On the Feasibility of a Smartphone-based Solution to Rapid Quantitative Urinalysis using Nanomaterial Bioprobes

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ABSTRACT

The main objective of this research is to design and develop a smartphone-based urinalysis device known as uTest that has the ability for patients themselves to conduct rapid quantitative diagnosis of human serum albumin (HSA) in urine using the aggregation-induced emission (AIE) nanomaterial bioprobes anytime, anywhere and with any mobile device. Work reported in this study has confirmed the feasibility of such a solution, which can achieve accurate urinalysis for HSA concentrations in the range of 0-100 mg/dL.

CCS CONCEPTS

• **Human-centered computing** → **Smartphones**; **Ubiquitous and mobile computing design and evaluation methods**;

KEYWORDS

Urinalysis, Mobile Devices, Image Analysis, 3D Printing

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1 INTRODUCTION

Urinalysis - urine diagnosis - is a standard method for the identification of people at earlier time points in the trajectory of chronic kidney disease. One urinalysis method is to measure the amount of Human Serum Albumin (HSA) [6], a serum protein that would normally be present at high concentrations in blood and should not appear in urine more than a clinically normal threshold value of 30 mg/dL. It relies on bulky and costly bench-top urine analysers and trained skills only available in laboratory settings, thereby requiring successive patient visits to clinics or hospitals and long turnaround times [1].

Point-of-care (POC) testing is preferred to laboratory urinalysis as it can provide rapid results on the site, particularly suitable for screen for prevention, treatment monitoring, and patient self-testing [2, 7]. Existing POC urinalysis devices in the market use reagent strips and most of them can only provide qualitative results [5, 8]. The main objective of this research is to design and develop a smartphone-based POC urinalysis device known as uTest for rapid quantitative diagnosis of HSA in urine using the aggregation-induced emission (AIE) nanomaterial bioprobes anytime, anywhere and with any mobile device.

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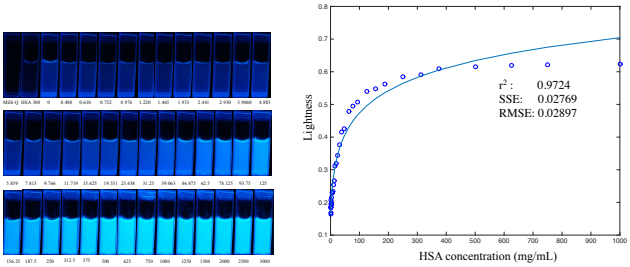
2 IMAGE PROCESSING AND ANALYSIS

BSPOTPE, an environmentally stable and synthetically readily accessible FL (Fluorescent Light) probe for HSA detection and quantitation, was specifically synthesised for albumin urinalysis using the proposed uTest device according to published procedures [4]. It is unperturbed by the miscellaneous bioelectrolytes in the artificial urine. The non-luminescent BSPOTPE becomes emissive in the presence of HSA, according to the aggregation induced emission (AIE) phenomenon, in such a way that the FL intensity responds linearly to HSA concentrations in the range of 0-660 mg/mL (0-66 mg/dL) (Figure 2(a)) [4].



(a) Images of HSA concentrations **(b) Correlation between image luminance and HSA concentration**

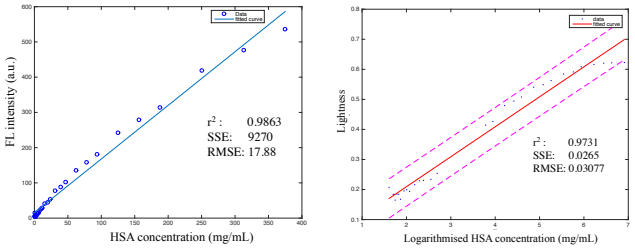
Figure 1: Images' response to HSA concentration

Figure 1(a) shows the images of different concentrations of HSA stained with 30 μM BSPOTPE, which were taken under the illumination of a UV lamp by a Samsung Galaxy S3 smartphone with a 500±12.5 nm optical filter. Figure 1(b) depicts a logarithmic reaction from BSPOTPE images to HSA = 0-1000 mg/mL. The non-linear correlation is caused by a specialised colour encoding process when a raw image is compressed for more efficient tonal encoding [3].

After performing k-fold cross-validation ($K = 7$) on the generated dataset containing the logarithmised HSA concentration and the lightness of the corresponding image, we arrive at the following best fitted linear function (Figure 2(b)). The result has confirmed the hypothesis that our smartphone-based solution can be used to test HSA concentrations in the range of 0-1000 mg/mL (0-100 mg/dL),

covering the full spectra of trace, 1+ and 2+ microalbuminuria [1].

$$f(x_0 \rightarrow y) : y = a \log(x_0 + b),$$

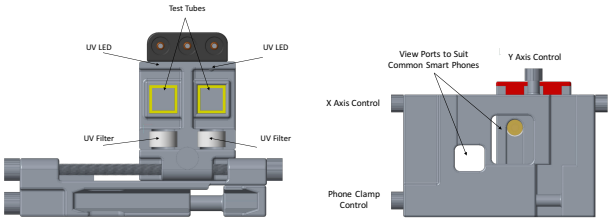


(a) FL's response **(b) Image luminance's response**

Figure 2: BSPOTPE's response to HSA concentration

3 DEVICE PROTOTYPE

As a proof of concept, we designed and developed the uTest prototype device comprising an existing Samsung Galaxy S3 smartphone, a custom-built external imaging housing, and a specially designed Android application.



(a) Imaging housing **(b) Application interface**

Figure 3: The uTest imaging housing

The image housing (Figure 3(a)) is an 3D-printed optomechanical blackbox installed on the existing camera unit of the smartphone for holding the test tubes and for blocking external light for the analysis of reagent assays. To support a tremendous variety of smartphones in the market, the imaging housing is made lightweight and adjustable to work with existing smartphones that have different dimensions and camera positions, as shown by Figure 3(b).

(a) Displaying result **(b) Viewing trend**

Figure 4: The user interface of the uTester device

Figure 4(a) shows the user interface of the mobile application displaying the current urinalysis result. It uses the traffic light metaphor to visualise the result: red denotes 2+ microalbuminuria (30-100 mg/dL), yellow denotes 1+ microalbuminuria (20-30 mg/dL), green denotes trace (5-20 mg/dL), and grey denotes no trace, followed by the explanation notes elaborating the current test result. All test results are timestamped and saved in the smartphone so that the patient can view their urinalysis trend later (Figure 4(b)).

The mobile application first takes the image of a new urine test, then retrieves its lightness value, and finally maps the lightness value to its HSA concentration value using the following equation:

$$x_0 = e^{\frac{y-d}{c}} - b,$$

where y is the lightness value, x_0 is the HSA concentration value, and $a = 0.1019$, $b = 4.994$, $c = 0.0997 \in [0.09328, 0.1061]$, and $d = 0.01002 \in [-0.01618, 0.03622]$ are the coefficients derived from the training data. Table 1 shows 4 examples of smartphone-based urinalysis. In particular, for the lightness of 0.6020 of a testing image, its HSA concentration is 41.91 ± 0.07 mg/dL, which corresponds to 2+ Microalbuminuria, as shown in Figure 4(a).

Image Lightness	HSA Concentration (mg/mL)	Lower Bound	Upper Bound	Microalbuminuria Grading
0.2792	16.4412	15.7903	17.0841	No trace
0.4793	122.4056	121.7626	123.0573	Trace
0.560	275.0118	274.3646	275.6744	1+
0.6020	419.0920	418.4410	419.7618	2+

Table 1: Examples of smartphone-based urinalysis

4 CONCLUSIONS AND FUTURE WORK

Work reported here has confirmed that using a cheap and portable smartphone augmented with a custom-built imaging housing and a specially designed mobile application for image capturing, processing and analysis is a viable solution to urinalysis with the BSPOTPE reagent. While this work has proven the feasibility of the proposed solution, we are conscious of the work required to fully accomplish our objective, including device agnosticism, synthesis of an optimal BSPOTPE that responds linearly to higher HSA concentrations, and creatinine test to measure albumin-to-creatinine ratio (ACR) [5].

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