Soil pH periodic assortment with smart irrigation using aerial triboelectric nanogenerator

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ABSTRACT

The paper presents an idea on pre-emptively ascertaining the soil pH value on an agriculture field amalgaming drone for aerial photo and subsequent smart irrigation model with the help of internet of things (IoT). The drone used for the aerial footage (multispectral imaging) consists of specialized cameras with filters that would help in ascertaining vegetation and health of the crops in the agriculture land. The IoT device used in smart irrigation model consists of sensors which accumulate data and execute the commands given in a recurring fashion of delay. Moreover, the use of triboelectric nanogenerator (TENG) would help in feasible energy harvesting for agricultural land use.

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1. INTRODUCTION

The agricultural and farming activities are hugely impacted by the soil properties and the presence of essential nutrients in the soil. To ensure the presence of ample nutrients, mapping and monitoring of soil properties is necessary as it provides farmers with various solution required for agricultural activities. The analysis of soil properties requires an observation of different mapped soil units that are obtained from an aerial photo. With the help of spectroscopy, these image(s) are used to find out the different aspects of vegetation that give us an idea about how the soil and nutrient levels are at present in the agricultural land.

The required information is figured out at different places of the land area using multiple software tools and the soil pH is determined by consistent computations. The land can also be used for monitoring the presence of ample nutrients required for thecrops to grow. Nonetheless, by making use of the IoT applications we can easily draw out a quantifiable data on the suitability of soil to farmers. A significant development in the field of farming and agriculture can be done with the help of triboelectric nanogenerators to harvest the energy using the electricity produced by the electrolyte-substrate interface [1], [2].

2. RESEARCH METHOD

Using various updated software and hardware tools the mapping and monitoring of soil properties over an agricultural land has been investigated. The subsequent steps pertaining to irrigation and farming were made simple and conventional with the help of some important tools. The steps followed below explains about the step-by-step process behind the research investigation of the work.

2.1. Drone mapping of the agricultural land

As discussed previously in the introduction, soil mapping is one of the primary reasons behind getting good yield of crops in an agricultural land. However, performing soil sampling is a tedious task and requires a lot of hard work, time and energy. Therefore, a drone was used to map the parts of an agricultural land. A F450 quadcopter or drone has been reperesnted in Figure 1. Was used to take the aerial image from 100 m above the ground with the help of a first-person view (FPV) camera at a resolution of 700 television lines (TVL). Figure 2 shows the captured image was then processed and edited to highlight the sections of land area. It was divided into 9 sections with irregular patterns of crop growth to analyse and study the soil and nutrient properties [3]-[6].

2.2. Multispectral imaging of the agricultural land

The image was then converted to an infrared one with the help of software applications to derive the pH values and vegetative indices of the land repsresented in Figures 3 and 4. The drone camera utilized for taking the aerial image has Bayer filter mosaic (a colour filter array responsible for arranging red, green, and blue (RGB) colour in the image) embedded in it. The RGB values were obtained after processing the imagein MATLAB software [7]-[11]. Ultimately, three different images were retrieved and utilized for the successive spectral process has been represented in Figure 5.

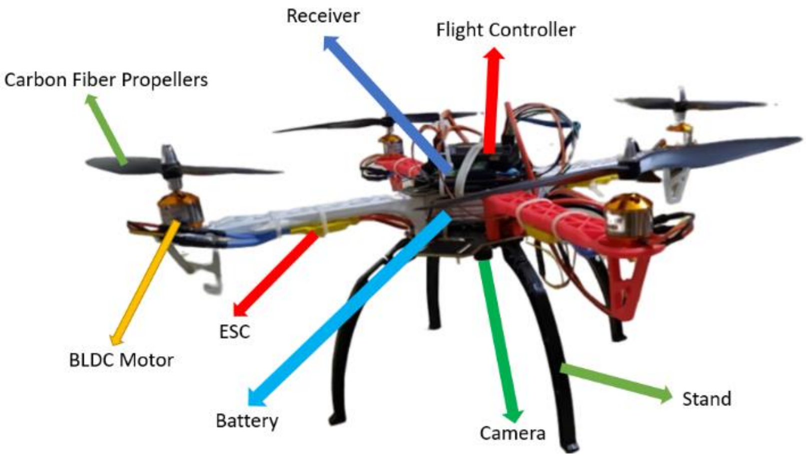

Figure 1. The F450 quadcopter

Figure 2. Aerial image of the agricultural land

Figure 3. The agricultural land with 9 divisions

Figure 4. The near infrared image of the land

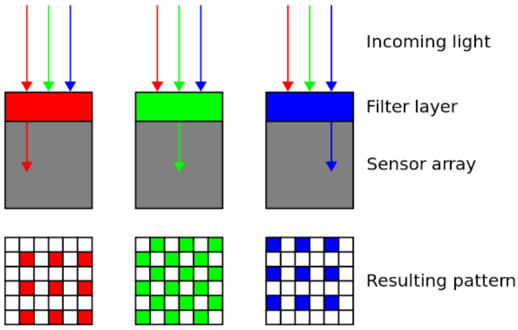

Figure 5. Working of Bayer filter mosaic

2.3. Quantum geographic information system (QGIS)

The quantum geographic information system (QGIS) is an open-source geographic information system that is used for editing, viewing and analyzing of the geospatial data or information. The QGIS is used here for determining the normalized difference vegetation index (NDVI), green normalized difference vegetation index (GNDVI), and visible atmospheric resistance index (VARI) respectively, and identify the vegetation and nutrient patterns in the agricultural land has been shown in Figures 6-9. From the figures we come to a validation of the process which we made.

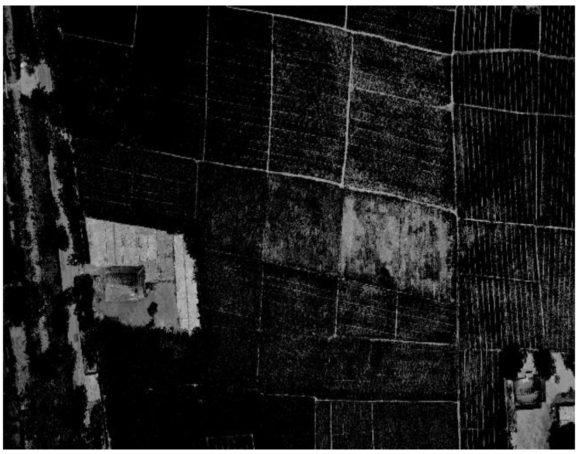

Figure 6. The red spectral image of the land

Figure 7. The green spectral image of the land

Figure 8. The blue spectral image of the land

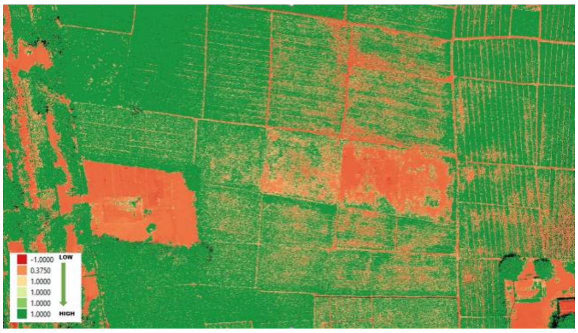

Figure 9. The NDVI image of the land

2.3.1. Normalized difference vegetation index (NDVI)

This index is a measure of vegetation in remote sensing that captures the amount of near infrared (NIR) light reflected in contrast with the visible red light. It helps in differentiating plants and grass over soil and arid regions to detect the crop stages. The formula for calculating normalized difference vegetation index is:

$$NDVI = (NIR - RED) / (NIR + RED) \tag{1}$$

by utilizing the formula and substituting the parameters with the spectral images of NIR and red respectively, a geospatial image was obtained with varying colour indices on different parts of the land [12]-[17].

The red and orange regions in the NDVI image represent the area of low vegetation or chlorophyll content. It also represents the maximum absorption of solar radiation by chlorophyll. The yellow or light green regions represent the moderate vegetation and the green regions represent the good vegetation index, chlorophyll content and presence of the macronutrients.

2.3.2. Green normalized difference vegetation index (GNDVI)

Green normalized difference vegetation index (GNDVI) is similar to NDVI with an exception that instead of the red regions in the agricultural land, it accounts for the green regions. It represents the photosynthetic process in the healthy and good vegetation areas. In addition, it is more sensitive to chlorophyll content compared to NDVI. Similar to NDVI, it helps in differentiating plants and grass over soil and arid regions to detect the crop stages. The formula for calculating green normalized difference vegetation index is (2).

$$GNDVI = (NIR - GREEN) / (NIR + GREEN) \tag{2}$$

By utilizing the formula and substituting the parameters with the spectral images of NIR and green respectively, a geospatial image was obtained with varying colour indices on different parts of the land [18]-[20]. Similar to NDVI, the red and yellow regions shown at Figure 10. Represent the lesser concentration of chlorophyll content and the green ones represent a good vegetation index and ample macronutrients.

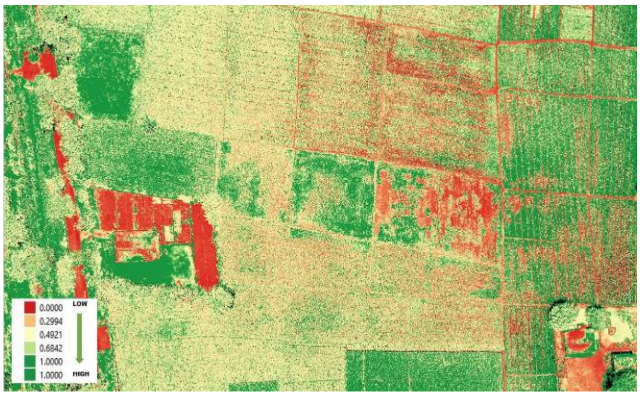

Figure 10. The GNDVI image of the land

2.3.3. Visible atmospheric resistance index (VARI)

Visible atmospheric resistance index (VARI) shown at the Figure 11 is the measure of the area of crop stress. With the determination of RGB spectrum in the NIR image, the acidity or alkalinity of soil can be obtained. The formula for calculating visible atmospheric resistance index is (3).

$$VARI = (GREEN - RED) / (GREEN + RED - BLUE) \quad (3)$$

By utilizing the formula and substituting the parameters with the spectral images of red, green and blue respectively, a geospatial image was obtained with varying colour indices on different parts of the land. The white and light green patches represent less crop stress or RGB spectrum and dark green patches indicate high crop stress and RGB spectrum.

Figure 11. The VARI image of the land

2.4. Nutrient monitoring and smart irrigation model

The mapping section of the prototype is done using the aerial images shot by a drone and analysing the spectral images to find out the NDVI, GNDVI, and VARI shown at Figure 12. However, the monitoring of nutrients in the soil still remains to be done and, as such, cannot be performed without the geospatial data obtained from the spectral images. The monitoring and irrigation model comprises of many components that would estimate the presence of macronutrients by analysing the moisture of the soil [21]-[23]. In addition to that, the irrigation part is also there which shall be discussed in the next section.

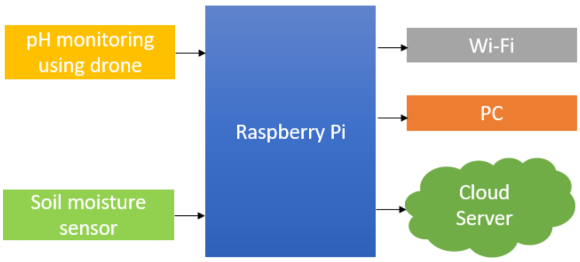

Figure 12. Nutrient monitoring using Raspberry Pi

The complete model consists of a microcontroller (Raspberry Pi 4 Model B), a soil moisture sensor, a relay switch, and a submersible pump to identify and detect the natural parameters in the agricultural land. The coding and other subsequent computational processes were done using python directories installed in the raspberry pi and the input command to drive the submersible pump motor. The probes of the soil moisture sensor provide us with the content of moisture in the soil which, if less, gives an input command to the motor to release water in the agricultural land.

2.4.1. Irrigation and water harvesting usingsmart irrigation model

The second part of the smart irrigation model comes with the installation of pipes, solenoidal valve array, and a reservoir for storing excess water which is pointed out in Figure 13. When the soil becomes moisture deficient, the raspberry pi gives command to the submersible pump motor to release water through pipe(s). If the moisture content is good, the motor does not run. The pipe is then subdivided into three sections placed between the trenches of the land to help increase the moisture content and nutrients in the soil [24], [25]. After the irrigation process, the water is redirected through an intersection in the rear end to the reservoir, where the water is again utilized by the motor and the process goes own, thereby harvesting and recycling water which is given clearly at the Figures 14 and 15.

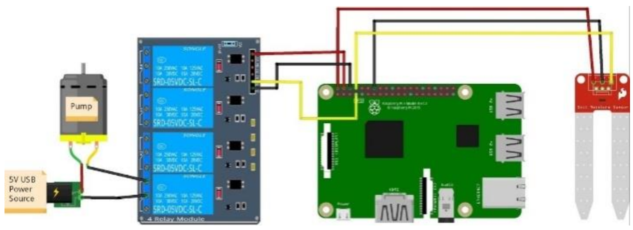

Figure 13. Diagram of the soil moisture and irrigation model utilized

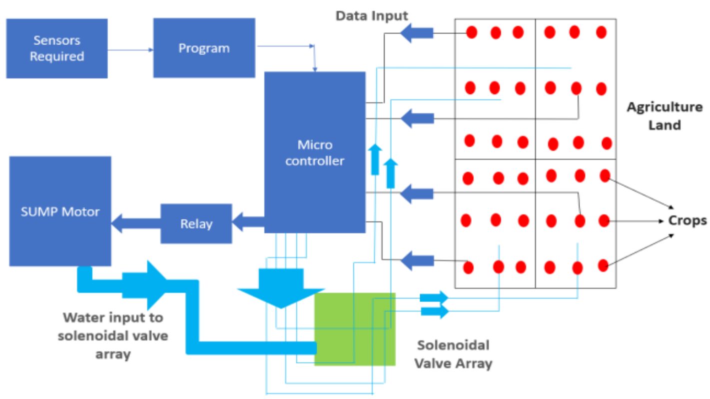

Figure 14. Irrigation and water harvesting using smart irrigation model

Figure 15. Practical setup of smart irrigation model

2.5. Energy harvesting using triboelectric nanogenerator (TENG)

Triboelectric nanogenerators (TENG) are used for energy harvesting and are also utilized in applications such as self-powered sensing, human, biomechanical motion sensing, and wearable electronics. These nanogenerators utilize the static electricity generation (triboelectrification) to generate a power to drive systems and sensors. The TENG was made using a sheet of paper, a Polyethylene terephthalate (PET) material, capacitor, rectifier, and the electrodes made with the help of 8B graphite pencils to bring out the electrolyte-substrate interface.

Figure 16 represents the practical model of a triboelectric Nanogenerator. The short circuit current ($I_{sc)}$ is measured with the help of a multimeter at 1 kΩ and the open circuit voltage is measured and the values are brought up at 100 MΩ. At low resistance, the power increases while with high resistance, it decreases. The TENG produce AC voltage which is then converted to DC voltage to discharge the capacitors. The rectifier is utilized to obtain DC voltage in the TENG for power output and energy harvesting applications. One of the advantages isharnessing mechanical and electrical energies or outputs within a stipulated time.

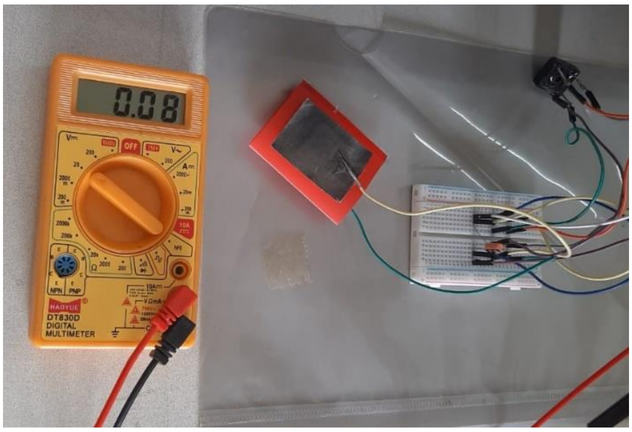

Figure 16. Practical model of a triboelectric nanogenerator

2.5.1. Working of the TENG

Figure 17 shows a triboelectric nanogenerator is an energy harvesting device that converts mechanical energy into electricity through triboelectric effect and electrostatic induction. The TENG was made with vertical contact-separation mode. Due to continuous separation and re-contact of the opposite triboelectric charges on the inner surfaces of the sheets, a periodic change in the potential difference is induced.

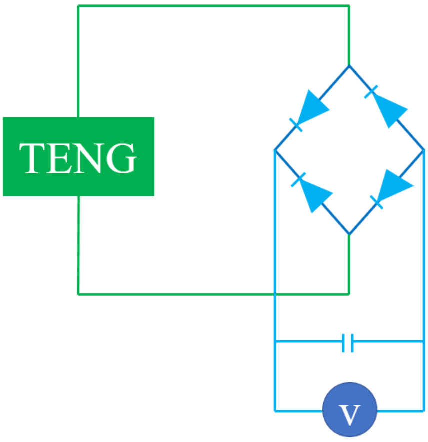

Figure 17. Circuit diagram of a triboelectric nanogenerator

When mechanical stress is applied to the TENG, these inner surfaces come into contact leading to a charge transfer. This leaves one side with positive charges and the other with negative charges. This phenomenon is known as triboelectric effect. Likewise, when the stress is released, the surfaces will lose contact with each other thereby generating an electric field and inducing potential difference across the top and bottom electrodes. The electricity will continue until the potential between the electrodes gets even. Now, when the two sheets are again brought in contact with each other, the induced potential difference becomes zero and the charges will flow back through the external load to generate current in the other direction.

3. EXPERIMENTAL DATA AND RESULTS

3.1. Soil pH assortment using VARI image

In soil mapping and monitoring section, the VARI image provided us with the levels of crop stress and RGB spectrum across the agricultural land. The tabulation below shows the RGB and the calculated $(VARI)^2$ values by substituting the RGB ones in the VARI formula which is shown in the Table 1. The higher $(VARI)^2$ values represent healthy vegetation and chlorophyll content with good RGB spectrum and the lower ones represent uneven concentration of chlorophyll, vegetation and RGB spectrum.

Table 1. Relationship between RGB and $(VARI)^2$ values

Sample	Red	Green	Blue	Mean	$(VARI)^2$	pH Values
1	59	77	53	63	0.046	5.4
2	57	77	46	63	0.065	6.2
3	60	86	72	73	0.123	5.8
4	16	58	34	36	1.102	5.1
5	58	104	83	82	0.338	5.9
6	22	48	14	28	0.215	6.2
7	57	74	42	58	0.036	6.1
8	45	52	33	43	0.011	5.6
9	68	89	42	66	0.033	5.8

3.2. Linear regression model

The use of linear regressions to show the fit of a consorted data onto a model for quasi-prediction is utilized. The slope encapsulates the data from a scattered medium nearing to zero if extrapolated further, the confidence boundaries being a rigorous set of boundaries or intervals would turnout with true parameters whose value would lies on the plane if the angle of slope falls too steep. Figure 18 shows the current curve/model is fit with rudimentary set of points (data is scattered) shown to varyingly differ based on the soil pH value as these tend to be 'response variable', changes in them show a drastic increment/decrement in the coefficient of determination (R2).

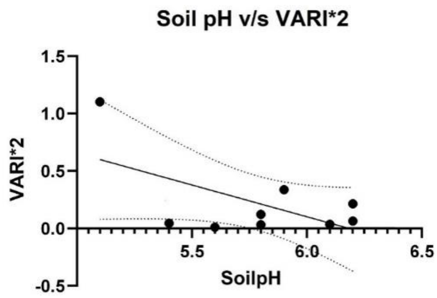

Figure 18. Linear regression graphwith $(VARI)^2$ relative to soil pH values

R^2 is leveraged in predicting values on how accurate and precise the equations fit with the basic set of data points. Here we show, the data fits a R^2 of value 0.384 suggesting the data to be accurate and consistent with the set of linear as shown in:

$$Y = -0.6267 * x + 3.9089$$

$$R2 = 0.384\ (38.4\%)$$

with these predicted values the error estimates in the model are negligible and would pave way for Ph forecasting and data assimilation in this case.

3.3. Moisture levels and motor operation

In the case of smart irrigation model, the values of soil moisture sensor (hygrometer) were recorded for different moisture levels. The tabulation below gives a relationship between moisture levels and operation of motor shown at Table 2. With the view of the tabulation result we can find the operation of the motor related to it's on and off. Its also shows the reults of moisture cutoff value vs motor turnon and turnoff condition.

Table 2. Relationship between moisture levels and operation of motor

Moisture levels	Operation of motor
Moisture>10%	Motor is turned off
Moisture<10%	Motor is turned on

4. CONCLUSION

The conventional method of soil analysis has limitations of huge time and energy consumption despite the advancements in techniques. Besides, analyzing soils samples is a tedious job to identify the nutrient disorders in the agricultural land. Soil mapping and monitoring, makes it relatively easy to analyze the soil properties using an aerial image shot by a copter or drone. With better and enhanced geographic information system software like QGIS, ArcGIS and Pix4D, the spectral images obtained can help in determining not only the soil properties but also the chlorophyll content and vegetation along with pH values. The nutrient monitoring model comprising the central unit as Raspberry Pi 4 Model B facilitates soil moisture and temperature and humidity sensing. For the irrigation model, the microcontroller is also responsible for operating the submersible pump motor that directs water to the field through solenoidal valve array to the farm and recycled for repeated usage. Overall, the entire idea of utilizing soil mapping and monitoring to make nutrient monitoring feasible makes it a better and efficient approach than the conventional ones in the field of agriculture and farming. For future enhancements, the addition of controlling solenoidal valve array in remote location without being physically present would prove to be a boon in case of large agricultural lands. The scope of ascertaining micronutrients and macronutrients to high regions of precision and accuracy would benefit in allocation of resources. In case of soil mapping and analysis using aerial photography by a drone, the use of high-quality multispectral camera and in larger drones with stabilized flight modes would help in dampened interference in image rendition.

REFERENCES

[1] N. R. Kitchen *et al.*, "Development of a conservation-oriented precision agriculture system: Crop production assessment and plan implementation," *Journal of Soil and Water Conservation*, vol. 60, no. 6, pp. 421–430, 2005.

[2] G. M. Laslett, A. B. McBratney, P. J. Pahl, and M. F. Hutchinson, "Comparison of several spatial prediction methods for soil pH," *Journal of Soil Science*, vol. 38, no. 2, pp. 325–341, Jun. 1987, doi: 10.1111/j.1365-2389.1987.tb02148.x.

[3] D. S. Read *et al.*, "Soil pH effects on the interactions between dissolved zinc, non-nano- and nano-ZnO with soil bacterial communities," *Environmental Science and Pollution Research*, vol. 23, no. 5, pp. 4120–4128, Mar. 2016, doi: 10.1007/s11356-015-4538-z.

[4] R. E. Lucas and J. F. Davis, "Relationships between pH values of organic soils and availabilities of 12 plant nutrients," *Soil Science*, vol. 92, no. 3, pp. 177–182, Sep. 1961, doi: 10.1097/00010694-196109000-00005.

[5] J. Weber *et al.*, "Agricultural and ecological aspects of a sandy soil as affected by the application of municipal solid waste composts," *Soil Biology and Biochemistry*, vol. 39, no. 6, pp. 1294–1302, Jun. 2007, doi: 10.1016/j.soilbio.2006.12.005.

[6] R. Sindhuja and B. Krithiga, "Soil nutrient identification using arduino," *Asian Journal of Applied Science and Technology (AJAST)*, vol. 1, no. 4, pp. 40–42, 2017.

[7] M. L. Staben, J. W. Ellsworth, D. M. Sullivan, D. Horneck, B. D. Brown, and R. G. Stevens, "Monitoring soil nutrients using a management unit approach," *PNW 570-E*, no. October, 2003.

[8] L. C. Gavade and A. D. Bhoi, "NPK detection & control for agriculture applications using PIC controller: a review," *International Journal of Engineering Research & Technology (IJERT)*, vol. 6, no. 04, 2017.

[9] D. V Ramane, S. S. Patil, and A. D. Shaligram, "Detection of NPK nutrients of soil using fiber optic sensor," *International Journal of Research in Advent Technology ACGT*, pp. 13–14, 2015.

[10] P. Mishra *et al.*, "Testing/monitoring of soil chemical level using wireless sensor network technology," in *14th Internacional Conference on Precision Agriculture*, vol. 4, no. 11, pp. 114–117, 2018.

[11] F. Wu *et al.*, "A flexible, lightweight, and wearable triboelectric nanogenerator for energy harvesting and self-powered sensing," *Advanced Materials Technologies*, vol. 4, no. 1, p. 1800216, Jan. 2019, doi: 10.1002/admt.201800216.

[12] J. Zhong *et al.*, "Finger typing driven triboelectric nanogenerator and its use for instantaneously lighting up LEDs," *Nano Energy*, vol. 2, no. 4, pp. 491–497, Jul. 2013, doi: 10.1016/j.nanoen.2012.11.015.

[13] G. Zhu, P. Bai, J. Chen, and Z. L. Wang, "Power-generating shoe insole based on triboelectric nanogenerators for self-powered consumer electronics," *Nano Energy*, vol. 2, no. 5, pp. 688–692, Sep. 2013, doi: 10.1016/j.nanoen.2013.08.002.

[14] Z. Lin *et al.*, "A triboelectric nanogenerator-based smart insole for multifunctional gait monitoring," *Advanced Materials Technologies*, vol. 4, no. 2, p. 1800360, Feb. 2019, doi: 10.1002/admt.201800360.

[15] P. Xianjie *et al.*, "Eye motion triggered self-powered mechnosensational communication system using triboelectric nanogenerator," *Science Advances*, vol. 3, no. 7, 2021, doi: 0.1126/sciadv.170069.

[16] A. Narayanmoorthy, "Drip and sprinkler irrigation in India : benefits , potential and future directions," *India's water future: Scenarios and issues. Strategic Analyses of National River Linking Project of India. Series*, vol. 2, pp. 253–266, 2009.

[17] J. M. Deumier, P. Leroy, and P. Peyremorte, "Tools for improving management of irrigated agricultural crop systems," in *Irrigation Scheduling: From Theory to Practice, Proceedings ICID/FAO Workshop*, 1996, pp. 39–49.

[18] M. Burton and B. O'Brien, "Water management study," *Odisha Community Tank Management Project OCTMP*, 2014.

[19] C. Wei and M. Li, "Advantages and problems of developing pipeline transportation water irrigation technology in Xinjiang," in *2011 International Conference on New Technology of Agricultural*, May 2011, pp. 492–495, doi: 10.1109/ICAE.2011.5943846.

[20] L. S. Eng, R. Ismail, W. Hashim, and A. Baharum, "The use of VARI, GLI, and VIgreen formulas in detecting vegetation in aerial images," *International Journal of Technology*, vol. 10, no. 7, p. 1385, Nov. 2019, doi: 10.14716/ijtech.v10i7.3275.

[21] T. M. Nasser, B. Chellali, A. Othmane, B. Denai, and Y. Mouloudi, "Characterization and modeling of power electronics device," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 5, no. 2, Oct. 2014, doi: 10.11591/ijpeds.v5i2.4318.

[22] H. Attia and A. Sagafinia, "Novel discrete components based speed controller for induction motor," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 7, no. 4, p. 1075, Dec. 2016, doi: 10.11591/ijpeds.v7.i4.pp1075-1084.

[23] A. Ali, M. N. Yasin, M. F. C. Husin, and N. A. A. Hambali, "Design and analysis of 2-coil wireless power transfer (WPT) using magnetic coupling technique," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 10, no. 2, p. 611, Jun. 2019, doi: 10.11591/ijpeds.v10.i2.pp611-616.

[24] M. Rehman, P. Nallagownden, and Z. Baharudin, "Efficiency investigation of SS and SP compensation topologies for wireless power transfer," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 10, no. 4, p. 2157, Dec. 2019, doi: 10.11591/ijpeds.v10.i4.pp2157-2164.

[25] G. Balamurugan, S. Punniakodi, K. Rajeswari, and V. Arulalan, "Automatic number plate recognition system using super-resolution technique," in *2015 International Conference on Computing and Communications Technologies (ICCCT)*, Feb. 2015, pp. 273–277, doi: 10.1109/ICCCT2.2015.7292759.

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