ABSTRACT

Analytical instruments have great importance in material research, chemistry, microbiology and clinical laboratories. Educational institutes, chemical and biological laboratories and industries use various analytical instruments for detection and analysis of different samples. Also, these instruments find applications in environmental monitoring, water and food quality assessment, medical diagnostics, agriculture, and forensic analyses. The sophisticated instruments are highly reliable, accurate and sensitive. However, the bulky size, high cost and complex analytical procedures make such devices in general, laboratory confined and less user-friendly. External computational systems and high voltage power supply are mandatory for the proper functioning of these tools. A conventional analytical device has low applicability for real time analyses in remote and resource-poor settings with these features.

Over the past few decades, research groups around the globe have designed various compact, portable and user-friendly analytical systems[1–5]. In this aspect, the use of smartphones for designing analytical platforms has been growing rapidly. Advanced smartphone technologies such as strong computational power, high quality inbuilt sensors and programmable software (Apps) motivate the researchers to develop different smartphone-based sensing and imaging devices [6–11]. Enormous smartphone-based spectrophotometers, fluorometer, turbidity readers, microscopes, colorimeters and pH meters have been designed in the past few years. Performance of these instruments has been tested by utilising them in different sensing applications. Smartphone devices developed for environment monitoring, point-of-care diagnostics, bio-sensing and food quality assessment have been demonstrated successfully [12–14]. Most of these tools utilise the smartphone as a detector and a computational device. Inbuilt smartphone sensors such as ambient light sensor (ALS), proximity sensor and camera are mostly used to design such platforms. These sensors are coupled with the custom-developed optical setups to enhance the analytical abilities

of such tools. To analyse the signals recorded by the embedded sensors, Android or ISO-based applications are developed and pre-installed on the phone. These tools can be used as an alternative analytical instrument for real-time analyses and field investigations in remote and resource-poor regions.

In water quality assessments, smartphones are extensively used for sensing various physical, chemical and biological parameters of water. Turbidity, pH, salinity, and dissolved minerals in water have been investigated using smartphones. This thesis work demonstrates various smartphone-based analytical platforms to monitor chemicals, heavy metals and biological contaminants in water. Here, the ALS and the rear camera of the phone have been used as photo-detectors to design various analytical platforms. The designed platforms use colorimetric, fluorescence, nephelometric and photometric based sensing approaches to estimate different quality parameters of water. Here, the estimations of mercury, zinc, sulphate and chloride ions in water have been carried out successfully. Here, indigenously developed Android applications are being used with the designed platforms to study different analyte concentrations. The thesis also demonstrates multi-model sensing schemes to determine multiple analyte on a single platform. The present study also demonstrate the simultaneous measurement of two different optical parameters of a sample. Finally, a universal smartphone holder compatible with all variant smartphones has been designed for multipurpose sensing and imaging studies. The designed smartphone-based analytical platforms are compact, cost-effective and easy to use.

In the first step of the thesis work, a fluorescence-based sensing system has been designed to estimate mercury ion concentration in field-collected water samples. The system has been designed to measure the fluorescence emission emitted by the sample inserted in the setup. The sensing principle of the system is based on the fluorescence quenching of rhodamine 6g (R6G) solution in an iodine buffer in the presence of mercury ions. Spectroscopic analysis indicates that the fluorescence intensity of the test sample gradually decreases with increasing mercury concentration. The system has been designed to capture the fluorescence signal at an angle 90° to the incident light by the phone's rear camera. The captured images were analysed by a custom-developed Android application to extract the colour channel values and correlate them with mercury concentration. The V channel intensity of the captured images has been extracted to evaluate the analyte concentration in the present investigation . The responses of the designed system have been compared with the data obtained from a standard atomic absorption spectrometer. A good degree of correlation between the responses obtained from both the platforms can be seen. The designed platform's detection limit is calculated to be 32 ppb.

In the next step of the research work, a smartphone nephelometer has been developed to monitor the growth kinetics of bacteria in the laboratory environment. The designed system records the scattered intensity coming from the bacterial sample using the ambient light sensor (ALS) of the phone and measures the turbidity of the sample. ALS of the phone has been positioned at an angle 90° to the incident light signal in the proposed system. As the bacterial inoculum is allowed to grow in the incubator, the turbidity of the sample gradually increases. The system has been utilised to measure the turbidity of the bacterial sample at different time points while growing for a period of 24 hours (hrs). All the responses collected at different time points are stored in a custom developed Android application, and finally, the data are used to plot the growth curve for the considered bacteria sample. The designed system has been used to evaluate the growth kinetics of *Escherichia coli E. Coli* and *B. Subtilis* bacteria samples. The performance of the system has been tested by comparing its responses with the standard spectrophotometer (OD600) and the colony-forming (CFU) measurement.

In the third step, a dual-mode sensing platform has been developed. The designed system is capable of measuring optical density (OD) and turbidity of a given sample. ALS of the phone has been used in the present study to record the transmitted and scattered light intensities for OD and turbidity measurements. Two different sensing schemes, namely photometry and turbidimetry, can be carried out on the designed platform. Both the modes of sensing can be used interchangeably through plug-and-play mode. As a proof-of-concept, sulphate and chloride concentrations in water samples collected from various locations have been examined under the designed system. The system can estimate the sulphate and chloride concentrations as low as 0.5 ppm and 0.4 ppm respectively. The performance of the tool has been evaluated through comparing the experimental data with the standard UV-VIS spectrophotometer and a nephelometer. A custom-designed application has been developed to record and analyse the incoming light signal to estimate the analyte concentration in the field-collected water sample. It is envisioned that the designed sensing system can be used for monitoring of other chemicals (both organic and inorganic) and microbial particles in water and could emerge as an alternative platform in those regions where access to laboratory-grade tools is very limited.

In the fourth step of the present thesis work, a smartphone-based analytical platform has been designed using two different embedded optical sensors, namely, the ALS and the rear camera of a smartphone. The system has been designed to measure the absorbance and fluorescence emission of a fluorophore at the same time. A single optical light source has been used for both the absorbance and fluorescence measurements in the present study. In the designed system, ALS of the phone records the transmitted light signal to measure the absorbance of the test sample. To measure the fluorescence emission of the sample, the rear camera of the phone has been utilised. Here the grayscale intensity of the capture images has been extracted to evaluate the emission spectra of the sample. The designed platform has been used to measure the zinc concentration in water samples. The limit of detection of the system is found to be 0.1 ppm. An Android application has also been developed to make the proposed system is stand-alone and user-friendly analytical platform.

In the final step, the working of a universal phone holder that can be used for various colorimetric, fluorescence and microscopic studies in different variant smartphones has been demonstrated. The holder can be coupled with any smartphone regardless of the dimension and position of the rear camera. The holder is compatible with phones of different physical dimensions ranging from 65 mm to 95 mm in width. Utilising the proposed holder, colorimetric, fluorescence and microscopic studies have been successfully demonstrated in the investigation. In this study, photometric and fluorescence sensing of rhodamine 6g (R6G) solution with varying concentrations have been carried out with a custom-developed colorimetric setup. Again, a microscopic setup has been developed to capture high quality images of micro-particles such as human red blood cells in the study. Three different company make smartphones, namely, Samsung, Xiaomi and Motorola have been utilised to realise the universal compatibility of the designed universal smartphone holder. It has been envisioned that with the designed holder, optical setup can also be coupled to the front camera and the phone's ambient light sensor (ALS) for other kinds of sensing studies, scattering and photometric based studies in particular. These studies will be carried out in the future course of work. The designed holder can be developed as a universal analytical platform where a smartphone can be used for different analytical purposes.

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