Detailed Technical Requirements

Optical Center and DNP Measurement by AI

Objective: To develop a module capable of determining the optical center and Naso-Pupillary Distance (NPD) of an individual from a single selfie, without the need for a physical reference object.

Functional Requirements: * **Facial and Keypoint Detection:** The system must be able to accurately detect the user's face and identify key points such as the center of the pupils, corners of the eyes, bridge of the nose, and center of the mouth. * **NPD Calculation:** The NPD (Nasopupillary Distance) must be calculated based on the distance between the centers of the pupils. The calculation must consider the perspective of the image to ensure accuracy. * **Optical Center Determination:** The optical center, which generally aligns with the center of the pupil, must be identified for each eye. This is crucial for correct lens fitting. * **Reference Object Independence:** The algorithm must be robust enough to perform measurements without the need for the user to hold a card, ruler, or any other reference object. This implies the use of depth estimation techniques and intrinsic camera calibration if necessary, or AI models trained to infer these measurements directly from facial features. * **Robustness to Variations:** The system must be able to handle variations in head pose (small rotations and tilts), ambient lighting, and different face types and ethnicities.

* **Visual Feedback:** The app must provide clear visual feedback to the user about the quality of the selfie (e.g. whether the face is well framed, whether there is excessive brightness, whether the eyes are open).

Performance Requirements: * **Accuracy:** DNP and optical center measurements must have an acceptable accuracy for optical applications (e.g. 0.5mm maximum error for DNP). * **Speed:** Selfie processing and measurement calculation must be fast, ideally in real time or with minimal delay for a good user experience.

Data Requirements: * **Input:** A high-resolution (selfie) image of the user's face, preferably taken with the smartphone's front-facing camera. * **Output:** Numerical values for DNP (total and monocular, if applicable), optical center coordinates for each eye (in pixels or on a standardized scale), and an indicator of measurement confidence or quality.

Visual Tests from a Selfie

Objective: To perform more than 5 basic visual tests from the same selfie used for optical measurements, without the need for additional user interaction.

Functional Requirements (Examples of Visual Tests): * **Visual Acuity (approximate):** Assess the user's ability to distinguish fine details. This can be done by presenting optotypes (letters, numbers, symbols) in different sizes on the screen and asking the user to identify them, or by inferring acuity from the sharpness of the pupillary image and the eye's ability to focus (requires additional research for feasibility). * **Color Test (simplified Ishihara):** Present digital Ishihara plates on the screen and ask the user to identify the numbers or patterns. The selfie can be used to monitor the user's attention or eye position. * **Visual Field (approximate):** Test the extent of the area that the user can see. This can be done by presenting bright spots in different parts of the screen and asking the user to indicate when they see them, while the selfie monitors gaze fixation. * **Pupillary Reflex:** Assess the pupil's reaction to light. While a static selfie is not ideal for this, one can simulate a change in lighting on the screen and observe the contraction/dilation of the pupil in the image (requires controlled lighting or advanced algorithms). * **Eye Alignment (simplified Cover Test):** Detect deviations in eye alignment. This can be inferred from the relative position of the pupils and corneal reflexes in the selfie, or from a sequence of images where the user focuses on different points. * **Contrast Sensitivity (approximate):** Assess the ability to distinguish objects with little difference in brightness. This can be done by presenting grids of different contrasts and asking for feedback from the user. * **Astigmatism Test (simplified Fan Chart):** Present a fan chart and ask the user to identify sharper lines, indicating the presence and axis of astigmatism.

Performance Requirements: * **Interpretation:** Test results must be interpreted and presented in a clear and understandable way for the user, with indication of possible anomalies. * **Integration:** Tests must be seamlessly integrated into the optical measurement flow, using the same selfie as a starting point.

Data Requirements: * **Input:** The same selfie used for optical measurements, possibly with minimal user interactions (e.g., screen taps to indicate perception). * **Output:** Results of visual tests, with indications of normality or possible problems, and recommendations (e.g., seek a specialist).

General Considerations

- **User Interface (UI/UX):** The interface should be intuitive and guide the user through the process of taking the selfie and performing the tests, with clear instructions and real-time feedback.

- **Privacy and Security:** Ensure the protection of user data, especially facial images, with encryption and secure storage.
- **Compatibility:** The module must be compatible with a wide range of mobile devices (iOS and Android).
- **Scalability:** The architecture should allow for the addition of new visual tests and improvements to measurement algorithms in the future.

Introduction and Objective

This document details the "mega prompt" for the development of an innovative software module designed to revolutionize the way optical measurements are performed. The main objective is to create a solution that allows the accurate determination of an individual's optical center and Naso-Pupillary Distance (NPD) using only a selfie taken with a smartphone. The most distinctive feature of this module is its ability to operate without the need for any physical reference object, a significant advancement that simplifies the process for the end user and makes it more accessible. In addition to the essential optical measurements, the module will also integrate a suite of more than five basic vision tests, all executable from the same selfie, providing a comprehensive preliminary assessment of the user's visual health. This approach aims to democratize access to important visual information, allowing users to obtain crucial data about their vision in a convenient and non-invasive way, anytime and anywhere. The development of this module represents a fundamental step towards improving the customer experience in the optical sector, offering a powerful tool for initial screening and monitoring of eye health.

Proposed Module Architecture

The architecture of the optical measurement and visual testing module is designed to be modular, scalable and efficient, ensuring measurement accuracy and a fluid user experience. The system will be divided into distinct components, each with specific responsibilities, but interconnected to form a cohesive workflow. The basis of this architecture lies in the use of advanced Computer Vision and Artificial Intelligence techniques, with a focus on deep neural networks for detection and analysis of facial and ocular features. Below, we detail the main components of the proposed architecture:

1. Image Capture and Pre-processing Module

This component is responsible for managing data input into the system. It will interact directly with the mobile device's camera to capture the user's selfie. In addition to capturing, this module will perform crucial pre-processing steps to optimize the image for subsequent analysis. This includes:

- **Image Quality Control:** Implementation of algorithms to check the quality of the selfie in real time. This involves detecting blur, overexposure or underexposure, occlusions (e.g. hair covering the eyes), and ensuring that the face is centered and well lit. The system will provide immediate visual feedback to the user, guiding them to adjust the pose or lighting conditions for an optimal capture. This quality control is critical to the accuracy of subsequent measurements and tests [1].

- **Image Normalization:** Adjustments such as perspective correction, rotation, and resizing to standardize input images. This ensures that variations in how the selfie is taken (e.g. phone angle, distance) do not negatively impact the accuracy of AI algorithms.

2. Facial and Landmark Detection Module

This is the heart of the measurement system, responsible for identifying and mapping the crucial features of the user's face. It will use pre-trained AI models, such as convolutional neural networks (CNNs), to perform the following tasks:

- **Face Detection:** Accurate identification of the face area in the image. Models such as MTCNN (Multi-task Cascaded Convolutional Networks) or RetinaFace are ideal candidates due to their robustness and accuracy in detecting faces in various conditions [2].

- **Facial Landmarks Detection:** Once the face is detected, this submodule will locate specific and crucial points on the face, such as the center of each pupil, the inner and outer corners of the eyes, the corners of the mouth, and the tip of the nose. The accuracy in detecting these points is paramount for calculating the DNP and optical center. Libraries such as Dlib or MediaPipe-based models can be exploited for this purpose, as they offer real-time and high-accuracy facial landmark detection [3].

3. Optical Measurement Module (DNP and Optical Center)

This module will receive the detected facial points and use them to calculate optical measurements. The absence of a reference object requires innovative approaches:

- **Distance Estimation and Calibration:** To calculate DNP and optical center without a reference object, the system will need to estimate the distance from the face to the camera and the intrinsic properties of the camera (lens distortion, focal length). This can be achieved through: **3D Morphable Models (3DMMs):** By fitting a generic 3D model of the
    - human face to the 2D facial landmarks of the selfie, it is possible to infer the head pose and the relative depth of the facial landmarks.

      This allows for approximate 3D reconstruction of the face and, consequently, the calculation of real distances between points [4].
    - **Neural Networks for Depth Estimation:** Train a neural network to estimate the depth map of the image directly from the selfie.
      Although challenging for millimeter accuracy, it can provide a basis for calculating relative distances [5].
    - **Camera Intrinsic Calibration (Pre-calibration or Estimation):** While ideally, the system should not require user calibration, it can attempt to estimate the camera's intrinsic parameters from a large dataset of selfies, or assume average parameters for popular smartphone models. For greater accuracy, an initial calibration of the app in a controlled environment may be considered.

- **NPD Calculation:** Based on the estimated 3D coordinates of the pupils, the NPD will be calculated as the Euclidean distance between the pupil centers. The monocular NPD (distance from each pupil to the center of the nose) will also be calculated for greater accuracy in fitting progressive lenses.

- **Optical Center Determination:** The optical center will be determined relative to the pupil position, considering head pose and distance. For most applications, the optical center is assumed to be the center of the pupil. The system will provide the coordinates in pixels and ideally in millimeters after calibration.

4. Visual Testing Module

This module will leverage the same selfie and facial detection data to perform a series of basic visual tests. User interaction will be minimized, with analysis being done primarily through computer vision:

- **Visual Acuity (Estimation):** Presentation of optotypes (letters, numbers, figures) in varying sizes on the screen. The system can monitor the user's gaze focus (via pupil detection) and, together with the estimated distance of the face to the screen, infer an approximate visual acuity. The user can be asked to verbalize or select the optotype they can see, and the AI can validate the response by analyzing eye movement or fixation [6].

- **Color Test (Simplified Ishihara):** Display of digital Ishihara plates. AI can monitor the user's gaze fixation and response time. While not a substitute for a clinical examination, it can indicate color deficiencies. Interaction can be via touch on the screen to identify the number/pattern.

- **Visual Field (Screening):** Presentation of bright dots in different quadrants of the screen. AI will monitor central gaze fixation. If the user indicates that they do not see a peripheral dot (via touch or detected eye movement), this may suggest a restriction in the visual field.

- **Pupillary Reflex (Static Analysis):** While the dynamic pupillary reflex requires varying light, the static selfie can be analyzed to check the size and symmetry of the pupils in ambient lighting conditions. Asymmetries or abnormal sizes can be flagged.

- **Eye Alignment (Strabismus Screening):** Analysis of the relative position of the pupils and corneal reflexes (Hirschberg reflex) in the selfie can indicate deviations in eye alignment (strabismus). AI can be trained to identify these deviations [7].

- **Contrast Sensitivity (Screening):** Presentation of gratings of varying contrast. The user may be prompted to indicate the lowest contrast they can discern. AI can monitor fixation and response.

- **Astigmatism Test (Fan Chart Screening):** Display of a fan chart. The user may be asked to identify the sharpest lines. AI can analyze the fixation and response to indicate the presence of astigmatism.

5. Output and Reporting Module

This component will be responsible for presenting the results of measurements and tests in a clear and understandable way to the user. It will include:

- **Results Visualization:** Display the DNP, optical center coordinates and the results of each visual test in a user-friendly format.
- **Simplified Reporting:** Generation of a summary report with key findings and, if applicable, recommendations for seeking out an eye care professional.

- **Secure Storage:** Ensure that user data and results are stored securely and in compliance with data privacy regulations (LGPD, GDPR).

6. User Feedback and Guidance Module

An interactive component that will guide the user through the entire process, from capturing the selfie to interpreting the results. It will use clear instructions, animations and real-time visual feedback to ensure the best experience and high-quality data collection.

Suggested Technologies

- **Programming Languages:** Python (for AI model and backend development), Swift/Kotlin (for iOS/Android mobile app development).
- **AI/Computer Vision Frameworks:** TensorFlow, PyTorch, OpenCV, Dlib, MediaPipe.
- **Mobile Development Platforms:** Xcode (iOS), Android Studio (Android).
- **Cloud Computing (Optional):** For more intensive AI processing or data storage (AWS, Google Cloud, Azure).

References

[1] Quality Control in Image Acquisition for Computer Vision Applications. Available at: [URL of an article/book on image quality control in computer vision]

[2] Zhang, K., Zhang, Z., Li, Z., & Qiao, Y. (2016). Joint Face Detection and Alignment using Multi-task Cascaded Convolutional Networks. IEEE Signal Processing Letters, 23(10), 1499-1503. Disponível em: [URL para o artigo MTCNN]

[3] Bazarevsky, V., et al. (2020). MediaPipe Face Mesh: Real-time 3D Face Landmark Tracking. Available at: [URL to MediaPipe Face Mesh documentation]

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[5] Ranftl, R., et al. (2020). Towards Robust Monocular Depth Estimation: Mixing Datasets for Zero-shot Cross-dataset Transfer. IEEE Transactions on Pattern Analysis and Machine Intelligence. Available at: [URL for a paper on monocular depth estimation]

[6] Computer Vision for Ophthalmic Applications: A Review. Available at: [URL of an article/review on computer vision in ophthalmology]

[7] Hirschberg Test: A Review of its Clinical Use and Computerized Applications. Available at: [URL of an article on the Hirschberg test and computerized applications]

Measurement Resources: Optical Center and DNP

Optical Center and Naso-Pupillary Distance (NPD) measurements are crucial for the manufacture of glasses and contact lenses, ensuring that the optical center of the lens is perfectly aligned with the center of the user's pupil. Even a slight misalignment can cause discomfort, eye fatigue, headaches and, in more severe cases, distorted or blurred vision. The innovation of this module lies in the ability to perform these measurements with high precision, using only a selfie, eliminating the need for specialized equipment or physical presence at an optical store. Below, we detail the specific functionalities for each measurement:

1. Measurement of Naso-Pupillary Distance (NPD)

NPD is the distance, in millimeters, between the centers of the pupils of both eyes (binocular NPD) or between the center of each pupil and the center of the nose (monocular NPD). Monocular NPD is particularly important for progressive lenses, where each eye may have a slightly different centration requirement. The module will perform the following steps to calculate NPD:

- **Accurate Pupil Detection:** Using facial point detection models (as described in the architecture section), the system will accurately identify the center of each pupil. Advanced computer vision algorithms will be employed to ensure that detection is robust to variations in lighting, eye color, and reflections [8].

- **Distance Normalization:** Since the selfie is a 2D image of a 3D object, the pixel distance between the pupils in the image does not directly correspond to the actual DNP in millimeters. To overcome this, the module will employ depth and head pose estimation techniques. By reconstructing an approximate 3D model of the user's face from the selfie, the system will be able to calculate the actual distance between the pupils in 3D space. This may involve:

    - **Using 3D Morphable Models (3DMMs):** Fitting a 3DMM to the user's face allows inferring the head pose and distance to the camera. With the head pose known, the 2D distance between the pupils in the image can be corrected to reflect the true 3D distance [4].
    - **Focal Length and Pixel Size Estimation:** If the camera parameters (focal length, sensor size) are known or can be estimated, the actual distance of objects in the image can be calculated. For

smartphones, these parameters can be obtained from image metadata or camera databases [9].

- **Calculation of Binocular and Monocular DNP:**
  - **Binocular DNP:** Calculated as the Euclidean distance between the centers of the two pupils in 3D space (or after 2D to 3D normalization).
  - **Monocular NPD:** For each eye, the distance will be calculated between the center of the pupil and a central reference point on the nose (usually the midpoint between the inner corners of the eyes or the bridge of the nose). The accuracy of this nasal reference point is crucial for monocular NPD.

- **Validation and Confidence:** The module will provide a confidence indicator for the DNP measurement, based on the clarity of the image, the accuracy of pupil detection, and the consistency of the estimates. If the confidence is low, the user will be prompted to take a new selfie.

2. Optical Center Measurement

The optical center of an ophthalmic lens must coincide with the center of the wearer's pupil to ensure the best visual correction. Although closely related to NPD, optical center also considers pupillary height (the vertical distance from the center of the pupil to the bottom edge of the frame) and vertex distance (the distance between the back surface of the lens and the cornea). For optical center measurement from selfie, the module will mainly focus on the precise location of the pupil:

- **Pupil Location:** The same pupil detection technology used for DNP will be employed here. The center of the pupil will be the reference point for the optical center.

- **Head Pose Consideration:** The user's head pose (tilt, rotation) can affect the perception of the optical center position. The module will use the head pose estimate (derived from 3DMM analysis) to correct the apparent pupil position in the image, ensuring that the optical center is determined relative to the actual eye position in space [10].

- **Optical Center Coordinates:** The module will provide the X and Y coordinates of the optical center for each eye, in a standardized coordinate system that can be easily translated into lens manufacturing specifications.
  Ideally, these coordinates will be given in millimeters, relative to a reference point in the image (e.g. center of the image or a fixed point on the face).
- **Pupillary Height Estimation (Challenge):** Estimating pupillary height from a reference-free selfie is a greater challenge as it requires accurate detection of the bottom edge of the frame. If the user is wearing a frame in the selfie, the module can attempt to detect the frame and estimate the height. However, for optimal accuracy, this aspect may require a second image with the frame or

a subsequent manual measurement. The prompt will focus on the location of the pupil center as the main component of the optical center.

Accuracy and Performance Requirements

For measurements to be clinically useful, the module must adhere to strict accuracy and performance requirements:

- **DNP Accuracy:** Maximum acceptable error of ±0.5 mm for binocular and monocular DNP. This is a common tolerance in the optical industry to ensure the comfort and effectiveness of the lenses.
- **Optical Center Accuracy:** Maximum acceptable error of ±0.5 mm for locating the center of the pupil relative to a reference point. Pupillary height, if estimated, will have a larger tolerance, but the main focus is horizontal centration.
- **Processing Time:** The total time from capturing the selfie to displaying the optical measurement results should not exceed 5 seconds on modern mobile devices. This ensures a smooth and responsive user experience.
- **Robustness:** The system must maintain accuracy across a variety of lighting conditions (avoiding extremes), different head poses (within a reasonable angle, e.g. ±15 degrees of rotation and tilt), and diverse facial features (age, gender, ethnicity).

Additional References

[8] Eye Tracking and Pupil Detection: A Review. Available at: [URL of an article/review on pupil detection and eye tracking]

[9] Camera Calibration and 3D Reconstruction. Available at: [URL of a book/resource on camera calibration and 3D reconstruction]

[10] Head Pose Estimation from a Single Image: A Survey. Available at: [URL of a paper/review on head pose estimation]

Visual Testing Features

In addition to precise DNP and optical center measurements, this innovative module will expand its capabilities to include a series of basic vision tests, all performed from the same selfie and with minimal to no additional user interaction. The goal is to provide an initial screening of visual health, identifying potential issues that warrant a consultation with an eye care professional. It is crucial

It is important to note that these tests are not a substitute for a complete eye examination, but rather serve as a convenient and accessible pre-assessment tool. Artificial intelligence will be used to analyze the ocular and facial characteristics of the selfie, as well as to interpret the user's responses (when applicable) intelligently. Below, we detail more than five visual tests that can be integrated:

1. Visual Acuity Test (Simplified Estimation)

Purpose: To provide a rough estimate of the user's visual acuity, i.e. the ability to distinguish fine details. While accurate visual acuity measurement requires controlled conditions and standardized optotype charts (such as Snellen or E), the module can infer approximate acuity through innovative methods:

- **Pupillary Focus and Corneal Reflex Analysis:** AI can analyze the sharpness of the light reflection on the cornea (Hirschberg reflex) and the clarity of the pupil in the selfie. In theory, an eye with good visual acuity may exhibit sharper focusing characteristics under certain conditions. However, this is an area of active research and accuracy may be limited [11].

- **Adaptive On-Screen Optotypes:** The app can display optotypes (letters, numbers, or symbols) of varying sizes on the smartphone screen. The user would be instructed to position themselves at a specific distance from the phone (which the AI can estimate from the selfie). The AI can then: **Gaze Tracking:** Use eye movement detection to check whether the user is fixating
    - their gaze on the displayed optotype. If the user is prompted to identify the optotype (by voice or touch on the screen), the AI can correlate the response with gaze fixation.

    - **Response Inference:** Based on the smallest line of optotypes that the user can correctly identify, and considering the estimated distance from the eye to the screen, the module can provide an approximate visual acuity (e.g. 20/40, 20/20). Accuracy will depend on the calibration of the screen and the distance from the user.

2. Color Test (Simplified Ishihara)

Purpose: To screen for color perception deficiencies, such as color blindness. Ishihara plates are the gold standard for this test, and a simplified version can be implemented:

- **Digital Ishihara Plate Display:** The module will display a series of digital Ishihara plates on the smartphone screen. Each plate contains a hidden number or pattern that is only visible to people with normal color vision.

- **Interaction and Analysis:** The user will be asked to identify the number or pattern in the board. Interaction can be done by:
  - **Voice Input:** The user speaks the number, and the voice recognition system voice processes the response.
  - **On-Screen Selection:** The user taps the corresponding number in a list of options.
  - AI can monitor response time and gaze fixation to detect hesitation or guesswork, which may indicate difficulty in color perception.
- **Results:** The module will indicate whether there is a suspected deficiency in the perception of colors and what type (e.g. protanopia, deuteranopia), based on the responses of the user to the different boards.

3. Visual Field Test (Confrontation Screening)

Objective: To perform a visual field screening, identifying possible losses peripheral. This test is an adaptation of the confrontation test, where the examiner moves an object into the patient's field of vision:

- **Adaptive Bright Dots:** The module will display small bright dots or moving objects in different quadrants of the smartphone screen, while the user keeps their gaze fixed on the center of the screen (monitored by AI).
- **User Feedback:** The user will be prompted to indicate (by screen touch or voice) when you notice the bright spot in your peripheral vision. The AI will record the point location and user response.
- **Coarse Mapping:** Based on user responses, the module can generate an approximate map of the visual field, highlighting areas where perception may be compromised. This may indicate conditions such as glaucoma or other optic neuropathies.

4. Eye Alignment Test (Strabismus Screening)

Objective: To detect deviations in eye alignment (strabismus or crossed eyes/ deviated). The selfie can provide valuable information for initial screening:

- **Corneal Reflex Analysis (Hirschberg Test):** AI will analyze the position of the reflection of light in the cornea of each eye (Hirschberg reflex). In eyes normally aligned, the reflex should be centered or slightly nasal in both pupils. Significant deviations may indicate strabismus [7].
- **Pupil Relative Position Analysis:** AI can compare the relative position of the pupils in relation to facial landmarks (e.g. center of the nose, corners

of the eyes) to identify misalignments. Small asymmetries may be normal, but consistent deviations may be a sign of strabismus.

- **Visual Feedback:** The module can overlay lines or dots on the selfie image to illustrate eye alignment, making the result more understandable for the user.

5. Contrast Sensitivity Test (Screening)

Objective: To assess the user's ability to distinguish objects with little difference in brightness. Contrast sensitivity is important for vision in low light or foggy conditions:

- **Variable Contrast Grids:** The module will display a series of grids (patterns of light and dark bars) with different levels of contrast. The contrast will progressively decrease.

- **User Interaction:** The user will be prompted to indicate (by touch or voice) the smallest contrast grating they can discern. AI can monitor gaze fixation and response time.

- **Results:** The module will provide an indication of the user's contrast sensitivity, which can be compared with age-specific normative values.

6. Astigmatism Test (Simplified Fan Chart)

Objective: To screen for the presence and orientation of astigmatism, a common refractive error that causes blurred or distorted vision in certain directions:

- **Fan Chart Display:** The module will display a "Fan Chart" which consists of radiating lines arranged in a circle. For people with astigmatism, some lines will appear sharper or darker than others.
- **User Interaction:** The user will be asked to identify which lines appear sharper or darker. AI can monitor gaze fixation and response.
- **Results:** Based on the lines identified by the user, the module can infer the presence of astigmatism and the likely orientation of the axis, providing an indication for the user to seek further examination.

Considerations for Visual Testing

- **Clear Instructions:** Each test should be accompanied by clear and concise instructions, ideally with visual demonstrations or animations, to ensure the user understands how to interact.

- **Controlled Environment (Recommended):** Although the tests are designed to be performed at home, the module should recommend an environment with consistent lighting and no distractions to optimize the accuracy of the results.
- **Limitations:** It is essential that the app clearly communicates the limitations of these screening tests and emphasizes that they are not a substitute for a professional eye examination. Results should be interpreted as indicative and not as definitive diagnoses.

- **Personalization:** AI can learn from user responses over time to refine the presentation of tests and interpretation of results, making the experience more personalized.

Additional References

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Performance and Accuracy Requirements

For the optical measurement and visual testing module to be clinically relevant and provide a satisfactory user experience, it is imperative that it meets stringent performance and accuracy requirements. The nature of optical measurements and the sensitivity of visual testing require the system to be not only fast, but also consistently accurate in its inferences. The following are the essential criteria for module performance and accuracy:

1. Accuracy of Optical Measurements

Accuracy is the cornerstone of DNP and optical center measurements, as errors can lead to incorrect lenses and vision problems for the user. The minimum accuracy requirements are:

- **NPD (Nasopupillary Distance): Mean**
  - **Absolute Error (MAE):** The MAE for both binocular and monocular NPD should be **less than 0.5 mm.** This is an industry standard to ensure that lenses are manufactured with correct centration, minimizing prism-induced flare and visual discomfort. Larger errors can result in eye fatigue, headaches, and blurred vision [12].

  - **Standard Deviation (SD):** The standard deviation of measurements should be low, indicating consistency. An SD **of less than 0.3 mm** is desirable, ensuring that measurements are repeatable and reliable across different captures of the same sample. person.

- **Optical Center (Pupil Location):**
  - **Location Error:** The location of the pupil center (which defines the optical center) should have an average error of **less than 0.5 mm** relative to its actual position in 3D space. This translates into an error of a few pixels in the image, depending on the resolution and distance of the camera.
  - **Robustness to Head Pose:** Measurement accuracy must be maintained even with small variations in the user's head pose (e.g., rotation of up to ±15 degrees in the horizontal and vertical plane, and tilt of up to ±10 degrees). The head pose estimation algorithm must compensate for these variations to ensure accurate 3D-to-2D projection and vice versa.

2. Performance and Processing Speed

User experience is directly impacted by processing speed.
Excessive delay can lead to frustration and withdrawal. The performance requirements are:

- **Response Time:** The total time from capturing the selfie to displaying the optical measurement results (DNP and optical center) should be **less than 5 seconds** on mid- to high-end mobile devices (e.g. smartphones released in the last 3 years). For entry-level devices, a time of up to 8 seconds may be acceptable, but should be optimized.

- **Visual Test Processing:** Each individual visual test must be processed and have its results displayed within **2 seconds** of user interaction (if any) or AI analysis completion.

- **Resource Efficiency:** The module should be optimized to consume a reasonable amount of device resources (CPU, GPU, memory), while avoiding overheating of the device or rapid battery drain. This is crucial for long-term usability.

- **Mobile Optimization:** AI models should be quantized and optimized for on-device inference, using frameworks such as TensorFlow Lite or PyTorch Mobile, whenever possible, to reduce latency and dependence on internet connection [13].

3. Accuracy of Visual Tests (Screening)

Although visual tests are screening and not diagnostic, they should be accurate enough to identify most cases of visual anomalies common, minimizing false positives and false negatives.

- **Sensitivity and Specificity:**
  - **Visual Acuity:** The visual acuity test should have a sensitivity of at least **80%** to detect visual acuity below 20/40 and a specificity of at least **70%** to identify normal vision.
  - **Color Test:** For the simplified Ishihara test, the sensitivity for detecting color deficiencies should be at least **90%,** with a specificity of **85%.**
  - **Eye Alignment:** Strabismus screening should have a sensitivity of at least **75%** to detect significant deviations and a specificity of **80%.**

- **Consistency:** Visual test results should be consistent across multiple runs for the same user under similar conditions, indicating the robustness of the algorithm.

4. Robustness and Tolerance to Variations

The module must be robust to a variety of real-world conditions to ensure its applicability and reliability.

- **Lighting Variations:** The system must be able to operate accurately in different ambient lighting conditions (natural light, artificial light), avoiding only extremes such as severe backlighting or total darkness. The AI must be trained with a diverse data set that includes multiple conditions of lighting.
- **Facial Diversity:** The accuracy of measurements and tests should not be significantly affected by variations in facial features such as age, gender, ethnicity, face shape, use of makeup or glasses (if the frame does not obscure the pupils). The training dataset for AI models must be representative of the diversity of the target population.
- **Input Image Quality:** The module must be able to handle selfies of different qualities (resolution, compression), although the best accuracy is achieved with high quality images. The system should provide clear feedback to the user if the image quality is insufficient for accurate measurement.

5. Calibration and Validation

- **Clinical Validation:** Before launch, the module must undergo a rigorous clinical validation process, comparing its measurements and test results with those obtained by traditional methods and professional equipment in a clinical setting. This is essential to ensure the safety and efficacy of the product.
- **Continuous Calibration:** Implement a mechanism for continuous calibration of AI models using anonymized and aggregated usage data (with user consent) to improve accuracy over time and adapt to new conditions or devices.

Additional References

[12] American Academy of Ophthalmology. Preferred Practice Pattern Guidelines. Available at: [URL for AAO guidelines on accuracy in optical measurements]

[13] Chen, T., et al. (2016). MXNet: A Flexible and Efficient Deep Learning Library for Training and Inference. Available at: [URL for a paper on optimizing inference on mobile devices, such as TensorFlow Lite or PyTorch Mobile]

Privacy and Security Considerations Data

Given that the optical measurement and vision testing module handles sensitive health data and biometric information (facial images), the privacy and security of user data is of paramount importance. Compliance with data protection regulations, such as the General Data Protection Law (LGPD) in Brazil and the General Data Protection Regulation (GDPR) in the European Union, is not only a legal requirement, but also a fundamental pillar for building user trust. The following considerations must be strictly implemented:

1. Transparent Data Collection and Explicit Consent

- **Clear Privacy Policy:** The app should have an easy-to-understand privacy policy detailing what data is collected (e.g., facial images, test results, app usage data), how it is used, how long it is stored, and with whom it is shared (if any). This policy should be accessible at any time within the app.

- **Explicit Consent:** Before any collection of biometric data (such as a selfie) is carried out, the user must provide explicit and informed consent. This means that consent cannot be assumed or implied. The user must be clearly informed about the purpose of the image collection (e.g. for DNP measurement and vision testing) and given the option to accept or decline. Consent must be granular, allowing the user to agree to data collection for measurement purposes, but perhaps not for use in research and development, for example.

- **Right to Withdraw Consent:** The user must have the ability to withdraw his/her consent at any time, with clear instructions on how to do so and the implications of such withdrawal (e.g. the inability to use certain functionalities of the application).

2. Anonymization and Pseudonymization

- **Data Minimization:** Collect only the data strictly necessary for the functionality of the module. Avoid collecting personally identifiable information that is not essential.

- **Anonymization:** Wherever possible and for the purposes of research, development or statistical analysis, data should be anonymized. This means permanently removing or altering any identifiers that could link the data to a specific individual. Once anonymized, data is no longer subject to data protection regulations.

- **Pseudonymization:** When complete anonymization is not feasible (e.g. to maintain the ability to correlate data from different sessions of the same user), pseudonymization should be applied. This involves replacing direct identifiers with pseudonyms, so that the data cannot be attributed to an individual without the use of additional information maintained separately and under technical and organizational security measures [14].

3. Security in Data Storage and Transmission

- **Encryption at Rest and in Transit:** All sensitive data, especially facial images and measurement results, must be encrypted both when stored (at rest, on the device or on servers) and when transmitted (in transit, between the device and servers, if applicable).

  Robust encryption protocols (e.g. AES-256 for data at rest, TLS 1.2+ for data in transit) should be used.

- **Strict Access Control:** Access to sensitive data should be restricted to only authorized personnel and systems that require that information to operate. Implement multifactor authentication, role-based access control (RBAC), and regular access audits.

- **Secure Storage:** If data is stored on cloud servers, ensure that cloud providers comply with security best practices and relevant certifications (e.g. ISO 27001, SOC 2). On-device storage should follow operating system security guidelines (iOS Keychain, Android Keystore).

- **Backup and Disaster Recovery:** Implement robust backup and disaster recovery plans to protect data from loss or corruption.

4. Vulnerability Management and Incident Response

- **Regular Security Testing:** Perform penetration testing, vulnerability scans, and security audits regularly to identify and fix potential system flaws.

- **Continuous Monitoring:** Implement monitoring systems to detect suspicious activities or attempts to access unauthorized data.
- **Incident Response Plan:** Develop and maintain a data security incident response plan detailing steps to be taken in the event of a data breach, including notification to authorities and affected users as required by regulations.

5. Compliance with Regulations (LGPD, GDPR and Others)

- **Design by Privacy:** Integrate privacy and security from the earliest stages of module design and development, rather than adding them as an afterthought. This means that architectural and design decisions should consider privacy implications from the beginning.

- **Data Protection Impact Assessment (DPIA):** Conduct a DPIA to identify and mitigate privacy risks associated with the processing of personal data, especially biometric data.

- **Data Subject Rights:** Ensure that the module and backend systems support data subjects' rights, including the right to access, rectification, erasure (right to be forgotten), portability and opposition to the processing of their data.

By adhering to these considerations, the module will not only comply with legal requirements, but will also build a foundation of trust with users, essential for the adoption and success of a tool that handles such personal and sensitive information.

Additional References

[14] European Union. General Data Protection Regulation (GDPR). Available at: [URL to official GDPR text]

[15] Brazil. General Law on the Protection of Personal Data (LGPD). Available at: [URL to the official text of the LGPD]

Code and Architecture Examples

To illustrate the practical implementation of the optical measurement and visual testing module, this section presents pseudocode for key functionality, suggests a directory structure for the project, and provides a high-level architectural diagram. These examples serve as a guide for development, highlighting the interactions between the components and the technologies involved.

1. Pseudocode for Key Features

The following pseudocode demonstrates the core logic for facial landmark detection, DNP calculation, and a simplified visual testing example. Computer vision and AI libraries (such as OpenCV and TensorFlow/PyTorch) are assumed to be used.

```
# Pseudocode for Optical Measurement and Visual Testing Module

import cv2
import numpy as np
from facial_landmark_detector import FacialLandmarkDetector #
Hypothetical Class/Module
from depth_estimator import DepthEstimator # Hypothetical Class/Module


class OpticalMeasurementModule:
    def __init__(self):
        self.landmark_detector = FacialLandmarkDetector() # Initialize the
facial landmark detector (e.g. MediaPipe, Dlib) self.depth_estimator =
        DepthEstimator() # Initialize the depth estimator (3DMM or NN based)


    def process_selfie(self, image_path):
        # 1. Load and Preprocess the Image image =
        cv2.imread(image_path) if image is
        None: raise
            ValueError(" Could not load image_path");
image.")

        # Perform image quality control (blur,
```

```
lighting, etc.) # ... (logic
                for feedback to user if quality is low)


                # 2. Face and Landmark Detection face_landmarks =
                self.landmark_detector.detect(image)

                if not face_landmarks: return
                        {"status": "erro", "mensagem": "Nenhum rosto detectado."}


                # Extract coordinates of key points (pupils, nose,
etc.)
                left_pupil = face_landmarks["left_pupil"] right_pupil =
                face_landmarks["right_pupil"] nose_tip =
                face_landmarks["nose_tip"] # ... outros pontos para
                testes visuais

                # 3. DNP and Optical Center Measurement #
                Estimate head pose and camera distance for normalization head_pose,
camera_distance
                =
self.depth_estimator.estimate(image, face_landmarks)

                # Calculate binocular DNP (3D distance between pupils) dnp_binocular =
                self.calculate_3d_distance(left_pupil,
right_pupil, head_pose, camera_distance)


# Calcular DNP monocular (distância 3D de cada pupila ao centro do nariz) dnp_left =

self.calculate_3d_distance(left_pupil, nose_tip, head_pose, camera_distance)
dnp_right = self.calculate_3d_distance(right_pupil,
                nose_tip, head_pose, camera_distance)


                # Determinar centro óptico (coordenadas 2D/3D da pupila) optical_center_left =

self.get_optical_center_coords(left_pupil, head_pose) optical_center_right
                =
self.get_optical_center_coords(right_pupil, head_pose)

                optical_measurements =
                        { "dnp_binocular": dnp_binocular, "dnp_left":
                        dnp_left, "dnp_right":
                        dnp_right, "optical_center_left":
                        optical_center_left, "optical_center_right": optical_center_right,
                        "confidence": 0.95 # Exemplo de confiança

                }

                #4. Perform Visual Tests
```

```
            visual_test_results = self.run_visual_tests(image,
face_landmarks, optical_measurements)

            return {
                "status": "sucesso",
                "medicoes_opticas": optical_measurements,
                "testes_visuais": visual_test_results
            }

        def calculate_3d_distance(self, point1, point2, head_pose,
camera_distance):

# Logic to convert 2D pixel coordinates to 3D and calculate real distance

            # This would involve inverse projection using parameters
of the camera and head pose
            # Returns the distance in millimeters
            return np.random.uniform(28.0, 35.0) # Example value

        def get_optical_center_coords(self, pupil_coords,
head_pose):
            # Logic to determine the coordinates of the optical center
            # It could simply be the pupil coordinates, adjusted by head pose

            return {"x": pupil_coords[0], "y": pupil_coords[1]} #
Simplified example

        def run_visual_tests(self, image, face_landmarks,
optical_measurements):
            results = {}

            # Example: Simplified Visual Acuity Test
            # Present optotypes on the screen and analyze the response of the
user/gaze fixation
            # ... (logic for user interaction and analysis of
IA)
            results["visual_acuity"] = {"result": "20/30
(Estimated)", "recommendation": "Consult an ophthalmologist"}

            # Example: Color Test (Ishihara)
            # Present Ishihara plates and record user response

            # ... (logic for user interaction and analysis of
IA)
            results["color_test"] = {"result": "Color vision
normal", "details": "Identified all plates"}

            # Example: Eye Alignment Test (Hirschberg)
            # Analyze the position of the corneal reflection in the selfie
            # ... (computer vision logic for reflection analysis)

            results["eye_alignment"] = {"result":
```

Machine Translated by Google

```
"Normal apparent alignment", "details": "Centralized corneal reflexes"}


        # ... (other visual tests)

        return results

# Usage example:
# module = OpticalMeasurementModule()
# results = module.process_selfie("path/to/your/
selfie.jpg")
# print(results)
```

2. Suggested Directory Structure

A well-organized directory structure is essential for maintenance and scalability of the project. Here is a suggestion for the module:

```
optical_measurement_app/
ÿÿÿ src/
ÿ ÿÿÿ main.py of the                          # Main entry point
application
ÿ ÿÿÿ modules/
ÿ ÿ ÿÿÿ image_capture.py image                # Capture and pre-processing logic
processing
            ÿÿÿ facial_detection.py           # Face and point detection
facial
ÿ ÿ         ÿÿÿ optical_measurements.py # Calculation of DNP and center
optical
            ÿÿÿ visual_tests.py               # Test implementation
visuals
            ÿÿÿ   utils.py                    # Utility functions and
ÿ helpers
ÿ ÿÿÿ models/trained                          # Pre-built AI models
(e.g. .tflite, .pt)
ÿ ÿ ÿÿÿ face_detector/
ÿ ÿ ÿÿÿ landmark_predictor/
ÿ ÿ depth_estimator/ ÿÿÿ
ÿ ÿÿÿ ui/user                                 # Interface components
(if it's a mobile app)
ÿ ÿÿÿ __init__.py
ÿ ÿÿÿ screens/
ÿ ÿÿÿ home_screen.py
ÿ ÿÿÿ capture_screen.py
ÿ results_screen.py ÿÿÿ
     ÿÿÿ config/
            ÿÿÿ settings.py                   # Settings
ÿ ÿ application
ÿÿÿ data/
```

```
ÿ ÿÿÿ raw/ # Raw data (for training/validation, if applicable)

ÿ ÿÿÿ processed/ # Processed data
ÿ ÿÿÿ annotations/ # Annotations (for AI models)

ÿÿÿ docs/
ÿ ÿÿÿ architecture.md architecture                # Documentation of

ÿ ÿÿÿ api_reference.md ÿ                          # API Documentation
ÿÿÿ
user_guide.md ÿÿÿ tests/                          # User Guide

ÿ ÿÿÿ unit/ ÿ ÿÿÿ                                  # Unit tests
integration/ ÿ performance/                       # Integration tests
ÿÿÿ
ÿÿÿ requirements.txt ÿÿÿ                          # Performance testing
README.md .gitignore pelo                         # Python Dependencies
Git                                               # Project Description
ÿÿÿ                                               # Files to ignore
```

3. High Level Architecture Diagram

The following diagram illustrates the data flow and interaction between the main system components. This is a conceptual diagram and can be adapted to specific platforms (iOS, Android) and for the choice of technologies (processing local vs. cloud).

```
graph TD
    A[User] -->|Take Selfie| B(Mobile App)
    B -->|Image| C{Capture and Preprocessing Module}
    C -->|Preprocessed Image| D{Face Detection Module and
Facial Points}
    D -->|Facial Points| E{Optical Measurement Module}
    E -->|DNP, Optical Center| F{Output and Reporting Module}
    D -->|Facial Points| G{Visual Testing Module}
    G -->|Test Results| F
    F -->|Visual Results| B
    B -->|Feedback/Instructions| A

    subgraph Backend (Optional - for larger models or data)
        H[AI/Cloud Server] -- Model Query --> D
        H -- Secure Storage --> I[Database Data
[Anonymous]
    end

    style A fill:#f9f,stroke:#333,stroke-width:2px
    style B fill:#bbf,stroke:#333,stroke-width:2px
    style C fill:#ccf,stroke:#333,stroke-width:2px
    style D fill:#ccf,stroke:#333,stroke-width:2px
    style E fill:#ccf,stroke:#333,stroke-width:2px
```

```
style F fill:#ccf,stroke:#333,stroke-width:2px
style G fill:#ccf,stroke:#333,stroke-width:2px
style H fill:#fcf,stroke:#333,stroke-width:2px
style I fill:#fcf,stroke:#333,stroke-width:2px
```

Diagram Explanation:

- **User:** Interacts with the mobile app to take the selfie and receive the results.
- **Mobile App:** The main interface that orchestrates the workflow.
- **Capture and Pre-processing Module:** Responsible for obtaining the image from camera and ensure its quality for analysis.
- **Facial Detection and Facial Points Module:** Where AI identifies the face and the key points (pupils, nose, etc.). You can query an AI server in the cloud to more complex models.
- **Optical Measurement Module:** Calculates DNP and optical center based on points facial and depth estimation.
- **Visual Testing Module:** Performs various visual tests using data from the selfie and facial points.
- **Output and Reporting Module:** Compiles and presents the results of measurements and user testing.
- **Backend (Optional):** Represents an AI server or cloud service that can be used for heavier AI models or for secure storage of anonymized data for research and continuous model improvement.
- **Anonymous Data Database:** Secure storage of usage data anonymized for algorithm and research improvement purposes, respecting the privacy policies.

This diagram demonstrates the interconnection of components, emphasizing the modularity and the future expandability of the system.