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Soil Monitoring System for Efficient Soil Biome Management and Crop Guidance

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ABSTRACT

The paper describes an Internet of Things based data driven soil monitoring system that could be planted on varied locations of an agricultural field for tracking various essential soil health parameters like carbon content, nitrogenous content or NPK, in general, soil moisture, temperature (both at soil level and above surrounding environment), colour, etc. in real-time for quick and efficient management of soil health and thus, providing an all-round mechanism for ensuring optimal soil health quintessentially for use in agriculture-dependent domains. Some ready-to-use out-of-the-box features of the system are weather monitoring and alert in case if harsh weather is predicted in the nearby future, location tracking of the device, crop recommendations based on soil profile and a novel design to mimic a scare-crow in order to attract less attention from miscreants while performing a traditionally effective way to fend of avian attacks on the crop.

Key words : Internet of things, soil monitoring system, soil biome management

INTRODUCTION

Agriculture has been with mankind from its cave-dwelling days and is a major supporting force in growth of the human race. It has been passed from one generation to another while adding some advancement, adaptability and the cycle has continued till now. We've seen significant increases in yields, profitability, and so on. However, all of this came at a cost as the productivity of the soil was reaching its tipping point and the very fertilizers that provided the boost in the yield slowly made the soil unsuitable for agricultural usage by altering its natural composition. The excessive use of fertilizers on the field which results in left over nitrogen, sulfur, etc. that hasn't been absorbed by the plants, reacts with the environment to produce Green House Gases (GHGs), primarily nitrous oxides, etc. (Jacob, 2018). Agricultural practices alone account for 70% of all nitrogen emissions which is a major Greenhouse Gas. This leads to a much bigger problem of climate change, a situation that has arison only due to the widespread sub-optimal practices performed by unaware farmers. So, in this paper, we present a complete soil monitoring system that could potentially help the farmers make smart decisions with the help of real-time tracking of the key soil parameters, getting forecast for harsh weather ahead in order to better prepare for that and recommend crop combinations for rotation cycle and other cover crops in order to ensure a good yield with high biodiversity thus, providing the soil enough time to replenish its nutrients which are used away when a single variety of crop is planted every year.

MATERIALS AND METHODS

The aforementioned device is a step towards widespread incorporation of new age technologies like AI, IoT and Cloud to increase the efficiency of the most basic yet important lifeline of humanity, namely, agriculture. Climate change has taken a toll on agriculture for the worse and currently there are no signs of this situation getting any better in the near future unless a smarter way to do things is adopted. Uneven precipitation patterns and extremities in heat waves would become very common and would result in shrinking agricultural zones, failure of traditionally high yielding crops, floods, droughts, threats from new types of pest and consequently usage of high amounts of additives like fertilizers, pesticides to sustain in such scenario (Climate Change and Agriculture, 2019). This would lead to a recursive cycle of events that would send ripples through the agriculture sector with no clear way out. Agriculture dependent economies would take the major hit without a proper support mechanism in place. Thus, in order to prevent the upcoming agrarian crisis, there is a dire need to optimize the sub-optimal agricultural practices that are a major reason behind climate change.

It would be a decisive step forward in order to ensure sustainability of the agricultural sector if the farmers could know the key parameters of soil health in real-time, where and how much fertilizers or other additives need to be added, and even to protect the crops from the approaching bad weather through early alert mechanisms. This would ensure that the additive chemicals are efficiently absorbed by the crops and the leftovers don't get converted into harmful greenhouse gases (GHGs). At the same time, this would help to maintain a long-term fertility of the soil and reduce the disease infestations by building a natural defense mechanism that could blend into the normal agricultural practices.

Lindores *et al.* (2015) disclosed a system for agricultural and prediction comprised a first reporting agent, a second reporting agent, a database, and a processor. The first reporting agent is configured for reporting aerial data representing relative measurements of an agricultural metric in a geographic area, the relative measurements having an unknown bias. The second reporting is configured for reporting ground-based data representing absolute measurements of the agricultural metric for a portion of the geographic area. The database is configured for storing the absolute measurement data and the relative measurement data along with other farming data for a wide geographic area. The processor is configured for accessing the database and using the ground- based data for the portion of the geographic area to calibrate the aerial data, thereby synthesizing absolute measurements of the agricultural metric for the geographic area from the aerial data.

Lindores (2018) disclosed a method of generating a crop recommendation, a plurality of data sets are received by a computer system from a plurality of disparate data sources, wherein each of said plurality of data sets describes a factor affecting a crop. A benchmark is created by the computer system for each of the data sets which describe how the factor affects the market value of the crop. A model is generated by the computer system which describes the crop based upon each of said benchmarks from the plurality of data sets. A report is then generated by the computer system comprising at least one recommendation to increase the market value of the crop.

Though this approach has the benefit of increasing the yield of agricultural land and short-term profits, it lacks the central motive of sustainability. With minimal biodiversity on large fields of land due to the prime focus on getting more profit, this dependency on a single high-yielding crop is susceptible to greater risks from pest attacks and the lack of diversity further amplifies the problem of climate change (Climate Change and Agriculture, 2019).

Ersavas *et al.* (2020) disclosed a wireless system provided for monitoring environmental, soil, or climate conditions and controlling irrigation or climate control systems at an agricultural or landscape site. The wireless system includes a wireless sensor network including a plurality of sensor nodes for monitoring environmental, soil, or climate conditions and controlling one or more irrigation or climate control systems at the site. The wireless system also includes a server computer system located remotely from the site. The server computer system is coupled to the wireless sensor network over a communications network for receiving data from and controlling operation of the sensor nodes. The server computer system is also coupled to a device operated by an end-user over a communications network for transmitting the data to and receiving remote control commands or queries from the end-user.

A problem that a system mentioned in Ersavas *et al.* (2020) would face in unfenced agricultural fields especially in developing countries like India, Bangladesh, etc. where majority of agricultural land has little to no fencing at all is a matter of concern as the sensors would surely acquire unnecessary attention from passer-by and always carry a risk of being damaged by miscreants. That would be a major setback to the farmers installing it in their fields. Consequently, the acceptance of such a device would be very low in these potentially huge markets unless some sort of counter measure is provided so that the sensor module blends in with the environment.

Hernandez (2016) disclosed a real-time interactive monitoring system for precision agriculture for obtaining the real conditions of a plot or piece of land. The system comprises : a plurality of sensors situated in various parts of the piece of agricultural land and connected to a central node by means of a network of nodes; a data processing system for working with large volumes of data; at least one database located in at least one server; and a web interface that allows the collected data to be viewed.

The solution proposed in Hernandez (2016) could be further enhanced by making a multilingual mobile application that could be widely accepted in agrarian economies with a vibrant diversity in terms languages spoken like in India. This would ensure an ease of knowledge transmission along with wider acceptability rates.

The primary objective of the present invention is to provide a cost-effective IoT and Cloud-based solution to counter the aforementioned agrarian crisis, a waterproof casing to encapsulate the collection of sensors used in the device, a microcontroller for IoT, a wifi-module to communicate with the REST API deployed in the cloud, a location tracker, a power source.

The soil monitoring device containing the array of sensors can be left at the agricultural land or any other region of interest to track various key chemical and physical parameters of soil like carbon monoxide, nitrogenous content (Arun *et al.*, 2018), Tianlong (2010) humidity and Raju *et al.* (2019) soil moisture, pH, colour, etc. of the soil and the weather of surrounding environment in real-time using the device's location, forecasting of harsh changes, and generating alerts.

The following diagrams display the key functional units of the device and in no circumstances should it be considered as the limitation to scope of this proposal (Figs. 1 and 2).

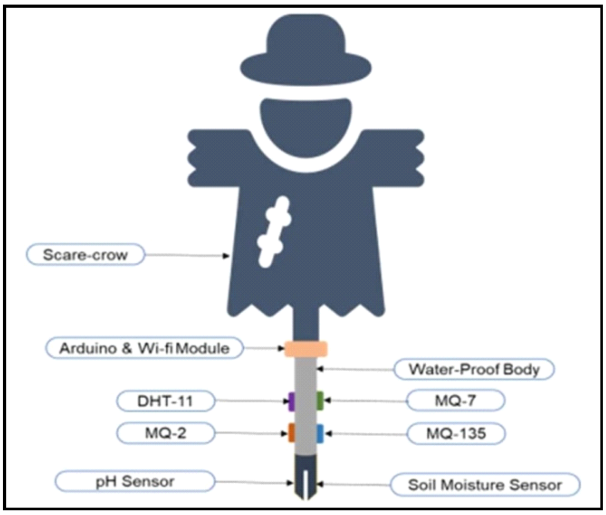

Fig. 2. Design of the proposed invention.

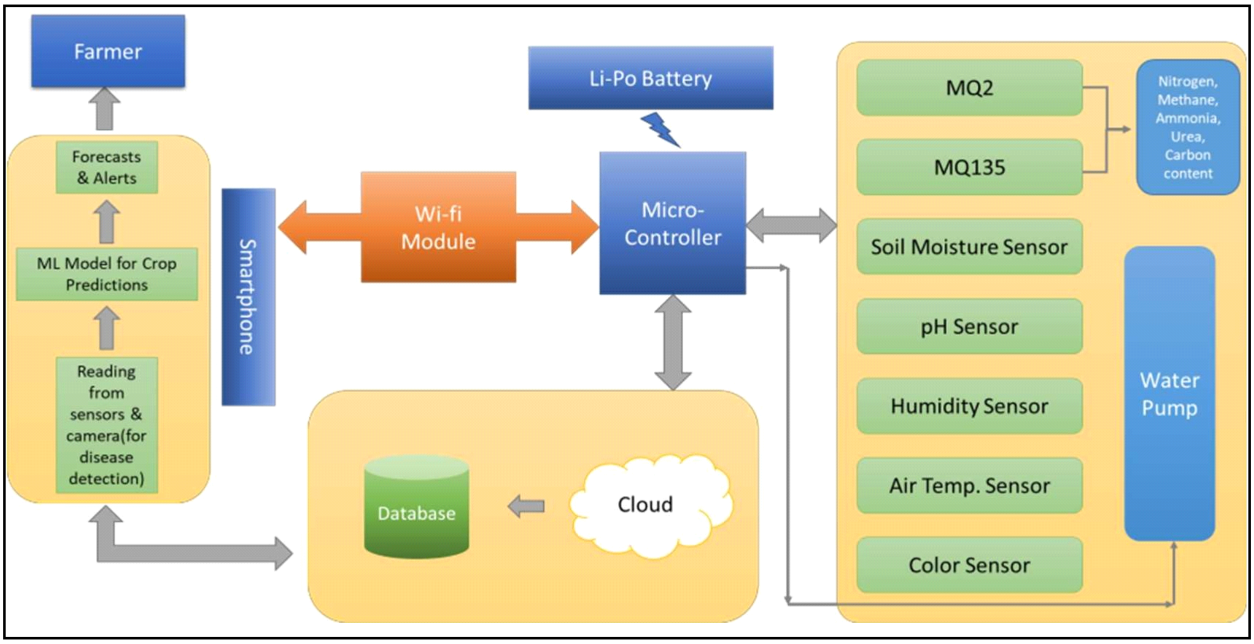

Fig. 1. Block diagram of the device of the invention.

RESULTS AND DISCUSSION

This monitoring device once planted generates near real-time alerts on overuse of fertilizers due to which the leftover nitrogen, sulfur, etc. that hasn't been absorbed by plants reacts with the soil to produce dangerous greenhouse gases (Fig. 3).

Additionally, after gathering some data points containing these aforementioned key parameters affecting the soil health, the system would feed this data into an AI model trained on past soil data (Jian *et al.*, 2021) to get suggestions for not only the optimal crop for the soil that would provide the best yield but also the crop combinations that complement each other's nutrients needs and thus, lower the dependency on chemical additives in the form of fertilizers. Furthermore, once there is a substantial amount of data from the current field, the AI model is retrained using transfer learning to generate more useful recommendations, alerts and insights for that particular soil profile (Fig. 4).

Consequently, this would bring more diversity into the agricultural lands further reducing the fast depletion of some particular kind of soil nutrients, decreasing the need of chemical additives that cause climate change and would result in a more resilient soil biome that is sustainable and beneficial from the farmer's perspective as well the climate's point of view.

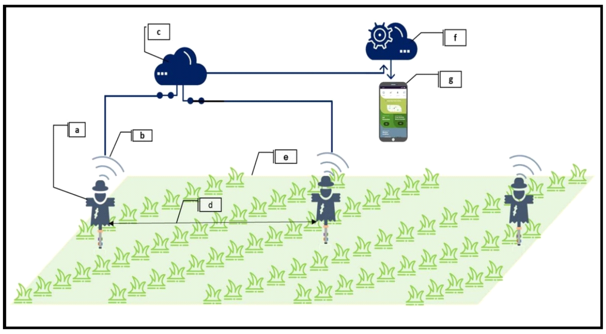

Fig. 4. Functioning of the soil monitoring system once device is planted in an agricultural field.

(a) Describes a soil monitoring device comprising of a wide range of sensors each for tracking the required soil parameters; a microcontroller for IoT and data input from sensors; a wifi-module for networking with the API and the cloud; a rechargeable Li-Po power

Fig. 3. Discloses some graphs of the key soil parameters, namely, humidity, soil moisture, nitrate contents and surrounding temperature the device tracks.

source; a waterproof fabrication enclosing the sensors; a GPS Tracking feature; a scare-crow like appearance prevents the crops from the birds while hiding in plain sight; a feature to account for the weather conditions in the device's location and forecasting; the data could then be viewed on any mobile device through the app.

(b) The data from (a) are channelled towards the REST API using a suitable network where these are fed into the AI model for crop recommendations and insights.

(c) Crop recommendations/crop-pair recommendations, soil insights, alerts, forecast, etc. are generated by the backend REST API deployed on cloud and sent forward to (f) in JSON format.

(d) A minimum distance of 20 feet is recommended for efficient performance of the cluster of devices.

(e) The agricultural field of interest where devices need to be planted.

(f) The JSON response data are processed into desired formats by the mobile app to extract the crop recommendations, soil insights, alerts, forecast generated in (e).

(g) The processed data from (f) are then displayed on the app's user interface in their local language owing to the multilingual feature.

(h) The process of testing the proposed system involved collecting soil samples from agricultural lands, then the sensory device was planted on the sample to track the aforementioned soil parameters (Table 1). The device's location was tracked and the corresponding weather data of that location are retrieved from the weather API. The collection of the soil parameters, weather and location data was converted into an input vector at each time stamp and sent as the input for the AI model to produce crop recommendations. Simultaneously, these data were tracked and tested whether all parameters were inside the safe range or not. Subsequently, the alert mechanism was triggered when a deviation (if any) was detected in real-time.

(i) The findings from the primary analyses provided the sensor readings (Fig. 5) and weather data (Fig. 6) at the test location. The analyses found that the key soil parameters like temperature,


```
▾ sensor_data:
    Temperature:        "26.00"
    Humidity:           "50.00"
    Carbon_Monoxide:    "0.00"
    Nitrates:           "1.78"
    Soil_Moisture:      "441.00"
    Smoke:              null
    Color_Indicator:    null
▾ Soil_Moisture:
    condition:          "In suitable range"
    soil_respiration:   "Optimal"
    counter_measures:   "Not Required right now!"
▾ Fire_&_CO:
    condition:          "CO levels in safe range."
▾ Denitrification:
    condition:          "Nitrate levels in safe range."
```


Fig. 5. Sensor response data from the API with associated conditions and counter-measures.

Table 1. Component table

S. No.	Name of component	Responsibilities
1.	MQ-2 Gas Sensor	Tracking methane
2.	MQ-7 Gas Sensor	Tracking carbon content
3.	DHT-11 Sensor	Tracking environment's humidity and temperature
4.	FC-28 Sensor	Tracking soil moisture
5.	MQ-135 Sensor	Tracking nitrogenous content
6.	ESP-01 Wifi Module	Providing network connectivity to the REST API and Cloud
7.	Filament Material	Providing waterproof body
8.	Arduino uno	Microcontroller
9.	Li-Po battery	Power source
10.	Scare Crow Design	Acts as a camouflage and protects against avian attacks
11.	Thing Speak Cloud	Stores soil data and provides visualization

```
▾ weather_data:
    observation_time:      "10:32 AM"
    temperature:           32
    weather_code:          113
  ▾ weather_icons:
    ▾ 0:                   "https://assets.weatherstack.com/im
  ▾ weather_descriptions:
      0:                   "Sunny"
    wind_speed:            12
    wind_degree:           235
    wind_dir:              "SW"
    pressure:              1013
    precip:                0
    humidity:              10
    cloudcover:            0
    feelslike:             30
    uv_index:              8
    visibility:            10
    is_day:                "yes"
▾ Alerts:
    safety_measures:       "All good right now."
```


Fig. 6. Weather response data from the API with associated alerts and safety-measures.

soil moisture, carbon content, smoke or nitrate content, and the weather at the device's test location were in suitable ranges. Thus, no alert or counter- measures were reported by the system. The value in the smoke field of the sensor response data was tracked as null due to lack of detection of smoke at the test location. Furthermore, the colour indicator field of the sensor response data was also tracked as null due to the inability to match the soil sample's colour with the predefined soil colour standard. This is an issue that could be solved using more soil samples while setting the colour identification threshold.

(j) Additionally, the weather response data from the API kept track of vital weather information like environmental temperature, wind speed, atmospheric pressure, precipitation, humidity, cloud cover, uv-index and visibility. Out of these data, the environmental temperature, precipitation and humidity were used alongside the sensor data and location data (Fig. 7) mentioned before and an input vector is created for the AI model to generate crop recommendations for the soil


```
▾ location_data:
    name:              "Vidisha"
    country:           "India"
    region:            "Madhya Pradesh"
    lat:               "23.533"
    lon:               "77.817"
    timezone_id:       "Asia/Kolkata"
    localtime:         "2021-03-02 16:02"
    localtime_epoch:   1614700920
    utc_offset:        "5.50"
```


Fig. 7. Location response data from the API.

sample. The rest of the weather parameters were tracked by a rolling window approach and sampled the data of the previous week in order to identify any pattern of upcoming harsh weather conditions detrimental to crop growth and generated alerts (if any) with appropriate safety measures.

(k) In the secondary analyses, the input vector created in the previous step is fed into the model which works on a voting classification methodology, effectively, the model used outputs from its component models and used these outputs to vote in favour of the best possible combination of crops suitable for the current cropping season while at the same time, the combination should be of companion crops (Companion Planting, 2021). That exhibit some kind of symbiotic relationship for mutual benefit and thus, reducing the chemical additives into the soil. The final crop recommendation (Fig. 8) exhibits such behaviour.

(l) The model was built on a partial fit approach (Tom and Scalable, 2017) with the consideration of future changes to the underlying data and thus, leveraging the power of incremental learning through batches of incoming data that are then scheduled into the learning routine. Though, the trade-off in terms of skewed learning and possibility of a high variance in these types of model needed to be kept in check while ensuring high scalability and adaptability.

```
▼ crops_suitable:
    0:    "Wheat"
    1:    "Gram"
    2:    "Mustard"
    3:    "Sugarcane"
    4:    "Sun Flower"
    5:    "Pea"
    6:    "Linseed"
    7:    "Banana"
```


Fig. 8. Crop recommendation response data from the API.

The lack of knowledge among the farmers about the importance of soil testing before the beginning of a crop season has serious implications both on the yield of the farm and more importantly on the environment. Earlier proposed soil agricultural monitoring systems as in (Lindores *et al.*, 2015; Lindores, 2018) provide a decent enough benchmark for further improvements as a system that is capable of solving the soil testing problem using real-time analysis, alerts and recommendations based on the soil's physical and chemical profile. Another problem highlighted in Climate Change and Agriculture (2019) is the negligence of the industrial model of agriculture wherein there is a complete disregard for soil biodiversity with no crop rotations, relying too much on a single cash crop and fertilizers for a better yield, which is unsustainable in the long run. To counter that, the model proposed in this paper instead of recommending a single crop variety for a higher yield, recommends crop combinations wherein either both crops complement each other's nutritional requirement or one of them acts as a natural insecticide that protects the other from pest attacks. This way the system ensures a general diversity on the field as opposed to the industrial model while reducing the dependency on chemical additives like fertilizers, etc. as now the soil is more resilient due to less consumption of a particular kind of nutrient which occurs when a single crop variety is planted every year providing very less time for the soil to replenish the lost nutrients naturally and thus, increasing the need of fertilizers.

Another key factor in maintaining a healthy soil biome is preparing for harsh weather like heavy rains, hailstorms, etc. Though the damage cannot always be mitigated but at least it can be minimized if an early forecast system is put in place. Keeping that in mind, the proposed device is equipped with weather tracking of its location and an alert mechanism that triggers in case of an anomaly. This allows for a better response plan and sufficient time to minimize the risk.

CONCLUSION

This paper presents a cost-effective IoT and AI based soil monitoring system for efficient soil biome management and crop guidance that helps to counter an upcoming agrarian crisis that is further, amplified due to the widespread of sub-optimal agricultural practices being followed across the globe that leads to overuse of chemical additives on the soil for better yield and profits with a complete disregard of the consequences. The proposed system helps in real-time monitoring, alerts on overuse or imbalance in any key parameter of the soil, forecasts weather of its location to better prepare, recommends cropping cycles that are necessary for the long-term sustainability while balancing the yield as well and finally combines all of these features into an easy-to-use multilingual mobile app for knowledge transmission among the masses. Apart from that, the sensory device is designed to give it a scare-crow like appearance that serves multiple purposes efficiently like preventing the crop from avian attacks, hiding in plain sight by blending in with the environment unlike other related proposed systems which fail to take it into account and could easily draw attention from passer-by. A promising direction for further advancements is to explore alternative renewable energy sources to power the device.

REFERENCES

Arun Sai, G., Bharat Kumar, B., Likhitha, K. S. and Anitha, R. (2018). Detection of noxious gases by implementing internet of things technology. *Int. J. Eng. Tech.* **7** : 18-22.

Climate Change and Agriculture (2019). A perfect storm in farm country, Mar. 20, 2019. *https://ucsusa.org/resources/climate-change-and-agriculture.*

Companion Planting (2021) : *https://en.wikipedia.org/wiki/Companion_planting.*

Ersavas Bulut, F., Pekol Semih and Bodur Atakan (2020). Method and system for irrigation control. US8649907B2, United States Patent and Trademark office. *https://app.dimensions.ai/details/patent/US-10362739-B2.*

Hernandez, Sergio (2016). Real-time interactive monitoring system for precision agriculture. *WO2016191893A1, https://patents.google.com/patent/WO2016191893A1/en.*

Jacob Koshy (2018). *Nitrogen emissions going up: study. https://www.thehindu.com/sci-tech/energy-and-environment/nitrogen-emissions-going-up-study/article 24090131.ece.*

Jian, J., Vargas, R., Anderson-Teixeira, K. J., Stell, E., Herrmann, V., Horn, M., Kholod, N., Manzon, J., Marchesi, R., Paredes, D. and Bond-Lamberty, B. P. (2021). A global database of soil respiration data, version 5.0. ORNL DAAC, Oak Ridge, Tennessee, USA. *https://doi.org/10.3334/ORNLDAAC/1578.*

Lindores, Robert J. (2018). Generating a crop recommendation. US10115158B2. United States Patent and Trademark office. *https://patents.google.com/patent/US10115158B2/en.*

Lindores, Robert J., Robert, Ted, E. Mayfield and Morrison Ulman (2015). Wide-area agricultural monitoring and prediction. US9058633B2, United States Patent and Trademark office. *https://patents.google.com/patent/US8731836B2/en.*

Raju Anitha, D., Suresh, P., Gnaneswar, M. and Puneeth, M. (2019). IoT based automatic soil moisture monitoring system using raspberry PI-Raju. *Int. J. Innovative Tech. Exploring Eng.* **9** : 4375-4379.

Tianlong, N. (2010). Application of single bus sensor DHT11 in temperature humidity measure and control system. *Microcontrollers & Embedded Systems* **6** : 026.

Tom Augspurger and Scalable, M. L. (2017). Partial Fit. *https://tomaugspurger.github.io/scalable-ml-02.html.*