ABSTRACT

Soil is described as a thin layer of the earth's crust that acts as a natural environment for plant development. When comes the case of healthy plants growth and production, it has been found that approximately 60% of crops yield depends on soil fertility [1]. Therefore soil is a fundamental resource that one needs to manage carefully. Soil fertility or quality is primarily determined by the soil's chemical, physical and biological properties. Soil's physical and biological properties such as its water content, the growth of other microorganisms etc. are visible to eyes but we can't see the chemical compositions such as its pH level and important nutrients like phosphorous, nitrogen, potassium and other metal elements present in the soil. The knowledge of exact type and quantity of fertilizers to be used in a specific farmland is very important as it prevents wastage of money on the unnecessary use of fertilizer in the agricultural land. The lack of knowledge of the soil nutrient content and over-fertilization in soil affects the eco-system of our environment in many ways [2–5].

More than 50% of India's total population is currently engaged directly or indirectly with agriculture [6]. However, a large section of people associated with this sector has no scientific knowledge for monitoring of soil quality of their paddy land. Various sensors such as conductivity measurement, optical and electrochemical-based sensors are commercially available; but it requires technical knowledge to handle these tools. Further, with the available sensing systems the field collected data cannot be shared and thus, immediate measures on controlling of the nutrients of an affected farmland cannot be taken. Although different governmental agencies have been established to assist farmers in various levels, such facilities are inadequate and still not available in many remote and interior areas of our country. Thus, a farmer from a remote place needs to put a great effort to get his soil quality checked from an expert usually available in the district or sub-divisional areas in many parts of our country. Many batch wise chemical techniques are available for determination of soil nutrients. However batch method consumes a long time, a large amount of chemi-

cals and a bulky instrument like spectrophotometer is needed, however, it becomes expensive and difficult to be employed on the field. Nowadays, several commercial test kits are available for soil analysis but these devices only offer an approximation of the nutrient content (i.e., low, medium and high), thus, they are suitable for using as initial screening purposes only [7–10]. Hence, there is an urgent need for a simple, field-portable, user-friendly and relatively low-cost alternative approach using which a common farmer residing in the interior region can monitor the soil quality of his farmland.

This thesis work reports the design of low-cost, user-friendly smartphone based sensing systems for detection and analysis of different environmental and agricultural parameters with reference to the resource-poor regions. The usability of in-built sensors of the smartphone has been explored for agriculture and environment monitoring purpose. The CMOS image sensor, Ambient Light Sensor (ALS) and USB port (for powering) of smartphone have been utilized to make a complete standalone smartphone based sensing system. Different plastic compact cradles have been fabricated using 3D-printing technology to assemble various optical components which can be attached easily to the smartphone. Along with the optical setup, custom-designed smartphone applications have been developed to make the sensing system a truely standalone tool. The usability of the developed systems have been demonstrated for detection of soil parameters such as pH level, macronutrients (Phosphorus and Nitrogen), toxic metal ions (Arsenic and Lead), etc. and chlorophyll content in plant leaf.

In the first step of the thesis, a cost-effective, portable and user-friendly smartphone-based sensing system has been developed and demonstrated its usability for monitoring of pH value in soil. To convert the phone into a pH sensing tool, the smartphone has been converted into a spectrometer. In this work, a piece of DVD has been used as a grating element that disperses the focused broadband line source into its component colors. The use of DVD in this work reduces the overall cost of the tool. A 3D printed compact set-up has been developed that houses the required optical components for the present set-up. The performance of the designed smartphone sensor has been compared with a laboratory-grade spectrometer. The designed tool has been successfully implemented for accurate and reliable estimation of the pH value of different field-collected soil samples. Furthermore, the designed sensor has been utilized for Localized Surface Plasmon Resonance (LSPR) based sensing of metal ions present in soil. For the present sensing studies the DVD grating element has been replaced by a commercial grating element for better sensitivity. The developed sensing tool is applied for detection of Arsenic(III) and Lead(II) ions using synthesized gold nanoparticles (AuNP). The LSPR peak of the AuNPs shifts to the longer wavelength region upon reaction with As(III) and Pb(II) which is used for sensing of these two particular ions. The change in the absorbance for each ion at the LSPR peak have been used for quantification of the two ions. An android based application "Soil Quality Monitoring" (SoQM) has been developed so that onsite detection and analysis can be performed. The performance of the device has been checked with field-collected soil samples and compared the results with standard tools for validation.

Monitoring of phosphorous levels in water and agricultural soil is critical for maintaining the water quality and soil fertility. Although several methods are available to estimate phosphorous concentration, but the existing approaches are laboratory-confined and involve costly equipment that are not suitable for autonomous operation in the field. To overcome these limitations, **in the second step**, a compact, portable, and cost-effective smartphone-based colorimetric analyzer has been designed and developed for the quantification of phosphate levels in water and soil. The integrated CMOS camera of the smartphone is used as an imaging detector to capture the images of the samples. The designed sensor converts the modulated signal in the form of color information which subsequently has been used to quantify the phosphate concentration present in the sample. A 3D printed cradle has been developed to hold the optical components which can be attached easily to the camera of the phone. By using two freely available android applications, the experimental data of the sensor have been analyzed within the phone itself thus, making the designed tool a standalone platform. The applicability of the proposed sensor has been evaluated by estimating the phosphate concentrations of different field-collected water and soil samples.

In the third step of the thesis, the design of a portable smartphone-based dual detection sensing tool for the onsite sensing of trace nitrite has been demonstrated. For this purpose, Carbon Nanodot-Neutral Red sensing medium has been synthesized where C-dots acts as donors and NR as acceptors. In presence of nitrite, the C-dot-NR sample shows colorimetric and fluorescence emission which has been utilized for dual model estimation of nitrite using smartphone with some optical components housing in a 3D printed cradle. The ALS and CMOS image sensor of the smartphone has been explicitly used for photometric and fluorescence-based nitrite detection, respectively. Two freely available android applications have been used for the nitrite measurement and analysis of the samples. The performance of the designed smartphone sensor in both the sensing schemes have been compared with the standard method. The designed tool has been successfully implemented for monitoring of the nitrite concentrations in different field-collected water and soil samples, offering a feasible method for determining nitrite residues on-site.

Chlorophyll content estimation in leaf is often required for monitoring stress level, nitrogen content and overall health condition of plants. Spectrophotometric and reflectance-based sensors are generally used for such purposes; however, the detection methods require relatively expensive, bulky and sophisticated instruments, thus hindering their use in resource-limited settings. Considering its need, **the thesis work ends** with the working of a low-cost, robust, user-friendly fluorescence-based sensor has been fabricated using a smartphone for estimation of chlorophyll content in plant leaves. The sensor has been developed using the inbuilt ambient light sensor of the smartphone as detector and coupling optical set-up to the phone. The extracted plant chlorophyll sample is excited with an optical source (475 nm), and the corresponding emitted fluorescence signal at 679 nm has been recorded by the phone's ambient light sensor (ALS). A 3D printed compact optical set-up has been designed to couple it with the phone to record the emitted fluorescence signal intensity from the sample. Using the designed sensing platform, chlorophyll concentrations in fresh tea leaves have been accurately estimated and the results have been compared with the commercial-grade chlorophyll meter.

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