On sensing non-visual symptoms of Northern Leaf Blight inoculated maize for early disease detection using IoT/AI

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Abstract

Conventional plant disease detection approaches are time consuming and require high skills. Above all, it cannot be scaled down to smallholder farmers in most developing countries. Using low cost IoT sensor technologies that are gas, ultrasound and NPK sensors mounted next to maize varieties for profiling these parameters on a given period. Here we report an experiment performed under controlled environment to learn metabolic and pathologic behavioral patterns on healthy and NLB inoculated maize plants by generating time series dataset on profiled Volatile Organic Compounds (VOC), Ultrasound and Nitrogen, Phosphorus, Potassium (NPK). Dataset has been preprocessed with pandas and analyzed using machine learning models which are dickey fuller test and python additive statsmodel and visualized using matplotlib library to enable the inference of an occurrence of a disease a few days post inoculation without subjecting a plant to an invasive procedure. This enabled a deployment and implementation of noninvasive plant disease detection prior to visual symptoms that can be applied on other plants. With analyzed data, the IoT technology in this experiment has enabled the detection of NLB disease on maize disease within seven days post inoculation because of monitoring VOC and ultrasound emission.

1 Introduction

Plant diseases are caused by chronic or emerging pathogens that result in stagnant growth of about 10% in the plant system [1]. Meanwhile, [2] has reported maize loss due to plant disease by 40% in East Africa, and these diseases keep spreading to other areas. [3] realized that food security as a part of zero hunger sustainable development goal number two (SDG-2) is becoming almost unattainable given the increase in global human population and plant diseases causing diverse effects on livestock health and human demographic patterns.

Existing technology-based approaches for early disease detection vary from the wide range of biomolecular approaches like Polymerase Chain Reaction (PCR) and Enzyme-Linked

Immunosorbent Assay (ELISA) [4]. Despite these approaches being accurate, the access to equipment and skills to perform such experiments is not affordable for smallholder farmers in developing countries. Furthermore, these experimentation approaches require a destructive procedure to a sample (plant) [5]. On the other hand, as an alternative to overcome those limitations [4] implemented a noninvasive approach that profiles volatile organic compounds (VOCs) to late blight-infected tomato using an imperceptible sensor patch integrated with graphene-based sensing materials, which captures the plant's Deoxyribonucleic Acid (DNA) properties for real time detection. However, development of such technology is highly expensive to make it viable for the mass market of smallholder farmers.

Moreover, the detection of crop diseases via VOCs has also been confirmed by [6]– [8] where plants emit VOCs in a peculiar pattern when infected by a disease and this can be profiled as a plant's mode of communication. Additionally, a study done by [9] confirmed the rapid growth interest in profiling plants' VOCs as a factor for identifying metabolic and pathologic processes in the plant system. In parallel to VOC, there are different modes of plant's communication, it has also been reported in [9] that when a plant is stressed/unhealthy it emits sounds. A few research works have been done on this area includes [10] who observed that tomato and tobacco when cut (stressed) emits a mean value of 65 dB for an airborne sound, compared with the ambiance sound level for the quiet urban daytime or suburban area which ranges from 45 – 50 dB [11]. Therefore, sound is an additional parameter that may be sensed to spot diseased crops and it has also been observed that the fertilizer consumption rate varies when a crop becomes unhealthy as per study done by [12], hence a special interest on these parameters.

In that regard, on leveraging the latest advances on IoT sensing technologies, this paper aims to present the data collection experimental approach for noninvasive disease detection by using affordable and low powered Internet of Things (IoT) technology. Moreover, given the lack of open dataset for characterizing diseased maize during the pre-visual symptom disease cycle, the paper describes the procedures for time series dataset generation for both healthy versus laboratory inoculated maize crop through data collection of VOCs, ultrasound and NPK consumption over a period starting from when the maize plant is cultivated to inoculation, up until when visual symptoms appear, in our experimentation this period was about 35 days. This paper is hereby categorized as follows; section 2 is focused on the experimentation approach for data collection by providing a clear depiction of the methodology used for generating inoculums and introducing the spores on maize plants; and it describes the IoT data collection devices used in our experimentation campaign. Section 3 provides the highlight of the analysis on the collected dataset and predictive machine learning model training. Section 4 concludes on the highlighted analysis of data versus the early detection of maize disease.

2 Materials and Methods

2.1 Experimentation Approach for Data Collection

Northern Leaf Blight on Maize: in this study, we identified Northern Leaf Blight (NLB) as the most prominent and almost neglected disease that affects maize plants in the region. NLB is caused by a fungus scientifically known as *Exserohilum turcicum* [13] and it can be identified by relatively large gray elliptical or cigar-shaped lesions that develop on leaves ranging from 1 to 6 inches long. It is favored by high relative humidity and cool to moderate temperature conditions. NLB occurrence results in yield loss of up to 30 to 50 percent when it develops early in the season, with the diseased plant undergoing a premature death due to inability to photosynthesize caused by leaf blighting [14], [15]. Under these circumstances, if the plant is left untreated or unattended, sporangia can spread to other plants since plant pathogens take up to 2 weeks [16] to spread from infected plants to uninfected plants; thus, causing a huge loss to the farmers.

Study Area and Field Management; controlled environment experiments were laid out at Sokoine University of Agriculture in Morogoro, Tanzania. Four maize varieties that are either resistant or susceptible to NLB disease were selected for this experiment considering that they are commonly used by small holder farmers and highly recommended by seed suppliers in the region. These varieties are: DK8033, DK9089, SeedCo 719 (Tembo) and SeedCo 419 (Tumbili). Maize seeds were sown in four liters plastic buckets, four seeds per pot, at 7 cm distance from each other (Fig. 1). The experiments were made up into two sets where set 1 contained treatment One (T1) as control (healthy) and set two with treatment Two (T2) NLB inoculated plants. Each set of treatment had eight buckets randomized in such a way each maize variety had equal chance of receiving light, temperature, and humidity gradients. The plants were irrigated twice per week and fertilized with 10 mg of NPK two weeks post sowing and after 6 weeks from first application (Fig. 1).

Fungal Isolation, Inoculum Preparation & Application; *E. turcicum* was isolated from diseased maize plants. The sterilized tissue pieces were cultured on potato dextrose agar (PDA) medium and incubated at 24°C for 14 days under specific light/dark cycles to induce sporulation. Fungal colonies were checked for *E. turcicum* spores and subcultured for pure culture production. After 14 days, pure cultures were used to prepare a spore suspension which was quantified using a hemocytometer. The spore concentration was adjusted to 106 spores/ml. The suspension was sieved, filled into bottles, and used to inoculate eight-week-old maize seedlings. Control plants (T1) were treated with sterile water, while experimental plants (T2) received the spore suspension. The inoculation was performed during cool hours to support spore survival and maintain humidity. Both sets of plants, placed 5m apart, were grown for 90 days under screen house conditions and checked bi-weekly for disease and pests. This ensured T1 plants remained healthy, while NLB affected T2 plants.

Fig. 1. Maize Plant Experiment set with inoculum, spore on the middle and last is the application of inoculum spores on maize plants

2.2 IoT Based Data Collection Approach

The study employed low-cost IoT sensors for non-invasive disease detection in plants. Placed 35 days post-inoculation, these sensors measured parameters including VOCs, soil nutrients (NPK), and ultrasound to detect non-visual symptoms of NLB as shown on Figure. 2. A Bosch BME688 Development Kit, connected to a 5000mAh power bank, was used to identify gas emission patterns. Ultrasound data was collected by two sound sensors - OSEPP Electronics Multiple Function Sensor and DAOKI Sound Microphone Sensor - programmed on ESP8266. These sensors transmitted data to the cloud via ThingSpeak. Taidacent Soil NPK and JXCT soil NPK sensors monitored NPK levels. These sensors were powered by a separate 12V adapter and communicated via the ELEGOO Nano Board CH 340/ATmega+328P microcontroller. All data was stored for later analysis. Environmental factors like temperature, humidity, and barometric pressure were also monitored to validate experimentation conditions.

Fig. 2. Data collection using IoT sensors on Volatile Organic Compounds, microphone sensors and NPK fertilizer.

3 Results and Discussion

In the study, time-series data were collected from both healthy and inoculated maize crops using VOC, ultrasound, and NPK sensors. Data cleaning was conducted to omit unrelated parameters, providing a univariate dataset. The Dickey-Fuller Test (ADF) checked data stationarity, indicating a strong trend and seasonality in VOC emission and ultrasound data, thus providing predictable patterns. The VOC emission profile for the control maize plant decreased over time, whereas for the NLB-inoculated maize plant, it increased as shown on Figure. 3. The statsmodels library was used to decompose the data into trend and seasonality, revealing a daily VOC emission pattern. Ultrasound values differed significantly between healthy and inoculated maize, with stress from disease inoculation increasing the sound emission above ambient levels in the latter. NPK consumption patterns were less clear, showing a lower, more systematic pattern in healthy maize and a more randomized, higher pattern in inoculated maize, suggesting less efficient nutrient consumption in diseased plants.

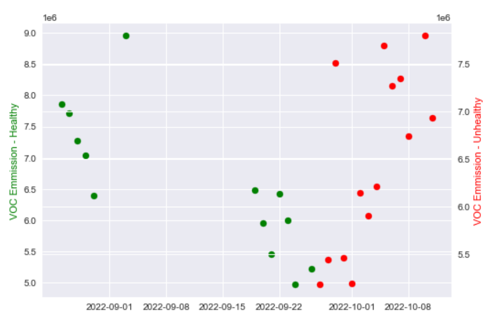

Fig. 3. Calculated mean sample of VOCs emission for healthy vs inoculated maize

4 Conclusion

The study leveraged IoT sensing technologies to detect non-visual symptoms of Northern Leaf Blight, a critical maize disease in East Africa, as a first step towards developing an early disease detection device. The research generated reusable time-series datasets and found that VOC and sound level patterns increase as the plant communicates its distress. Notably, the study proved that non-visual symptoms of the disease could be detected within less than seven days, earlier than visual symptoms, aiding in early detection and reducing yield loss.

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