Abstract

According to International Telecommunication Union (ITU), till 2017 there are more than 7 billion mobile phone subscriptions around the globe and among them more than 4 billion have connected with mobile broadband facility [1]. The penetration of mobile phones to such extent is possible due to its affordability and user oriented design approach. The penetration of mobile phones in developing as well as under developed countries is now promoting many developmental initiatives by various governmental or non-governmental organizations [2]. The rapid advancement in the embedded technology, miniaturized electronics, and computation facility accelerates the development of mobile phone technology into a smartphone in present form. The enormous processing power, storage capacity, and increasing battery life allows the integration of different consumer oriented sensors such as CMOS camera, LED flashlight, proximity and ambient light sensor, accelerometer, GPS, wi-fi, graphical user interface (GPU), and many other communication sensors in modern smartphones. Due to the advent of high megapixel count smartphone cameras and the inclusion of high-end GPU, rapid image processing can be possible within the smartphone which leads to the development of smartphone based platforms for colorimetric, spectroscopic, and microscopic imaging applications [4-7]. The usability of the embedded ambient light sensor (ALS) has been demonstrated as an optical detector and its applicability has been demonstrated in many bio-sensing applications [8]. The USB and bluetooth module of the phone have been used to demonstrate many electrochemical sensors [9]. The usability of the smartphone based sensing platforms have been extensively demonstrated as an affordable and reliable alternative over lab confined instruments with reference to remote and resource poor regions which can be operated by a person having no prior scientific expertise. This can promote the de-centralized monitoring of water quality which is essential for many remote and resource limited regions. Moreover, the capacity of data transmission can significantly help people from such areas to communicate with centralized laboratories or government agencies to initiate removal programme on time.

Towards this end, my research work is focused on designing of affordable and easy

to use smartphone based optical platforms to monitor water quality with reference to resource poor regions. One of the limitations of the demonstrated smartphone camera based sensing modalities is that the developed systems are only responsive to visible spectral regime (400 nm-700 nm). In the present thesis, the usability of the embedded ALS of the smartphone has been exploited as an alternative light intensity detector which is responsive both in visible and near infra-red spectral regime (350 to 1000 nm) [10]. Along with the optics design for development of the proposed sensors, custom designed smartphone applications have been developed which have been used for signal detection, data analysis and data transfer purpose. Moreover, effort has been made to reduce measurement error by implementing necessary statistical algorithms in the designed applications.

In the first step of the thesis work, a smartphone platform photometric system has been developed by using its ALS as a detector and the LED flash as a light source. The usability of the developed platform has been demonstrated for detection of fluoride level concentration in water samples. Since, the primary motive of this thesis is to find technological solutions which are meant to be used for resource poor region, therefore further optimization has been incorporated in the developed platform in terms of its design. In the second phase of the present work external LEDs have been used as light sources which were powered by the internal battery of the smartphone through USB-OTG protocol. Using external LEDs, the usability of the designed platform has been demonstrated for sensing investigations both in visible and NIR spectral regime by measuring iron (II) and phosphate concentration in water samples. The performance of the developed photometric platforms has been compared with the standard laboratory grade spectrophotometers.

Turbidity in water is considered as one of the important water quality defining parameter. In the second step of the thesis work a compact optical set-up has been developed which is based on the ISO 7027 standard for development of nephelometers for turbidity measurements [11]. Here, the ALS has been exploited again as a detector and an external LED with peak emission wavelength 870 nm (recommended by ISO 7027 method) has been used as a light source. A compact optical set-up has been designed by integrating optical components on a plastic nylon cradle which can be attached to the smartphone. The scattered light from the turbid medium has been received by the ALS at 900 as required by the standard method. The performance of the designed nephelometric platform has been compared with that of a standard laboratory grade turbidity meter by measuring turbidity of field collected water samples.

The third work is based on the development of optical platform for salinity measurement in water or more specifically in sea water. The direct light absorption based methods utilized in developing the photometric platforms are not so sensitive to colorless medium. To determine to salinity, the evanescent wave absorption based sensing scheme has been used which is found to be sensitive in the low salinity levels. Optical fiber based evanescent wave absorption sensing scheme has been integrated with smartphone based detection platform to visualize it as an affordable and field potable device. As an extended work, a 3D printed smartphone based refractive index sensor has been developed based on bending loss in optical fiber.

Beyond developing optical platforms for water quality monitoring, effort has been made to develop the smart optical systems for optical metrological applications. In the last step of the thesis work, using simple optics design, the smartphone has been converted into an interferometric system which has the ability to record and processing fringes within the smartphone itself. Rapid 3D printing technology has been used to develop the opto-mechanical components and smart applications have been used to visualize to process and analyse the interference fringes. The usability of the developed interferometric system has been demonstrated in measuring phase change in an interferometric process and small angular measurements.

References

[1] International Telecom Union. *ICT Facts and Figures 2017.* Retrieved on 19 Jan. 2018 from https://www.itu.int/en/ITU-D/Statistics/Pages/facts/default.aspx,2018.

[2] Hutchings, M. T., Dev, A., Palaniappan, M., Srinivasan, V., Ramanathan,

N., Taylor, J., Ross, N., and Luu, P. mwash: mobile phone applications for the water, sanitation, and hygiene sector. Report for Nexleaf Analytics and the Pacific Institute, 1-115, 2012.

[3] Market information and statistics, *smartphone users*. Retrieved on 19 Jan. 2018 from https://www.statista.com/statistics/330695/number-of-\\smartph/ /one-users-worldwide/,2018.

[4] McCracken, K. E. and Yoon, J. Y. Recent approaches for optical smartphone sensing in resource-limited settings: a brief review. *Analytical Methods*, 8(36):6591-6601, 2016.

[5] Yang, K., PeretzSoroka, H., Liu, Y., and Lin, F. Novel developments in mobile sensing based on the integration of microfluidic devices and smartphones. *Lab on a Chip*, 16(6):943-958, 2016.

[6] Vashist, S. K., Luppa, P. B., Yeo, L. Y., Ozcan, A., and Luong, J. H. Emerging technologies for next generation point-of-care testing. *Trends in biotechnology*, 33(11):692-705, 2015.

[7] Contreras Naranjo, J. C., Wei, Q., and Ozcan, A. Mobile phone based microscopy, sensing, and diagnostics. *IEEE Journal of Selected Topics in Quantum Electronics*, 22(3):1-14, 2016.

[8] Park, Y. M., Han, Y. D., Chun, H. J., and Yoon, H. C. Ambient light based optical biosensing platform with smartphone embedded illumination sensor. *Biosensors and Bioelectronics*, 93:205-211, 2017.

[9] Zhang, D. and Liu, Q. Biosensors and bioelectronics on smartphone for portable biochemical detection. *Biosensors and Bioelectronics*, 75:273-284, 2016.

[10] APDS-9930. *Digital Ambient Light and Proximity Sensor.* Retrieved on 12 June, 2016 from http://www.avagotech.com/products/optical-sensors/ integratedambient-light-proximity-sensors/apds-9930,2016.

[11] Determination of turbidity. In *Water quality part-1 ISO, 7027:1999*, International Organization for Standardization, 1999.