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Design of a radio frequency robot for the analysis of farmlands of avocado crops in Peru

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***Abstract*– Avocado is a fruit of high export demand. It is the third most exported product in Peru. To improve its quality, as well as the characteristics of the soil in which is gown strict supervision and control has to be taken; however, for the small and medium producers, this process is slow and costly, which generates possibilities of loss and consequently a decrease of export possibilities and economic growth. To overcome this situation, a robot has been developed to analyze the soil of the land, such as humidity, pH, macronutrients, Nitrogen, Phosphorus and Potassium. Additionally, a simple interface has been developed so that, after collecting the data, the farmer can read the results in multi-layer colored maps and perform the necessary actions to take care of the plants in a shorter time than in which is currently done.**

***Keywords*—precision agriculture, robot, avocado, radio frequency.**

I. Introduction

Avocado has a high demand in the international market, especially in North America and Europe. In the period 2000-2016 the worldwide production has increased to 435% [1], of which 90% corresponds to Mexico, Chile, and Peru [2]. Peru is a fruit exporter, mainly: grapes, nuts, mango, mandarin, banana and, of course, avocado [3]. Peru ranks third in the export of avocado [4], having two main growing seasons, the first is from January to March for the local market and the second is between April and June for export [5]. In the month of June 2022 alone, Peruvian avocado production totaled 168,404 tons with a growth of 10.1% compared to June 2021; with partial increases from 42.5% to 4.5% in 13 departments of Peru [6].

Avocado deserves special attention due to the high water consumption that it requires to be grown and it implies a high level of carbon and water footprint [7]. This explains the differences in the destination of the production between the first and second season of cultivation in Peru, since in the first season the production is destined to the local market. The, harvested avocados are smaller, because it is grown during the rainy months, whereas in the second period, irrigation water is required to produce for Europe, Great Britain and North America [5].

Considering that Peru has the third place in avocado exports worldwide, the analysis of the plant throughout its life cycle, mainly in the early stages, should be emphasized and perform it in a consistent manner; however, pests and scarce economic resources cause the decrease in crop yields [8] and losses in small and medium producers.

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The moisture control of the soil is important to improve the irrigation management and water sustainability which is more needed in places where this element is scarce [9]. It is very important to control the properties of agricultural soil by means of its characteristics. A poor use of water causes problems of product quality, early ripening and the incidence of pests or possible diseases will increase [10]. The plants water requirement is shown in Table 1.

TABLE I
WATER REQUIREMENT - DRIP SYSTEM DENSITY OF 416 PLANTS/HA, AVERAGE TEMPERATURE 20-25OC [10]

Age of the plant (Years)	Water requirement (Liters/week)
1 – 2	20 – 50
2 – 3	40 – 80
3 – 4	80 – 120
4 - 5	120 – 220
+5	400

Water is not the only factor to be monitored in avocado plantations, but also other factors must be analyzed, including the amount of macronutrients, such as Nitrogen (N), Phosphorus (P) and Potassium (K), in the outer layer of the soil and the acidity or basicity degree through the measurement of pH.

Fertilizers, especially those containing nutrients in NPK (Nitrogen, Forum, and Potassium) are a necessity for plant growth. Nitrogen (N) is fundamental to chemical reactions occurring in cells, and plants absorb it to make chlorophyll. Lack of nitrogen is the most common nutritional deficiency in plants that are not legumes [11]. The deficiency of this element produces an abnormal root elongation that triggers water stress with atrophied stem growth [12]. Phosphorus (P) is a basic element for life and plants. It is an essential element for photosynthesis [13]; it is also a fundamental component of ribonucleic acid (RNA), which, in turn, is necessary for various processes such as energy transfer and protein metabolism [14]. Potassium (K) is necessary for the physiological functions of plants; adequate amounts help the development of trees, increasing the height and size of the fruit [15], this element improves the useful life of crops, optimizing root growth for increased water absorption and disease resistance [16].

It is recommended that the pH in agricultural soils be in the range of 6 and 7.1, since it presents a greater resilience to the cycle of Carbon (C), the cycle of Nitrogen (N), copper (Cu) and heat stress. It is necessary to mention that when a soil has a measurement lower than 6, it is considered acid, so it is more likely to have denitrifying fungi than bacteria [17], with the possibility of harboring Ca, Mn, Zn and Sr, with a high coefficient of bioaccumulation [18] evidence of functional resistance.

On the other hand, if soil pH measurement is higher than 7.1, presenting an alkaline result, one effect is that it can reduce the absorption of heavy metals in plants, as the increase in heavy metals disrupts the normal activity of soil microbial communities [19]. An excessive accumulation of Cu can affect plants by varying the absorption of minerals and the oxygenation of the plant itself, which is why the soil condition must be monitored constantly [20]. This accumulation of Cu is not the only reason why you should have constant monitoring of the soil. The increasing industrialization, population, excessive use of pesticides and chemical fertilizers also affects it. It is also the cause why agricultural soil harbors toxic metals for both plants and consumers [21]. However, if the pH measurement reaches 7.8, the toxicity of Cu is eliminated by precipitation [22].

Concerning the cultivation of avocado, both in Central American and Peru, there are difficulties due to climate change, they correspond to two criteria: the first is that the soil is affected in both zones, by the complex geography; for instance, slopes together with the texture of the soil in the middle of the diversity of climates and the second criterion is the low pH of agricultural soil [23], due to these reasons, constant measurement of factors in avocado plantations is important.

Currently there are two ways to carry out analyses of agricultural soil in avocado plantations in Peru. The first is to collect information in situ with specialized personnel. This possibility is, however, complicated because large-scale plantations require many specialized staff, which increases the costs and analysis times of the whole terrain [24]. Another method is performed by unmanned aerial, vehicles equipped with multispectral cameras that are piloted by specialized personnel and driver license. In both possibilities, qualified personnel are required to perform data collection and analysis.

Moreover, regarding pests affecting avocado, there are Frankliniella occidental is, also the called "thrips" Heliothrips hemorroidalis, Thrips tabaci, or Frankliniella sp, which are the natural hosts of avocado [25] [26], feeding on soft tissues such as leaf buds, tender leaves and developing fruits. It initially affect the surface of the fruit creating grooves or protrusions, thus hindering them the possibility of export, due to their rough appearance, causing significant losses [27].

On the other hand, technical improvements in agriculture involve optimizing production efficiency, quality, minimizing environmental impact, and minimizing risks related to production, which correspond to what is called the evolution towards agriculture 4.0; however, in agriculture 4.0, not only considers the development of robots, drones or information and communication technology (ICT), but also incorporate the main actors: the farmers [28]

This research paper presents the design of a robot that uses radio frequency for the survey and analysis of five factors: NPK (macronutrients), humidity and pH in avocado plantations resulting in graduated color maps for a better understanding of the farmer.

II. Methods

In this document, it is emphasized the electronic design of the vehicle; however, the considerations that have been taken during the mechanical design of the robot will be explained.

A. *Mechanical design*

The designed robot is an unmanned ground vehicle with engines for traction in, with obstacle identifier to detect and evade objects in the middle of the route; image capture with cameras installed for data collection of leaves, with energy collection through solar panels in the upper external structure of the robot and also batteries.

For the external design of the robot, biomimesis is used with the shape of the Coccinellidae, also known as ladybug, a well-known insect that is also a natural pest controller, of Frankliniella occidentalis, however, little information is available on the positive effects of this insect on pest control [29]. In Fig.1, the use of biomimesis in the external design is observed. This is to teach and raise farmers' awareness of the use of natural pest controllers, thus to avoid the use of chemicals that can bring harmful effects to health when used and by the effects that they can have on consumers, also by diminishing their chances of economic improvement and bringing about an exportable product according to the requirements of the consumer countries.

Fig.1 External view of the of the avocado crop analyzer robot.

B. *Electrical and electronic design*

The robot records the necessary data of each avocado plant, so the detection mechanisms are near the stem. For the robot to perform its task efficiently and the best performance, two systems were provided: a radio control system and a data storage system, both systems are powered by a single power source. The radio control system is responsible for the interface of the robot. It can control only the locomotion of the vehicle to maneuver in almost any direction; on the other hand, the storage system will be responsible only for recording measurements of the ground, which will be stored for further analysis in the different programs and thus obtain the specific data of each sector of the field, obtaining a greater storage capacity for data collection. By dividing into two systems you have optimal performance of the robot, avoiding overloading the card with too many commands, as presented in Fig. 2.

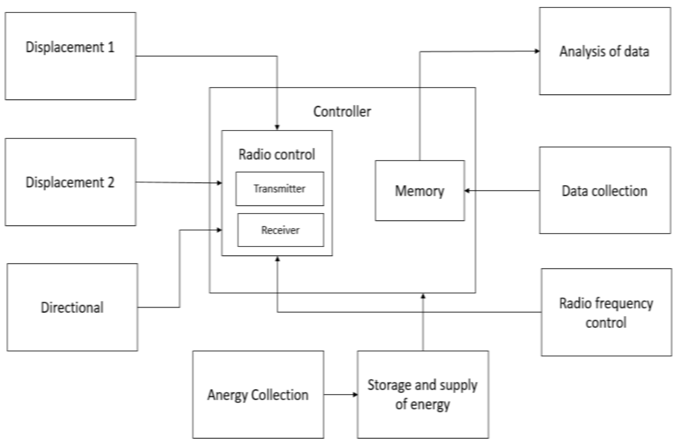

Fig. 2 Electronic scheme of operation

Wireless communication, one of the technology areas that advanced more over time, allows us to communicate and process signals [30]. Dynamic systems can have uncontrollable disturbances; the latter mechanism of the robot is to control a robot remotely by sensors or manually [31].

Radio frequency devices allow us to monitor remotely or control the actions of another device that has RF, [32]. There are different types of bands including 2.4 GHz, 8mo68MHZ and 433MHz, the most used is 2.4GHz. It is of free use worldwide; however, being one of the most reliable is usually saturated, [33]. That is why a reliable alternative is the 433MHz; however, this usually has some restrictions in Europe, China, Australia and USA.

This method of communication is used, as it allows us to make a stable connection with the robot, having a range of up to 200 meters depending on the antenna, [32]. It is possible to communicate between two 433MHz devices without interference, as their frequency is less than 90KHz [33]. On the other hand, the infrared remote control (IR) was discarded because it has a lower range, approximately 5 meters, apart from being a linear transmission, so it must point directly to the device to make the connection [32] being inefficient for this research work.

C. Algorithm architecture

For the operation of the robot a sequence was considered at the time of the analysis, as shown in the following Fig. 3, the robot will only take measurements when it is stopped and can
advance only when the sensor is inactive. This will prevent any kind of accident or malfunction that could affect the robots operation or infrastructure.

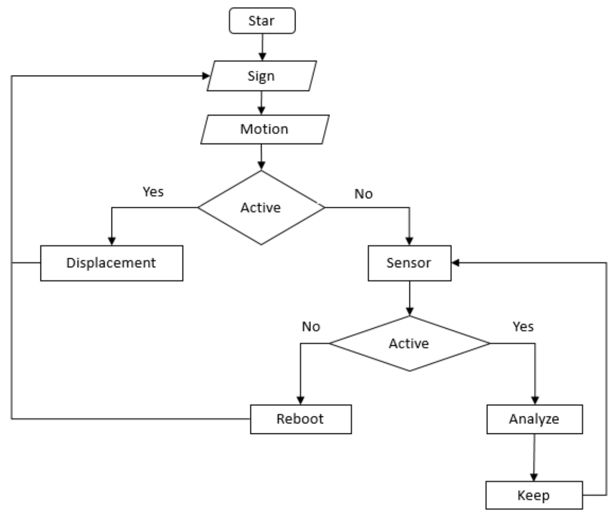

Fig. 3 Architecture of the operating algorithm

D. Data storage system

A micro SD memory was used which allowed to expand the memory for data collection, this will make the collection every time the robot is stopped. Sensor information was obtained in format. txt having a restart at each line change, which allows to manage the database in a more orderly and simple way, in this case a total of ten packets were obtained, with a total of ten data samples per packet, having a total of 100 sampling points.

E. Robot travel according to planting arrangement

The cameras and the intelligent obstacle recognition system permits the robot to make a journey in the avocado plantation for a whole hectare. It should be considered that this robot has been designed taking into account the small or medium producer, since it is necessary a constant measurement of the soil. In the world there are various matrices of cultivating avocados, of 20 x 20 meters, 10 x 10 meters, 5 x 5 meters to 2 x 2 meters [34]; however, this depends on geography and climate. In Peru, the Ministry of Agriculture recommends a rectangular frame planting system, in the case of the export avocado (Hass type) plantations can be 5 meters x 4 meters for a population of 500 plants per hectare for high density plantations and 6 meters x 4 meters with a population of 417 plants per hectare for applications with atomizer machinery [10], Fig 4 shows the robots path on one hectare.

Red dots mean stop or change of route of the robot, the red line indicates the desired route of the robot. As it is the responsibility of the farmer to have the roads or paths free of possible obstacles, the robot has been designed so that only one track is required for every two columns of trees. This allows the farmer to have more choices to perform maintenance on a constant basis.

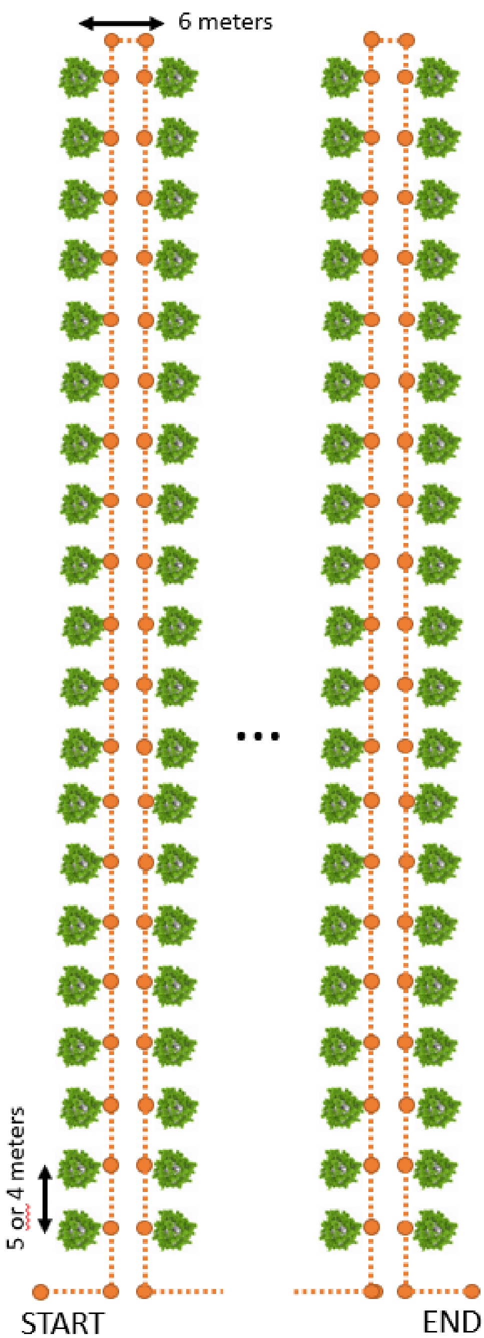

Fig. 4 Top view of the robot's path on a avocado growing plot

III. Results

Initially an array of the files with the different data was created, this was done in the Excel program considering that in the columns the different characteristics are found and in the rows the number of samples that were obtained, as shown in Table 2.

TABLE 2
INITIAL DATA

Point	Longitude_X	Latitude_Y	Nitrogen	Potassium	pH	Humidity	Phosphorus
1	-78.903	-7.219	676	2918	5.87	60.29	8.74
2	-78.906	-7.304	682	2926	5.65	60.68	9.13
3	-78.746	-7.21	694	2694	5.74	60.18	8.23
4	-78.744	-7.307	664	2630	5.82	60.66	7.08
5	-78.866	-7.215	645	2513	5.75	60.9	7.67
6	-78.779	-7.209	634	2714	5.56	60.76	9.12
7	-78.834	-7.213	681	2586	5.51	60.55	8.1
8	-78.811	-7.212	632	2865	5.63	60.63	9.62
9	-78.884	-7.217	655	2978	5.82	60.79	9.85
10	-78.758	-7.208	690	2855	5.9	60.27	9.02
11	-78.796	-7.21	620	2846	6.01	60.19	8.57
12	-78.849	-7.214	605	2975	6.13	61.93	9.37
13	-78.744	-7.283	616	2731	6.2	61.07	9
14	-78.744	-7.241	699	2757	5.58	60.79	7.77
15	-78.744	-7.226	678	2708	5.9	60.99	7.6

With the information already sorted in Microsoft Excel, the ArcGIS program can import the data directly. At each point where the readings were made, 07 data were stored: the first two geographical data (latitude and altitude) and the remaining five of the soil characterizations (Humidity, pH, Nitrogen, Phosphorus and Potassium), generating a simple initial view of a point map that simulates the terrain area, as shown in Fig 5.

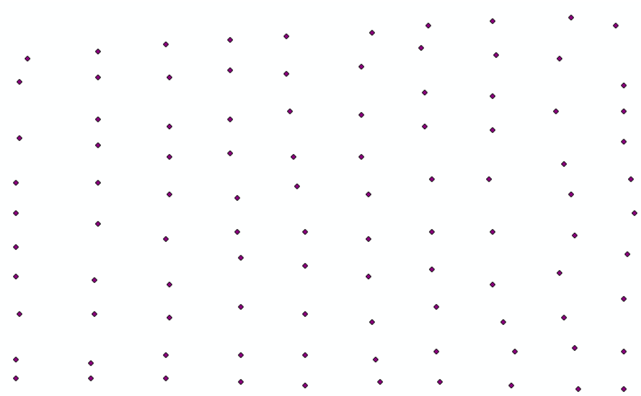

Fig. 5 Point map view with collected data

Table 3 shows how the ArcGIS program stores the data, so that each point stores the record of the 7 data mentioned above. This is of great importance to be able to generate multilayer maps depending on the data we want to observe.

TABLE 3
RECORDING THE 7 DATA FOR EACH COLLECTION POINT IN THE ARCGIS SOFTWARE

FID	Shape *	Point	Longitud_X	Latitud_Y	Potacio	PH	Humedad	Fosforo
0	Point	1	-78.903	-7.219	2918	5.87	60.29	8.74
1	Point	2	-78.906	-7.304	2926	5.65	60.68	9.13
2	Point	3	-78.746	-7.21	2694	5.74	60.18	8.23
3	Point	4	-78.744	-7.307	2630	5.82	60.66	7.08
4	Point	5	-78.866	-7.215	2513	5.75	60.9	7.67
5	Point	6	-78.779	-7.209	2714	5.56	60.76	9.12
6	Point	7	-78.834	-7.213	2586	5.51	60.55	8.1
7	Point	8	-78.811	-7.212	2865	5.63	60.63	9.62
8	Point	9	-78.884	-7.217	2978	5.82	60.79	9.85
9	Point	10	-78.758	-7.208	2855	5.9	60.27	9.02
10	Point	11	-78.796	-7.21	2846	6.01	60.19	8.57
11	Point	12	-78.849	-7.214	2975	6.13	61.93	9.37
12	Point	13	-78.744	-7.283	2731	6.2	61.07	9
13	Point	14	-78.744	-7.241	2757	5.58	60.79	7.77
14	Point	15	-78.744	-7.226	2708	5.9	60.99	7.6
15	Point	16	-78.744	-7.297	2961	6.07	61.55	7.39
16	Point	17	-78.742	-7.251	2637	5.88	61.92	9.41
17	Point	18	-78.743	-7.271	2968	6	60.66	8.26
18	Point	19	-78.744	-7.233	2801	5.85	60.27	9.6
19	Point	20	-78.741	-7.26	2691	6.03	61.37	8.56
20	Point	21	-78.886	-7.304	2919	6.01	61.56	9.24
21	Point	22	-78.866	-7.304	2880	5.97	61.3	8.91
22	Point	23	-78.846	-7.305	2883	6	61.29	9.7
23	Point	24	-78.829	-7.306	2527	6.09	61.85	7.32
24	Point	25	-78.809	-7.305	2567	5.89	61.76	7.19
25	Point	26	-78.793	-7.305	2659	6.17	61.99	9.69
26	Point	27	-78.774	-7.306	2754	6.12	61.13	8.39
27	Point	28	-78.756	-7.307	2817	6.13	61	7.15
28	Point	29	-78.757	-7.296	2803	5.91	61.69	8.7
29	Point	30	-78.773	-7.297	2906	5.82	61.55	7.84
30	Point	31	-78.794	-7.297	2536	6.26	62.39	8.39

1 (0 out of 100 Selected)

The first datum that can be observed is the concentration of nitrogen in the earth, obtaining a variation that depends on the place. This shows a minimum range of 586 and a maximum concentration of 795 parts per million (PPM), with the highest parameters being dark and a darker tone as the highest concentration, as shown in fig. 6.

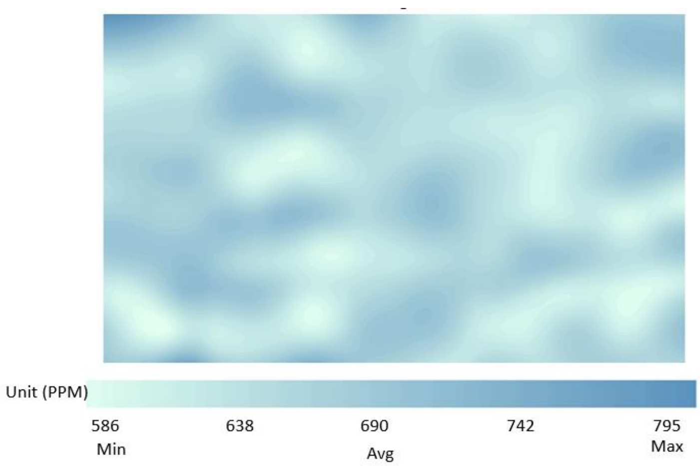

Fig. 6 Map of the concentration of nitrogen

In Fig 7, the variation of potassium in the soil can be observed. This nutrient is very important for plants as it is absorbed at the early stage and is associated with its growth, obtaining minimum readings of 2.29 and 3.56 at the most. Where the lower concentration is of a light color and higher concentration of a darker tone.

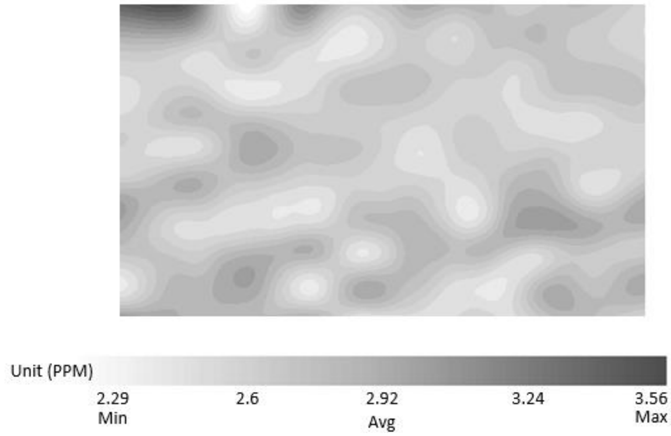

Fig. 7 Map of the potassium concentration

In Fig. 8, it is shown that parts of the land present a high quantity of acidity, for this purpose the color scale of pH was considered to have a better reading, having as results of at least 4.83 and 6.58 as maximum results.

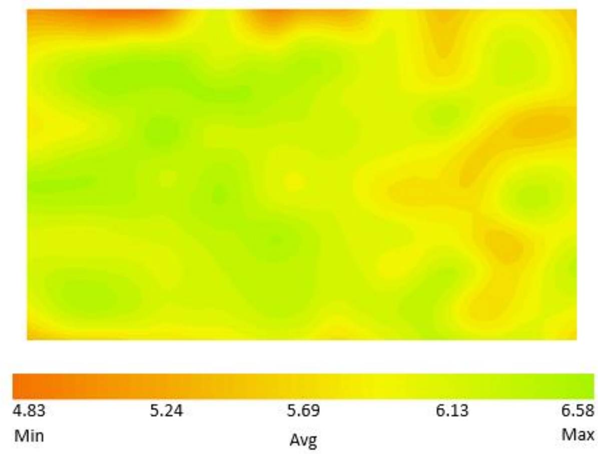

Fig. 8 Map of concentration of pH

Fig. 9 shows the percentage of humidity below the surface layer of the earth at about 3-5 cm, with a range variation of at least 55% and a maximum of 67%, lower humidity in light-colored areas and higher percentage in dark areas.

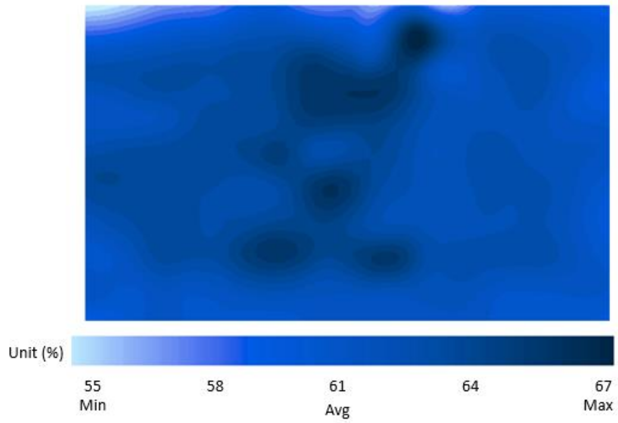

Fig. 9 Map of surface humidity

Fig. 10 shows the concentration of phosphorus in the soil, resulting in a minimum of 6.15 ppm and a maximum of 12.19 ppm.

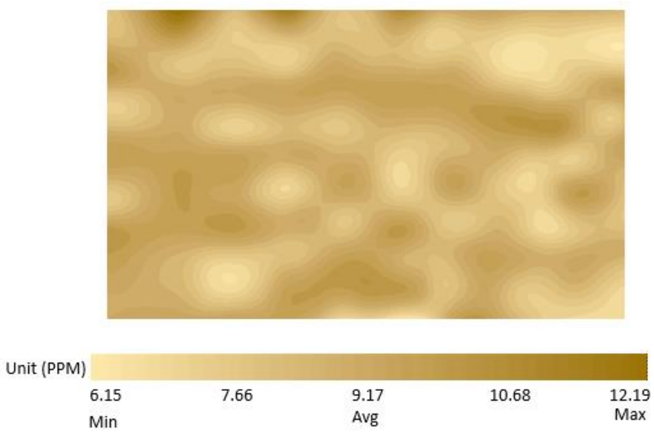

Fig. 10 Farmlands phosphorus concentration map

With the results obtained a user-friendly interface was created, where you can visualize the different data collected in more detail, in which you can change information just by clicking on the box you need. This window displays the maximum and minimum data on a color scale, as well as the terrain map, in addition to the standard deviation, summation and mean.

In Fig. 11, the interface is shown when the results of Nitrogen and Potassium are recorded; this will be seen similarly with pH, humidity and Phosphorus.

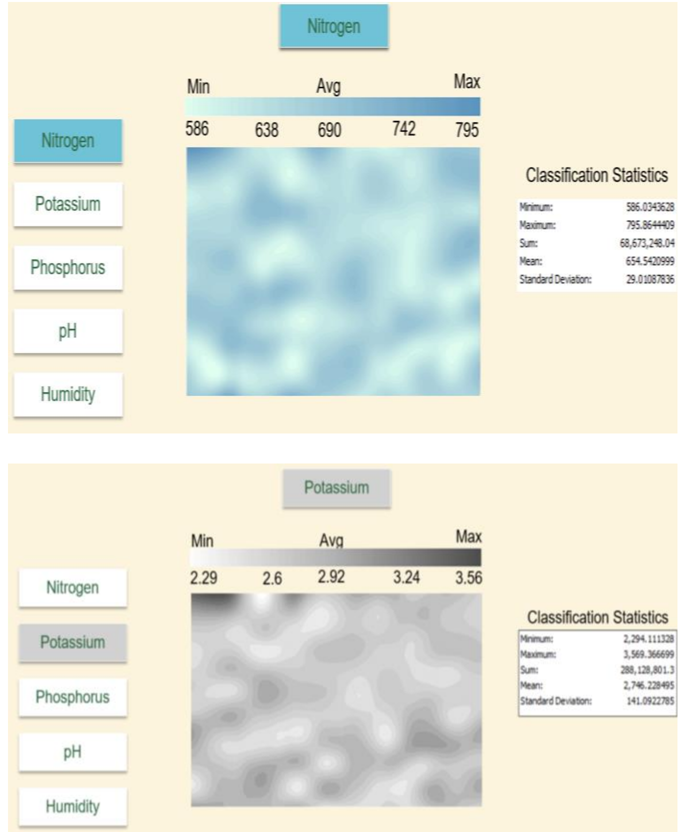

Fig.11 View of the interface that the farmer can observe when requesting the results, in this case, of Nitrogen and Potassium.

IV. Conclusions

In the process of data storage, dividing the data by packets allows a better control over the measurements, and thereby creating a single more orderly matrix facilitating its reading and organization of the different sampling points in the field. Thus it was possible to create a choropleth map of phosphorus, potassium, nitrogen, pH and humidity, to make it possible to visualize more clearly and quickly the most critical places in the cultivation area, where some kind of intervention by the specialist could be required.

The different variations presented by the different data, is because the soil is not always composed with the same amount of nutrients or concentration of minerals in the whole area, but this can vary due to irrigation channels, sub-soil water or other triggers. Which allows this form of data collection to be more reliable and effective, since it is known which is the affected area and can take actions required only in that part, without harming other parts of the field, thus better plant growth and economic savings for farmers can be generated,

Thanks to the design and the interface of the robot you have an intuitive handling which allows you to maneuver it with precision and have a stable connection at all times, allowing us to collect data more quickly and safely, this is due to the systems being formed by two parts for better performance, also interact with each other, facilitating the robot to make the data collection when it stops, thus safeguarding the structure and operation of this.

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REFERENCES

[1] D. Caro, A. Alessandrini, F. Sporchia y S. Borghesi, "Global virtual water trade of avocado," *Journal of Cleaner Production*, vol. 285, pp. 1-8, 2021.

[2] R. Pedreschi, E. Ponce, I. Hernández, C. Fuentealba, A. Urbina, J. González-Fernández, J. Hormaza, D. Campos, R. Chirinos y E. Aguayo, "Short vs. Long-Distance Avocado Supply Chains: Life Cycle Assessment Impact Associated to Transport and Effect of Fruit Origin and Supply Conditions Chain on Primary and Secondary Metabolites," *Foods*, vol. 11, no 12, 2022.

[3] INEI, "EXPORTACIONES DE FRUTAS Y FRUTOS CRECIERON 805,4% EN LOS ÚLTIMOS 12 AÑOS," 15 Enero 2015. [En línea]. Available: https://m.inei.gob.pe/media/MenuRecursivo/noticias/np_04_2015.pdf. [Último acceso: 15 Enero 2023].

[4] O. Ramirez, J. Cruz y W. Machaca, "Agroindustrial Plant for the Classification of Hass Avocados in Real-Time with ResNet-18 Architecture," *2021 5th International Conference on Robotics and Automation Sciences, ICRAS 2021*, pp. 206-210, 2021.

[5] I. Vásquez-Rowe, "In defense of the avocado: a life cycle perspective," *International Journal of Life Cycle Assessment*, vol. 27, no 8, pp. 1035-1037, 2022.

[6] INEI, "PRODUCCIÓN DE PALTA SE INCREMENTÓ EN 13 DEPARTAMENTOS Y CRECIÓ 10,1%," 24 agosto 2022 - N°140. [En línea]. Available: https://m.inei.gob.pe/media/MenuRecursivo/noticias/nota-de-prensa-no-140-2022-inei.pdf. [Último acceso: 10 Enero 2023].

[7] X. Esteve-Llorens, D. Ita-Nagy, E. Parodi, S. González-García, M. Moreira y G. Feijoo, "Environmental footprint of critical agro-export products in the Peruvian hyper-arid coast: A case study for green asparagus and avocado," *Science of the Total Environment*, vol. 818, 2022.

[8] B. Rivadeneyra y S. Huamán, "Method of Anomalies Detection in Persea Americana Leaves with Thermal and NGRDI Imagery," *Smart Innovation, Systems and Technologies*, vol. 202, pp. 287-296, 2021.

[9] N. N. Kourgialas y Z. Dokou, "Water management and salinity adaptation approaches of Avocado trees: A review for hot-summer Mediterranean climate," *Agricultural Water Management*, vol. 252, 2021.

[10] MINAGRI, Manual Técnico de Buenas Prácticas Agrícolas en el Cultivo de Palto, Lima: MINAGRI, 2010.

[11] J. Havlin, S. Tisdale, W. Nelson y J. Beaton, Soil Fertility and Fertilizers: An Introduction to Nutrient Management, 8th Edition ed., Pearson Education, 2013.

[12] X. Sun, F. Chen, L. Yuan y G. Mi, "The physiological mechanism underlying root elongation in response to nitrogen deficiency in crop plants," *Planta*, vol. 251, no 4, 2020.

[13] H. Lambers, "Phosphorus Acquisition and Utilization in Plants," *Annual Review of Plant Biology*, vol. 73, pp. 17-42, 2022.

[14] E. D. Lawrence, Mineral Nutrition and Plant Disease, Minnesota: Amer Phytopathological Society, 2007.

[15] E. Lahav, M. Bareket y D. Zamet, "California Avocado Society," de POTASSIUM FERTILIZER EXPERIMENT WITH AVOCADO TREES ON HEAVY SOILS, California, Volumen 60, 1976, pp. 181-186.

[16] J. Rawat, P. Sanwal y J. Saxena , "Potassium and Its Role in Sustainable Agriculture," 2016, pp. 235-253.

[17] X. Shu, T. Daniell, P.-. Hallett, E. Baggs y B. Griffiths, "Soil pH moderates the resistance and resilience of C and N cycling to transient and persistent stress," *Applied Soil Ecology*, vol. 182, 2023.

[18] S. Bravo, J. A. Amorós, C. Pérez-de-los-Reyes, F. J. Gacría, M. M. Moreno, M. Sánchez-ORmeño y P. Higueras, "Influence of the soil pH in the uptake and bioaccumulation of heavy metals (Fe, Zn, Cu, Pb and Mn) and other elements (Ca, K, Al, Sr and Ba) in vine leaves, Castilla-La Mancha (Spain)," *Journal of Geochemical Exploration*, vol. 174, pp. 79-83, 2017.

[19] N. Kourgialas y Z. Dokou, "Water management and salinity adaptation approaches of Avocado trees: A review for hot-summer Mediterranean climate," *Agricultural Water Management*, vol. 252, 2021.

[20] X. Zheng, G. Han y B. Liang, "Distribution of Cu in agricultural soils with different land uses through stable isotope analysis," *Ecological Indicators*, vol. 146, 2023.

[21] O. T. Kayode, A. P. Aizebeokhai y A. M. Odukoya, "Geophysical and contamination assessment of soil spatial variability for sustainable precision agriculture in Omu-Aran farm, Northcentral Nigeria," *Heliyon*, vol. 8, no 2, 2022.

[22] D. Fernández-Calviño y E. Bååth, "Interaction between pH and Cu toxicity on fungal and bacterial performance in soil," *Soil Biology and Biochemistry*, vol. 96, pp. 20-29, 2016.

[23] R. Grüter, T. Trachsel, P. Laube y I. Jaisli, "Expected global suitability of coffee, cashew and avocado due to climate change," *PLOS ONE*, vol. 17, no 1, 2022.

[24] M. Castillo-Guevara, F. Palomino-Quispe, A. Alvarez y R. Coaquira-Castillo, "Water stress analysis using aerial multispectral images of an avocado crop," *Proceedings of the 2020 IEEE Engineering International Research Conference, EIRCON 2020*, 2020.

[25] G. Bara y M. Laing, "Determination of the Natural Host Status of Avocado Fruit to Pestiferous Thrips (Thysanoptera: Thripidae) in KwaZulu-Natal, South Africa," *African Entomology*, vol. 27, no 1, pp. 245-253, 2019.

[26] H. Espino, A. Mendoza , J. Espino y V. Gómez, "Searching behavior and predatory capacity of Chrysoperla externa on Frankliniella occidentalis," *Southwestern Entomologist*, vol. 42, no 2, pp. 463-476, 2017.

[27] F. Maldonado, J. Ramírez, M. Rubí, X. Antonio, A. Lara , A. Acosta , R. Rivera y A. Ávila, "Modelling the spatial behavior of Frankliniella occidentalis (thysanoptera: Thripidae) in growing avocado," *Phyton-International Journal of Experimental Botany*, vol. 86, pp. 97-111, 2017.

[28] S. Santos Valle y J. Kienzle, Agricultura 4.0 - Robótica agrícola y equipos automatizados para la producción agrícola sostenible, Roma: FAO, 2021.

[29] G. C. Orta, H. A. Álvarez, F. Madeira y R. Albajes, "The Influence of Planting Periods on Herbivore and Natural Enemy Abundance on Yellow Sticky Traps in Bt Maize Fields," *Insects*, vol. 13, no 4, 2022.

[30] S. M. a. C. K. M. A. Maiti, RF Laboratory for Engineering Education, India: *IEEE Fourth International Conference on Technology for Education*, 2012.

[31] M. O. a. A. A. Ammo, "Design and development of a hybrid feedback control system for an RF remote-controlled robot," *Beirut: International Conference on Advances in Computational Tools for Engineering Applications*, 2009.

[32] S. K. A. K. a. R. A. T. Ramachandran, "Radio Frequency Based (RF) Control & Operation of Electrical/Electronic Appliances in Home/Offices", *Delhi: IEEE International Conference*, 2018.

[33] K. Z. N. M. a. P. J. M. H. G. Yang, "Finding Optimum Settings for a 433MHz Radio for Long Range Communication, Shanghai," *2nd International Conference on Information Science and Control Engineering*, 2015.

[34] M. H. Idris, S. Latifah, B. Setiawan, I. M. L. Aji y D. P. Sari, "Vegetation and Soil Carbon under Various Forest Management Types: Case of Karang Sidemen Community Forest in Lombok, Eastern Indonesia," *International Journal of Design and Nature and Ecodynamics*, vol. 16, no 6, pp. 641-648, 2021.