

Smart Lateral Flow Device with Embedded Gradient Nanoparticle Lines towards Enhanced Quantification via Smartphone

Silvia Demuru¹, Miha Markocic¹, Peter Spies², Dominik Meinel², Stefano Cattaneo¹, Maren Schinz³, Stefanie Dobitz³, Vitalijs Zubkovs¹

¹ Centre Suisse d'Electronique et de Microtechnique SA (CSEM), Landquart, Switzerland

² University of Applied Sciences and Arts Northwestern Switzerland (FHNW), Muttens, Switzerland

³ Diabetes Center Berne (DCB), Bern, Switzerland
vitalijs.zubkovs@csem.ch

Summary:

Smartphone-based lateral flow assays enable accessible point-of-care diagnostics but suffer from limited quantitative reliability. To address this limitation, this work introduces a lateral flow device with embedded gradient nanoparticle lines for on-strip optical calibration. The calibration gradient enables direct normalization of test signals at the time of image acquisition. A custom smartphone-supported web application performs automatic image recognition and signal processing. The proposed approach supports customizable quantitative healthcare and drug tests at low-cost without external optical accessories.

Keywords: lateral flow assay, nanoparticle calibration, smartphone sensing, quantitative diagnostics, point-of-care

Background, Motivation and Objective

Lateral flow assays (LFAs) are widely used for rapid diagnostics and are increasingly combined with smartphones to enable quantitative point-of-care and home-based testing, generally supported by dedicated optics or controlled imaging conditions [1]. Performance is often limited by illumination sensitivity and device-dependent bias, which restrict quantitative robustness in real-world use [2]. These limitations motivate calibration strategies that are intrinsic to the assay and independent of external accessories, potentially enabling improved quantification while keeping the cost as low as standard LFAs.

The objective of this work is to develop a smart lateral flow device integrating embedded gradient nanoparticle lines as on-strip optical references together with optimized image acquisition and signal processing, to enable robust, customizable, and accessory-free quantitative lateral flow readout using a smartphone.

Description of the New Method or System

- On-strip gradient nanoparticle calibration lines (GNLs) using the same gold nanoparticles (NPs) as the assay.
- Custom cassette markers for automatic region-of-interest (ROI) detection.

- Custom software for gradient extraction and test line quantification.

Results

The proposed smart LFA is envisioned for user-friendly, accessory-free operation in point-of-care or home-use settings. After applying the sample (Fig. 1a), the user captures a single image of the smart lateral flow cassette using a smartphone (Fig. 1b).

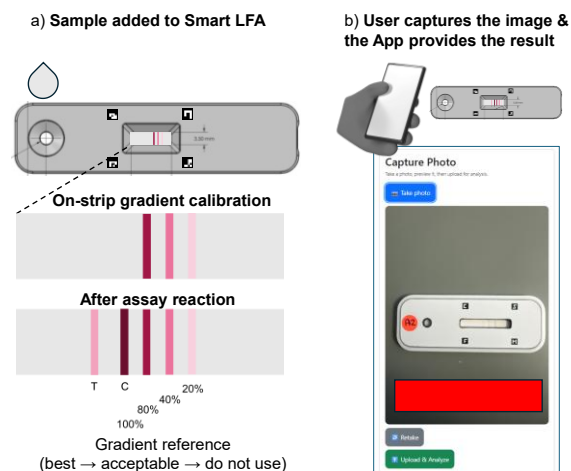


Fig. 1. Envisioned use of the smart LFA device with embedded gradient calibration and smartphone readout (a), with an example of a test result for checking sample degradation (b).

The custom application performs automated quantification, with the aim of providing a clear and actionable result for the user.

As a proof of concept, the envisioned calibration gradient composed of lines at increasing NPs concentrations (Fig. 1a) is fabricated using a BioDot AirJet dispenser (Model XYZ3210). Solutions of 40 nm gold nanoparticles (nanoComposix, AUCR40-5M), linearly diluted in standard buffer, are directly deposited onto FF120HP nitrocellulose membranes (Whatman GE Healthcare). The resulting five-line model nanoparticle gradient is integrated into a custom laser-cut cassette with engraved QR codes used as recognition markers (Speedy 300, TROTEC), as illustrated in Fig. 2a. This configuration enables automatic ROI identification and alignment as validated in Fig. 2b. All acquired images are processed using the developed custom modular software architecture for smartphone image analysis. The framework combines configurable analysis pipeline with reusable processing modules to ensure robust marker detection, ROI extraction, and quantitative analysis of intensity profile based on the GNLs.

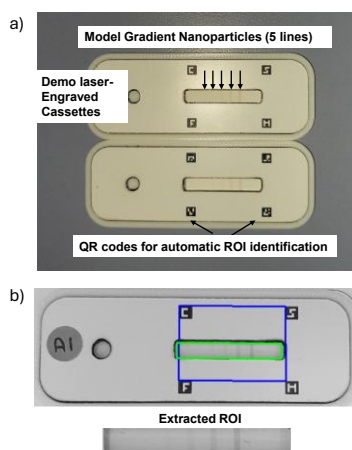


Fig. 2. Demonstration of the GNLs on-strip concept into customized cassettes with different engraved recognition markers (a), and example of automatic ROI quantification via the developed software (b).

The model nanoparticle gradient serves also as a tool for testing variability across different image acquisition platforms and generating a database for testing the developed algorithm, using stable, simulated test lines for repeatable measurements (Fig. 3). Direct images from various smartphones yield comparable results (Fig. 3b,c). All nitrocellulose strips were prewetted with PBS 1X before image acquisition to mimic real assay conditions, as wetting alters GNL optical properties without affecting line morphology. Ongoing work focuses on integrating the calibrated GNLs into a functional assay (Fig. 4), embedding recognition markers into the LFA cassette, and refining the mobile app for direct

gradient and test-line quantification to validate the smart LFA concept.

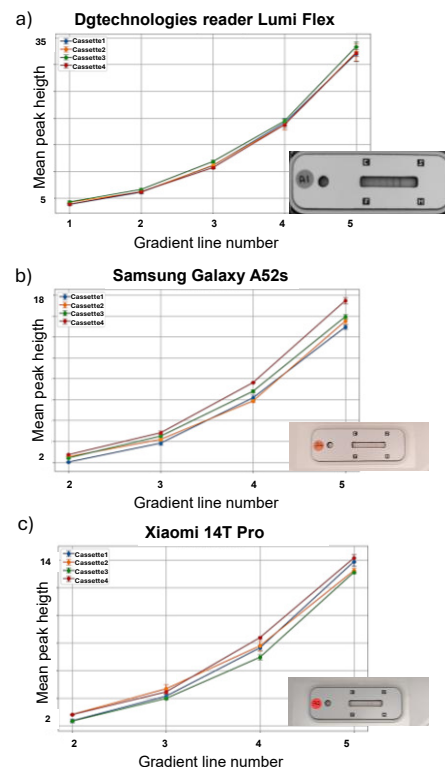


Fig. 3. Extracted GNL intensities comparing three different image acquisition tools for $n=4$ customized cassettes. With smartphones (b,c), the weakest GNL (line 1) cannot be detected.

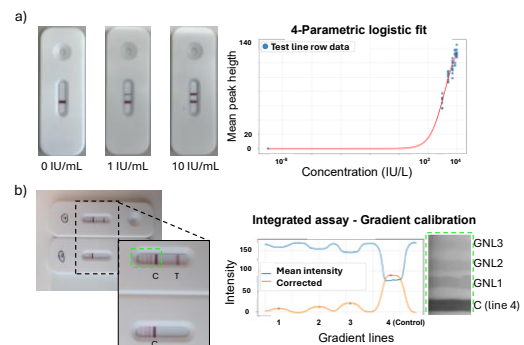


Fig. 4. Initial studies on a real model assay for hCG detection at different concentrations (a), and integration of 3 GNLs with the same assay (b).

References

- [1] Thakur, R. et al. Development of Smartphone-Based Lateral Flow Device for the Quantification of LH and E3G Hormones. *IEEE Sens J* 20, 14491–14500 (2020); doi: 10.1109/jsen.2020.3008566
- [2] Michaelis, S. et al. Performance evaluation of a smartphone-based home test for fecal calprotectin. *Clin Chem Lab Med* 63, 139–146 (2025); doi: 10.1515/cclm-2024-0422

Acknowledgements

This work was funded through the Swiss Innovation Agency under grant 119.383 IP-LS