Implementation of phantom-based performance test methods for medical fluorescence imaging systems

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INTRODUCTION

Medical imaging techniques are essential tools in modern medicine, enabling the non-invasive visualization of internal structures for diagnostic and therapeutic purposes [1]. Fluorescence is the process by which molecules absorb light at a specific wavelength and reemit it at a different wavelength within nanoseconds. These molecules, known as fluorophores, include indocyanine green (ICG), fluorescein, and protoporphyrin IX (PpIX), which are used in this work [2]. Radiometry - the measurement of electromagnetic radiation and its interaction with matter - also plays a central role in this context [3, 4]. Against this background, the leading question of this work is: How suitable is the proposed setup for objectively comparing NIR fluorescence imaging systems in medical applications?

METHODS

Five phantoms - two solid and three liquid - were prepared for performance evaluation. Three were doped with ICG, one with fluorescein, and one with PpIX. These phantoms were used to assess three different fluorescence imaging systems (one of which is illustrated schematically in Fig. 1). System performance was evaluated based on several key criteria: spatial resolution, sensitivity, depth of field (DOF), signal linearity, field of view (FOV), signal uniformity, and excitation light crosstalk.

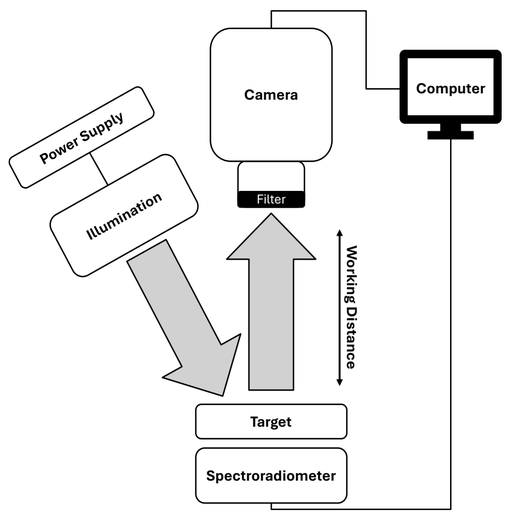

Fig. 1: Schematic representation of the experimental setup.

RESULTS

Spatial Resolution: Contrast decreases with increasing spatial frequency, starting at around 80% for the largest element (lowest spatial frequency) on the USAF 1951 target and declining towards zero (Fig. 2). The difference between vertical and horizontal contrast is negligible.

Sensitivity: For two systems, the signal-to-noise ratio (SNR) values at all concentrations clearly exceed the limit of quantification (LOQ) threshold (Fig. 3). In both cases, the SNR increases at low concentration but decreases as the concentration continues to rise. In contrast, all measured concentrations for the third system lie near the limit of detection (LOD) threshold.

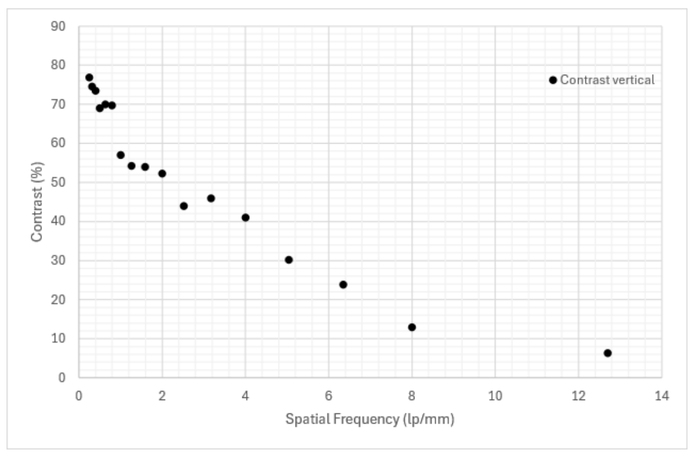

Fig. 2: Result for spatial resolution in the vertical orientation.

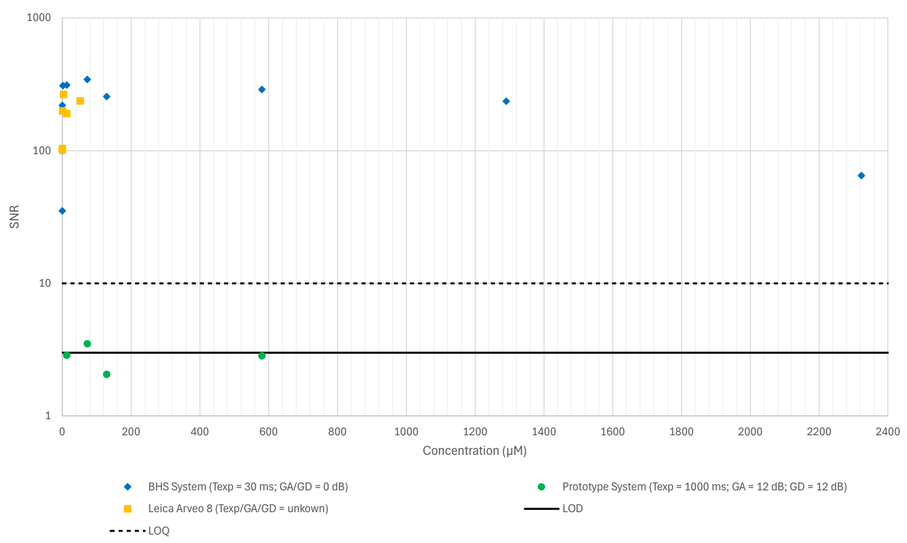

Fig. 3: Sensitivity results for all three systems using the liquid ICG phantom.

DOF: The black dots represent the measured data points, while the solid line corresponds to the Gaussian fit based on these points (Fig. 4). The dotted line indicates the FW90M, which is used to determine the DOF. The DOF was calculated to be 185,5 mm.

Crosstalk: Results from the multiwell phantom show that the crosstalk factor decreases with decreasing concentration (Fig. 5).

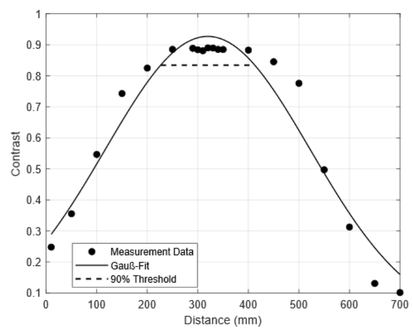

Fig. 4: Graphical representation of the DOF measurement.

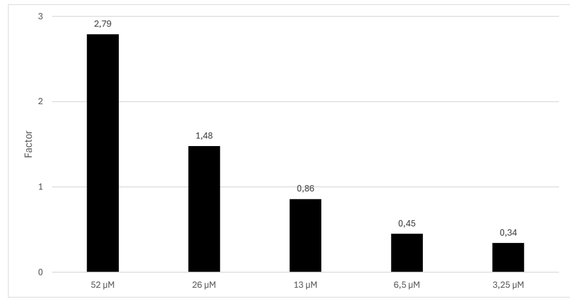

Fig. 5: Crosstalk factor as a function of ICG concentration.

DISCUSSION

(1) Overall, liquid phantoms were easier to prepare and yielded more readily detectable signals.
(2) Two out of three systems demonstrated robust performance across most evaluated criteria.
(3) Regarding the leading question: the proposed test setup is generally suitable for comparing different systems. However, the criteria DOF, FOV and penetration depth are considered less appropriate for objective comparison. In contrast, the remaining criteria provide meaningful and reliable measures for system evaluation.

COOPERATION PARTNER

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References: [1] A comparative study of medical imaging techniques, 2015. [Online]. Available: https://ilearn.th-deg.de/pluginfile.php/480243/mod_book/chapter/8248/updated_jxijsis2015.pdf
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