Low-cost Handheld Plant Health Monitoring Device for Resource Limited Regions

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***Abstract*—Nutritional deficiencies as well as bacterial or fungal diseases in rice (or Poaceae family) spread quickly and may hamper crop yield. Most of these diseases can be seen by naked eyes, but further microscopical study should be done to understand the real nature and extent of damage. The whole evaluation process is cumbersome, and involves sending samples to a testing center and waiting for results, leading to loss of valuable time, which might translate into loss of the entire crop. We have developed a low-cost handheld device for monitoring the chlorophyll content in the leaves of agricultural crops, which is a primary indicator of plant growth and vitality. This is achieved by high-resolution multispectral imaging (2 optical wavelengths and broadband illumination) implemented using a combination of individually addressable light-emitting-diode ring, hand-held microscope module and post-processing of imaging. The device doubles up as an *in-situ* microscopy unit to acquire high-resolution images of diseased plant parts. The acquired images are processed immediately on the attached mobile device using image analysis and machine learning methods, giving the farmer an early advisory in a remote location. The system is to be integrated with a wider network of agricultural monitoring centers to transmit selected data and receive expert advice. Our device can effectively automate the process of identifying the disorders, cut down the turnaround time and immediately deliver indicative results. This device allows farmers to take remedial measures sooner and help in a sustainable agriculture - in a long term safeguarding against financial and food crop losses.**

***Index Terms*—Agriculture, image processing, multispectral imaging, microscopy, automation, machine learning**

I. Introduction

South-east Asian economies, including India, are greatly dependent on agriculture. The weather in these tropical regions is hot and humid which makes plants more susceptible to diseases. Thus, for detection of diseases and crop development, agricultural scientists and computer experts have put forward tools for plant phenotyping and diagnosis. Modern techniques are now widely adopted and regularly used in plant health monitoring for better yield. Due to global warming and environmental changes, plant health is deteriorating and newer problem in agriculture has sprung up. However, farmers are not always aware of the emerging diseases caused due to changing plant health factors, and more often expert interventions become essential. However, getting timely help in rural theaters pose grave logistical challenges. In our project, we designed a low-cost automated tool for monitoring plant health. This handheld device can be used in the field directly, and automates the process of disease diagnosis through image analysis and machine learning on the local mobile (smartphone) platform. Further, the internet uplink (GPRS/Edge) was used to push annotated data to centralized server systems for advanced processing and expert reviews.

II. Problem statement and project goals

A. Technological Background

Nitrogen management in agriculture plays an important role on which health or greenness of the plant depends. Experimentalists have demonstrated that nitrogen management practices have produced good crop yield and resulted in healthier plants. Additionally, overuse of fertilizer is hazardous as well as costly and can contaminate both soil and water (flowing and underwater). A Soil and Plant Analyzer Development (SPAD) meter is a device that detects the greenness of the plant or its chlorophyll content. The device monitors nutrient supply and helps in the reduction of over-fertilization. It can detect chlorophyll value within a wide range without damaging the plant(s), and can easily be carried to the field [1]. However, the whole process is very time consuming and involved individually measuring each plant/leaves. Chlorophyll content of the leaf depends on the nitrogen present in the leaf [2], and the meter measures the chlorophyll content by computing the absorbance of the leaf between red and infrared regions (red-peak absorption maximum for chlorophyll is 680/700nm). For any particular species, higher SPAD value indicates healthy plant, e.g. the optimum value for rice leaf greenness is 36. If the SPAD value is below the optimum, nitrogen fertilizer should be applied. The reading of SPAD meter could be affected by many factors such as cultivator, year, growth stage, leaf thickness, leaf position and the measurement of the point of the leaf (Ata Ul-Karim *et. al.*, 2014; Hu *et. al.*, 2014) [3]. The different SPAD values are used to eliminate the influence of genotypes and developmental stages. Inspite of these advantages, the SPAD meter is too costly to afford for a farmer of developing countries (almost USD2000), which is further complicated by low per-capita landholding in these countries. On the other hand, countries like India has a very high mobile device penetration (more than 1 billions units in operation), thus we envisage developing simplified low-cost mobile tools that can accurately deliver chlorophyll quantification and disease detection using image analytics [4] and machine learning [5].

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Rice diseases are of three types- bacterial, viral and fungal. The common rice diseases are sheath blight, bacterial leaf blight, narrow brown spot [6] etc. The bacterial or fungal diseases in rice spread quickly and may hamper crop yield. Farmers should get proper training about disease detection, control measures and remedies. Most of these diseases can be seen by naked eyes, but further microscopical study should be done to understand the real nature and extent of damage. The whole evaluation process in cumbersome, and involves sending samples to a testing center and waiting for results, leading to loss of valuable time, which might translate into loss of the entire crop. Our device can effectively automate the process, cut down the turnaround time and immediately deliver indicative results. This will allow farmers to take remedial measures sooner and help in a sustainable agriculture - in a long term safeguarding against financial and food crop losses. For operational requirements we extended the ambit of the study to a broader Poaceae family (rice, wheat, maize) and were able to obtain reproducible results.

B. *Aims and Objectives and the implementation status*

- **To detect the chlorophyll content of the leaves:** Our primary goal is to develop a low cost device which delivers a reliable measurement of Chlorophyll in leaves. **Status:** The goal was completed between 1-8 months of the project and we developed 3 different working prototypes of the system (clip-on microscope, USB/ wifi microscope, and LED ring integrated imaging system).
- **To diagnose the disease in the rice plant:** Image acquisition was done using a low-cost microscope capable of taking high-resolution images of diseased part of the plants. These images can be processed on the mobile device (using an app) and matched against a database using machine learning (ML) methods to pin-point a disease early.
  Status: The app development (on Rasberry Pi) was completed and image processing /spectral unmixing tools was successfuly develeped. ML using Windows Azure platform is currently underway, followup grant has been secured.
- **Creating high-dimensional database using on-ground imaging system and demographic data:** Since the farmer is using his phone to take images of the crop and monitor its health, we can acquire rich data on soil and irrigation conditions, crop output and disease outbreak data year on year. This data can be fed into an integrated GIS which will help in better forecasting and policy formulation by governmental bodies, ensuring delivery of benefits directly to the farmers.
  Status: We have developed a rich dataset of 2000 + images and 40+ multispectral datasets using on ground images. Collaboration with NGOs and other government organizations for integrating with GIS has been initiated however, at time submission of report all necessary process has been completed due of operational delays, insufficient funding and delays in obtaining regulatory clearances.

C. *Key identifiers of the proposed system*

The key identifiers and innovations of the project are both technical and socio-ecological, the same are enumerated:

1) **Socio-economical** The final cost of the entire add-on imaging module for less than 34 USD (plus smartphone is available for approx 60-80 USD). This offers huge cost benefits over existing devices like SPAD meters (1000 USD and upwards)
2) **Technological** The system integrates both chlorophyll measurement as well as disease identification in the same module and delivers results on-field, such level of automation has not yet been achieved in existing state-of-the-art devices.
3) **Scientific** Automated multispectral imaging and spectral unmixing algorithms were implemented successfully. The spectrally enriched images enable early detection of diseases and offer new perspective in terms of plant health evaluations.

III. Description of developed solution

A. *System design and workflow*

The proposed system involved development of the hardware system as well as software/ image processing framework.

- The hardware module integrated a mobile phone, a multispectral light source, microscopy module and a solar charger module (for long electricity supply free operation).
- The software application was developed to acquire the images using the microscopy module and enable processing of the images. Several algorithm packages were developed by our team. The required algorithmic components included: (i) auto white-balancing, (ii) image acquisition, (iii) image segmentation, (iv) spectroscopic measurements (spectral unmixing) for detection of chlorophyll and (v) disease diagnosis by machine learning and cloud based learning networks.
- A Windows Azure cloud based storage and processing system is being developed for storage of data and development of deep-learning networks.

The imaging system (first prototype) is illustrated in Fig. 1 and image processing pipeline is shown in Fig. 3.

B. *System operation*

We took the images through mobile microscope (along with LED Plant growth light). We experimented with several microscope modules using clip-on microscopes, foldscopes [7], Raspberry Pi and USB/Wi-Fi microscope modules. Raspberry Pi was heavily used for rapid prototyping, development algorithms, and refining of graphics user interface (GUI), as seen in Fig. 2. The imaging system (first prototype) is illustrated in Fig. 1 and image processing pipeline is shown in Fig. 3. The final prototype (field deployment version) used a Wi-Fi microscope (Max-See Wi-Fi Digital Microscope) connected with the phone and the images were taken from the infected part as well as from the healthy part of the leaf. Images were taken in the sets of three colors (white, blue and red

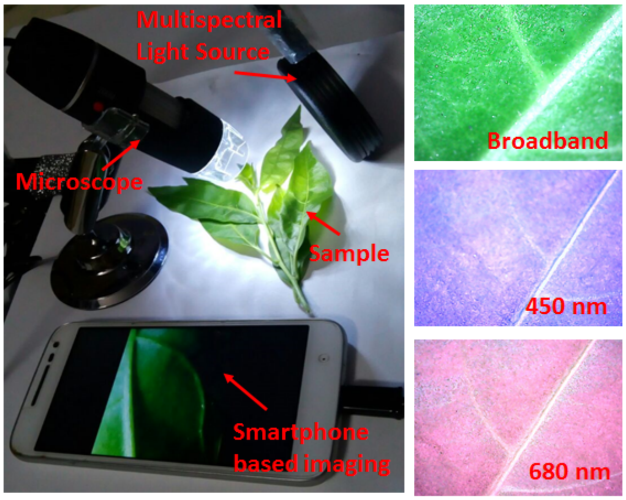

Fig. 1. System components and its integration. The images (right) shows the multispectral acquisitions at broadband and two different light bands.

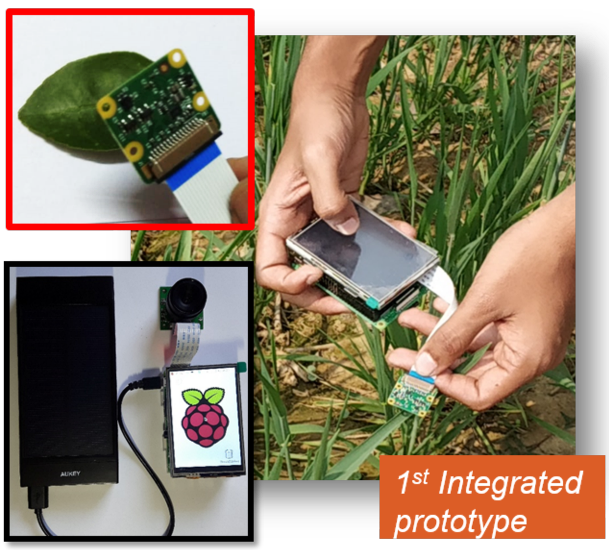

Fig. 2. First integrated prototype developed Raspberry Pi with integrated camera with multifocus lens module was used. The whole system was operated by a solar charged power bank. A easy to use GUI with touchscreen functionality was developed and tested on-field.

light) to make a multispectral dataset. The microscope and the LED light were used simultaneously over the selected leaf area, without any disturbance and the images were grabbed used the GUI on the mobile device. For standardization and white balancing, a color card was used (2 images per imaging session), for extended imaging session the calibration was re-checked every 45 minuted bases on changing sunlight [8]. For the images, the canopy leaves of the vegetative plant is chosen, as it contains the highest nutrition among the leaves and shows a better greenness, without damaging the leaf. The vegetative phase (tillering and stem elongation) is chosen for the study as this phase required maximum nutrient [9]. Images of green leaves and yellow leaves are also taken to compare the nutritional requirement. The yellow leaves indicate nutrient deficiency or lack of water in the field, also gives an idea about chlorophyll content. The greenness can be detected by the Leaf Color Chart developed by IRRI [6]. The complete statistical study on the greenness of leaf is still ongoing and is part of our future roadmap. We are hopeful that the proposed device and developed algorithms will be helpful for farmers of the developing countries to apply fertilizer as chlorophyll content is a good indicator for it, as per requirement and also to detect crop diseases. It will secure a high crop yield and low environmental hazard including excess use of chemical fertilizers and its leaching in the soil making the soil contaminated.

Fig. 3. Workflow of the automated segmentation pipeline, the system was able to detect the background and effective reject it; thereafter it selected the correct ROI and then automatically segment out the lesion.

C. Identification of diseases

The diseases that are detected from the imaging trials and the predicted remedies are as enumerated,

1) **Wheat Streak Mosaic**: The virus causes a yellow discoloration of leaves, this may also occur due to use of excess water.
   Remedy- Glyphosphate hercbicide can be used at least 3 weeks before planting, management practices of wheat curl mites (disease transmitter) and disease.
2) **Powdery mildew**: The disease appeared as white lesions on leaves with white cottony growth of fungus.
   Remedy- proper use of fungicide (foliar or ground spray) and use of fungicide treated seed.
3) **Leaf rust**: The symptoms are small, orangish-brown blister like lesions, that occur on the leaf blade and leaf sheath. Its mainly a fungal disease.
   Remedy- plants can be prevented by foliar spray of fungicide (triazole fungicides)

4) **Tan spot**: This is a fungal disease where the symptoms appeared as lesions with yellowish margin. The lesions are initially small but merge as they expand, resulting in large sizes.
   Remedy- Avoid planting in wheat residue and foliar spray of fungicide, one to two weeks interval depending on the outburst of the disease.
5) **Stagonospora nodorum blotch**: The lesions are brown colored or honey-colored fungal spots with yellow halo. Sometimes the shape of the lesions are irregular.
   Remedy- Seed treatment with fungicide, foliar spray of fungicide, crop rotation. Our system of capable of identifying these diseases (Fig. 4) and offer advisory to the user (farmer). But further development of ML engine and addition of larger training data is needed to make the process sufficiently robust and fully automated.

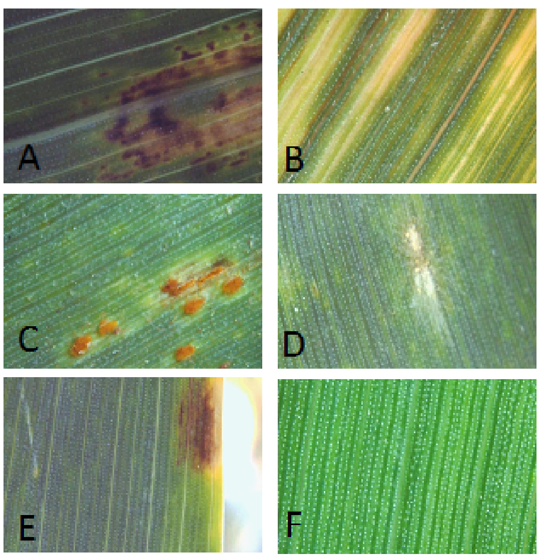

Fig. 4. The proposed system identified several disease conditions under field testing conditions, (a) Stagonospora nodorum blotch, (b) Wheat Streak Mosaic, (c) Powdery mildew, (d) Leaf rust, (e) Tan spot and (f) normal leaf (control).

D. Multispectral chlorophyll mapping

At the heart of the our system lies a novel mutlispectral unmixing algorithm for extraction of chlorophyll map. As mentioned earlier we used RBW color channels to obtain multiple images of scene / leaf segment. Thereafter, the images were suitably filtered and corrected for color drifts, chromatic aberrations, and interband motion to reduced variability while constructing the spectral data-cube. One the data-cube was prepared we applied a vertex component based fast multi-spectral algorithm [10], [11] to give each pixel a color code based on estimated value of chlorophyll. This created an leaf chlorophyll map as shown in Fig. 5. The generated leaf chlorophyll maps clearly shows the drop in chlorophyll content in leaves having lesion or lack of nutrition/ water content. The spectral values offers a (semi-)quantitative measure to understand the nutritional requirements of the food crops and detect onset of diseases early. A detailed description and analysis of several multispectral imaging methods developed by the research group is beyond the scope of current report, but interested readers are request to refer the cited literature of TU Munich [12].

The results of the chlorophyll mapping was validated by traditional (bright field) microscopy with manual annotation of high/low chlorophyll regions of individual leaves. Further, the general quantification value of healthy and unhealthy leaves were compared with literature values of SPAD meters. Overall, a 70% accuracy was achieved for spectral mapping, however strong crosstalk between the different molecular components exists.

IV. Project deliverable and experiences

A. Consolidated expenditure report and followup funding

The project balance sheet is provided in Table I, additional expenditure is expected to be incurred in the patenting process, which will be absorbed by team members and followup funding. The funding from IEEE RAS is primarily invested in hardware design and prototype development. In due course of the project we were able to obtain followup support by Microsoft Corporation under the AI for Earth program, where we are exploring cloud based solutions for big agricultural data processing. Given the successful completion of Phase-I, we are currently preparing our application for Government of India[1] [2] funding for further continuation and scale-up of the project.

TABLE I
Project Balance sheet (in USD)

Description of item/service	**Expenses**
Electronic Design (Hardware systems)	1335.33
Farm testing equipment (incl. pot expt.)	83.82
On-field testing (Farmer/ volunteer)	167.21
Lab. Analysis and Data Mangement	289.11
Chemicals/ Fertilizers (For control expt & analysis)	33.15
Conference/Training (Travel and registration)	950.84
Patents/ Publishing* (Partial payment)	402.43
Total † (233432 INR)+ Misc FC Markup (41.16)	**3303.05** USD

* In process (To be fulfilled by personal funds/ followup grants)
† Received in INR after FCY markup and deductions

Project timelines:

The total approved runtime of the project is tentatively 14 months, however, the proposed timeline was exceeded and the project is reported in 20 months. We thank for the patience on the part of IEEE RAS for accommodating the extensions and wait times. The project envisaged collecting data from two seasons, for data validation and reproducibility of methods. However in 2018, designated groups did not cultivate rice or were not successful due to environmental problems leading to inadvertent delays.

[1]Biotechnology Industry Research Assistance Council (BIRAC),
[2]Indian Council of Agricultural Research

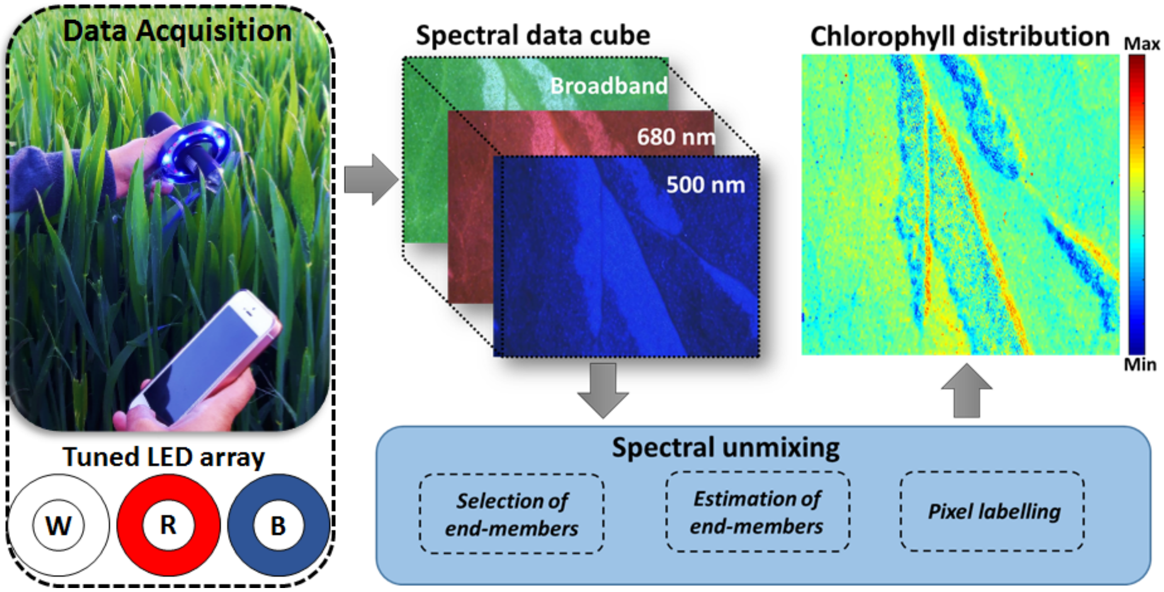

Fig. 5. Chlorophyll distibution mapping using multispectral data: The LED are tuned to different colors and image acquisition is synchronized to capture images at different wavelengths/colors (red-R, blue-B, and broadband/white-W) of incident light. The multi-wavelength images are reprocessed and co-registered to form a spectral data cube. A spectral unmixing algorithm is employed to map the pixels as per the chlorophyll distribution. In the current output image the midrib/veins of leaves show higher chlorophyll concentration, whereas the lesion show markedly low chlorophyll concentration.

B. Partnerships and social impact

The members of the project worked very closely with the Electrical engineering and Agricultural and Food Engineering departments of IIT Kharagpur and the IEEE Student Branch of IIT Kharagpur. We recruited an intern from KIIT University, Odisha who worked on hardware development. We made approximately 12-15 prototypes of different configurations and distributed to several student volunteers and farm labourers, thus creating a steady stream of data for our study. Additionally, we also carried out experiments with the collaborators in Germany (Munich/DE, Heidelberg/DE, Silesia/PL) leading to a more diverse dataset of wheat and maize, making the entire system more robust and useful. More recently we have established a research collaboration with ICRISAT Hyderabad, a nodal rice research institute globally to further our goals.

C. Dissemination of Results

The work was selected and presented at the 6th Heidelberg Forum for Young Life Scientists (EMBL Heidelberg) 2019 and Microsoft EarthLab 2019, Berlin. The project members participated in the 3rd APPN Meeting featuring Field Phenotyping and Remote Sensing in Vienna, Austria. Currently, we are working toward a patent for our hardware system and methods, publication of final results are due after conclusion of the patent filing process.

D. Overall achievements of the project and problems in implementation

In this project, we achieved the goal of developing a low-cost easy to used mobile phone based plant health monitoring system. We were able to execute spectral unmixing methods on the acquired data and obtain semi-quantitative maps of tissue chlorophyll content. The state-of-the-art chlorophyll measurements devices are costly difficult to operate, we were able to successfully demonstrate a more efficient methods of data extraction and understanding plant nutritional requirements. The new method being cost-effective and based on already existing mobile phone infrastructure has a high potential of being adopted in common agricultural use in near future.
Agricultural fields are hazardous work environments, our prototypes will require more testing and quality control before being able to withstand long working hours. Additionally, there are noticeable variation between crop varieties and environmental, addressing such challenges will require additional data collection from varied location and their analysis. Achieving the same will require sustained multi-year funding and laboratory support, which we are seriously limited with at this time. Further, the drought scenario in summer, and Indian elections in 2018 with local political volatility hindered data collection and field testing even though prototype was ready. Additionally, the farm working needed training on plant handling of instrument and using it to identify plant diseases. Given the limited period of project runtime and long learning curves, we had to recruit more trained volunteers as opposed to farm labourers for data collection. In this project, we initiated work on ML based automated disease detection but it will required more dataset (currently we are acquiring) to provide accurate results. We also envisage delivering results to farmers in vernacular languages, but this will be only attempted at later stages when development of core components of the device are complete. Alternatively, we used color coded results (red/ yellow/green) to give an easy indication of crop health to the users.

V. CONCLUSIONS

The developed portable plant imaging device costs only USD 20-30 per unit (approx. without phone) making it more affordable for small to medium scale farmers as compared to expensive SPAD meters. Moreover, we were able to identify plant diseases based on the plant images, which other spectral imaging devices are not useful for. In India, nowadays, android cellphones and internet is much cheaper and easily accessible [13] even in rural areas. The government is encouraging farmers in using different android apps and other facilities for improving agricultural yield [14]. Thus, handling of this device and apps will be even for affordable and accessible to the farmers. We believe our device can automate early disease identification in food crops and enable smart agriculture and empower the farmers in remote corners of developing world.

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