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PROJECT OUTLINE AND EXECUTION PLAN (PROOF OF CONCEPT): SLIP LAMP OBSERVER VIEW RECORDING SYSTEM

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1. Executive Summary

This document describes a phased proof-of-concept project to explore the feasibility of a low-cost, removable camera system capable of recording video through the observer monocular of an ophthalmic slit lamp. The intent is to capture exactly what the clinician sees during examination, enabling video documentation, teaching, and specialist communication using readily available components.

The project deliberately focuses on technical feasibility, usability, and image adequacy, and is not intended for diagnostic use, routine clinical deployment, or regulatory submission. No patient-identifying data is stored or processed as part of this proof-of-concept.

To minimise risk and avoid premature optimisation, the work is structured into clearly defined phases, each addressing a specific uncertainty:

- reliable headless hardware control via a single illuminated button
- optical feasibility of observer-view imaging
- mechanical stability and repeatable alignment through a removable mount
- clinician workflow integration and data handling

Each phase includes explicit decision gates and off-ramps, allowing the project to be paused or concluded early if key assumptions are not validated. This ensures that all work undertaken yields standalone technical insight and reusable learning, even if later phases are not pursued.

Mechanical design and 3D-printed mounting solutions are intentionally deferred until optical feasibility has been demonstrated using temporary, fully reversible fixtures. Where required, parametric CAD modelling and rapid prototyping are planned using open-source tools and consumer-grade additive manufacturing to enable fast iteration and low cost.

The outcome of this proof-of-concept is expected to be a demonstrable, non-diagnostic recording system and a clear evidence base to inform whether further development, refinement, or exploration is justified.

2. Project Overview

Problem Statement: "Current slit-lamp imaging solutions force clinicians to choose between cheap but awkward smartphone adapters and expensive, closed OEM camera systems. There is no affordable, dedicated, workflow-friendly way to record exactly what the clinician sees, especially as video."

Purpose: The purpose of this project is to design and validate a low-cost, removable camera system that records video through the slit lamp observer monocular, capturing exactly what the ophthalmologist sees during examination, enabling sharing of the video and still images with other specialists.

Objective Framework: This project is structured as a phased proof-of-concept, where each phase de-risks a specific technical, optical, or usability aspect before progressing further. Objectives are defined at both a programme level and a phase level, allowing incremental validation without premature optimisation or regulatory overreach.

Primary Objective (Programme-Level): To demonstrate the technical feasibility, usability, and image adequacy of a low-cost slit-lamp observer-view video recording system using readily available components, prior to any clinical certification or productisation.
Phase Level Objectives

Objective 1: Electronics & Control (Hardware Proof of Concept)
To demonstrate reliable, deterministic physical control of a headless camera system using a single illuminated button, including robust start/stop behaviour and clear recording-state feedback, implemented on a Raspberry Pi–based platform.

Objective 2: Optical & Imaging Feasibility
To demonstrate that usable slit-lamp observer-view video can be captured through the monocular eyepiece using a compact CS-mount camera, without significant vignetting, distortion, or loss of clinically relevant detail.

Objective 3: Workflow & Usability
To validate that the system integrates naturally into an ophthalmologist's slit-lamp workflow, requiring minimal cognitive load, no interaction with screens or software during examination, and no disruption to standard clinical practice.

Objective 4 – Data Handling & Demonstration Readiness:
To demonstrate predictable and safe handling of recorded video files, including automatic storage to removable media and straightforward retrieval for non-diagnostic review, sharing, or teaching.

Scope: This project is strictly a proof-of-concept. It is not intended for diagnostic use or routine clinical deployment without further regulatory, safety, and data protection assessment.

3. Success Criteria

The proof-of-concept will be considered successful if all the following conditions are met:

1. The system is capable of recording clear and stable video through the slit lamp observer eyepiece.

2. Recording can be started and stopped using a single physical button.
3. Video files are automatically saved to removable USB storage.
4. The system operates headless, without keyboard, mouse, or monitor.
5. The mounting solution does not damage the slit lamp, is removable, and maintains repeatable optical alignment.

4. System Architecture

Hardware Components:

1. Raspberry Pi Zero 2 W
2. Camera module (OV5647 or Raspberry Pi Camera v3)
3. Physical push button connected via GPIO
4. Status LED for recording state feedback
5. USB storage device
6. Power supply (USB wall adapter or battery pack)

Software Components:

1. Raspberry Pi OS Lite
2. Python-based control service running at boot
3. libcamera for video capture
4. GPIO interrupt handling
5. Automatic file naming and storage management

5. Overview of project phases and design

The work described in this document is structured as a series of clearly defined, sequential phases, each designed to validate a specific assumption or de-risk a particular aspect of the system before further effort is committed.

The phases are intentionally ordered to progress from low-cost, low-risk validation toward more involved mechanical and workflow development. Advancement between phases is contingent on meeting defined acceptance criteria.

This phased approach ensures that:

- technical complexity is introduced only when justified by results
- effort scales gradually rather than prematurely
- failure at any stage produces useful, standalone learning

Each phase addresses a distinct question:

Phase	Question
Phase 1 – Hardware Bring-Up	Does the core hardware function reliably in a headless configuration?
Phase 2 – Button-Controlled Recording Logic	Can the system be controlled deterministically and intuitively using a single physical interface?
Phase 3 – Optical Alignment	Is observer-view imaging optically feasible using compact, low-cost components?
Phase 4 – Mounting Strategy and Mechanical Development	Can optical alignment be maintained repeatably using a removable, non-invasive mount?
Phase 5 – File Handling and Data Flow	Can recorded data be stored, retrieved, and shared predictably and safely?
Phase 6 – Reliability and Workflow Enhancements	Is the system sufficiently robust and intuitive for demonstration in a clinical environment?

6. Phase 1 – Hardware Bring-Up

Objective: To verify that all hardware components function correctly in a bench-top setup.

Tasks:

1. Install Raspberry Pi OS Lite.
2. Enable the camera interface.
3. Verify camera operation using libcamera.
4. Wire and test the GPIO button input.
5. Verify that USB storage is automatically mounted.

Deliverables:

1. The Raspberry Pi boots reliably in headless mode.
2. The camera preview works consistently.
3. Button presses are detected correctly in software.
4. USB storage is recognised without manual intervention.

Acceptance Test: A 10-second test video is successfully recorded and saved to USB storage.

7. Phase 2 – Button-Controlled Recording Logic

Objective: To enable simple, clinician-friendly control using a single physical button.

Button Behaviour:

- A short press starts recording.
- A short press while recording stops recording.
- A long press of five seconds or more triggers a safe system shutdown.

Deliverables:

1. A Python service runs automatically on boot.
2. Recording starts and stops reliably using the button.
3. Video files are named automatically using timestamps.

8. Phase 3 – Optical Alignment

Objective: To achieve accurate optical alignment between the camera sensor and the slit lamp observer eyepiece.

Key Considerations:

- The camera must be aligned coaxially with the eyepiece.
- The camera sensor should be positioned close to the eyepiece exit pupil.
- Vignetting and optical distortion must be minimised.

Initial Approach (No 3D Printing):

- Rubber eyepiece sleeves or couplers.
- Foam spacers or rings.
- Adjustable hose clamps.
- Temporary and fully reversible attachment methods.

Acceptance Criteria:

1. The recorded image is circular with minimal vignetting.
2. Optical alignment is repeatable after removal and reattachment.

9. Phase 4A – Mounting Strategy

Non-Printed Prototype Mount

Objective: To validate optical performance and usability before committing to custom parts.

Characteristics:

- Low cost.
- Rapid iteration.
- Fully reversible.
- Suitable for demonstration and proof-of-concept testing.

Optional 3D Printed Adapter

Objective: To improve mechanical stability and repeatability after proof-of-concept validation.

Potential Features:

- Eyepiece sleeve adapter matched to slit lamp dimensions.
- Camera holder with axial adjustment.
- Locking mechanism to maintain focus and alignment.

3D printing can be outsourced to local makerspaces or commercial services.

10. Phase 4B: Design & Mechanical Development (Mount)

Objective: To design, prototype, and iteratively refine a non-invasive mechanical mounting solution that securely aligns the camera with the slit-lamp observer monocular, while remaining fully removable and compatible with different slit-lamp geometries.

Design Requirements

The mounting solution must:

- Maintain coaxial optical alignment between camera sensor and eyepiece
- Position the camera sensor close to the exit pupil of the observer monocular
- Be fully removable without tools or permanent modification
- Avoid damage to existing slit-lamp components
- Be stable under normal clinical handling
- Allow repeatable removal and re-attachment

Additional desirable characteristics include:

- Compact form factor
- Minimal added weight on the eyepiece
- Compatibility with multiple slit-lamp models where possible

Key Design Challenges

- Variability in eyepiece outer diameter between slit-lamp manufacturers
- Sensitivity of image quality to axial distance and tilt
- Avoidance of vignetting caused by misalignment or internal occlusion
- Mechanical stability without excessive clamping force

These challenges will be addressed through iterative prototyping and testing.

11. Phase 4C - CAD & Prototyping Workflow (FreeCAD + 3D Printing)

CAD Workflow (FreeCAD)

All mechanical components will be designed using FreeCAD, selected for its open-source nature, parametric modelling capabilities, and suitability for rapid iteration.

The proposed workflow is:

1. Initial Measurement & Reference Capture
    - Measure observer eyepiece outer diameter, length, and geometry
    - Record camera module dimensions and lens protrusion
    - Identify required axial spacing to achieve focus at infinity

2. Parametric Model Setup
    - Define key dimensions as named parameters (eyepiece diameter, wall thickness, clamp tolerance)
    - Enable rapid resizing for different slit-lamp geometries
3. Part Design
    - Eyepiece sleeve or collar
    - Camera holder aligned to optical axis
    - Axial adjustment features where required
    - Optional locking or retention features
4. Assembly & Interference Checks
    - Verify coaxial alignment in FreeCAD
    - Check for collisions and occlusions
    - Validate tolerances for friction fit or clamping
5. Export for Manufacturing
    - Export STL files
    - Apply print-specific adjustments (clearances, fillets, chamfers)

Rapid Prototyping & 3D Printing

Prototypes will be produced using a Bambu Lab A1 3D printer, selected for:

- High dimensional accuracy
- Reliable repeatability
- Rapid print turnaround
- Support for common engineering filaments

Initial prints will prioritise PLA or PETG for speed and ease of iteration, with the option to transition to more durable materials if required.

The prototyping loop will follow:

1. Print prototype
2. Test fit on slit lamp (non-clinical, no patient)
3. Evaluate alignment, stability, and usability
4. Update CAD parameters
5. Re-print and refine

This loop enables fast convergence toward a mechanically stable and optically reliable mount before any consideration of final manufacturing methods.

12. Phase 5 – File Handling and Data Flow

Objective: To enable simple retrieval and sharing of recorded videos.

File Strategy:

- Record video in H.264 format.
- Optionally convert recordings to MP4 automatically after capture.

Directory Structure:

- USB root directory contains a slit lamp recordings folder.
- Each recording is saved with a timestamp-based filename.

No patient-identifying data will be stored during the proof-of-concept phase.

13. Phase 6 – Reliability and Workflow Enhancements

Objective: To improve robustness and suitability for demonstrations.

Potential Enhancements:

- Read-only operating system configuration.
- Watchdog service for automatic restart on failure.
- Visual indicator to show recording status.
- Controlled and safe shutdown procedure.

14. Risks and Mitigations

- Optical misalignment risk is mitigated by adjustable mounting and iterative testing.
- Data loss risk is mitigated by controlled shutdown and robust file handling.
- Overheating risk is mitigated by passive ventilation and low-power hardware.
- User error risk is mitigated by a single-button interface.

15. Estimated Timeline

Week 1: Hardware bring-up and basic testing.
Week 2: Button-controlled recording implementation.
Week 3: Optical alignment testing.
Week 4: Stable mounting solution.
Week 5: Demonstration and review.

16. Cost Estimate (Proof of Concept)

Item	Cost
Raspberry Pi Zero 2WH	€25
Camera Module	€7.50 - €30
Cabling	€5
Mounting	€2
Buttons	€2

Optional: 3D Printer	€210
Optional: 3D Printing Service (External)	€50-200

Estimated total cost is €150 – 300.