by the Italian PNRR MUR project PE0000013-FAIR.

## Declaration on Generative AI

During the preparation of this work, the authors used Claude 3.7 Sonnet and Grammarly in order to: perform automated grammar and spelling checks; paraphrase and reword. After using these tools/services, the authors reviewed and edited the content as needed and take full responsibility for the publication's content.

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