Redesign of a drone (UAV) to obtain high flight autonomy, used in the analysis of Pitahaya crops based on neutrosophic control

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Abstract

The use of "drones" stands out in precision agriculture for the analysis of vegetation and soil indices, the present work contemplates a redesign, construction and implementation of a "drone" using computer tools based on software engineering and technologies of info-communications, which allows optimizing one of the existing platforms in the drone market (SKYWALKER (X8)) for the evaluation of vegetation indices, as estimators of changes in different types of vegetation cover in Pitahaya crops in the province del Guayas, also carry out precise monitoring of large extensions of crops, minimizing human presence, controlling soil conditions through special systems, such as hydration, temperature or plant growth rate, chlorophyll level, among others, and the appearance of plagues that could affect the Pitahaya crops located prematurely, as well as the bases for a neutrosophic control system in designing platforms by using simulators. For the neutrosophic control, neutrosophic uninorms were used for the aggregation of the measurement results by regions.

Keywords: Drone; precision agriculture; vegetation index; monitoring; neutrosophic control; neutrosophic uninorm.

1 Introduction

L.R. Newcome (2004) in his book states that “The term Unmanned Aerial Vehicle (UAV) was coined in the early 1990s as a replacement for the term Remotely Piloted Vehicle (RPV) used during the Vietnam War”, describing a robotic aircraft that does not load a human operator and can be piloted remotely, [1].

With the introduction of new methods, technologies and improvements in aeronautics, the application area of UAVs has expanded and various companies have invested in research and development to explore the potential of executing new tasks that take advantage of the characteristics of size and computational power of current aircraft and their automatic controls.

The diversification and expansion of the areas in which UAVs are used has grown during the last decade, the main use was applied in the military technological field, but thanks to the proliferation of new easily acquired platforms that are able to support new sensors, together with a tendency to miniaturize components and the inclusion of libraries that allow developers, researchers or enthusiasts of the subject to extend the ability to perform tasks of UAVs, a new ecosystem has been created in the construction of aircraft capable of meeting the needs and restrictions of new markets.

At the International Conference on Robotics and Smart Manufacturing (RoSMa2018) Review on Application of Drone Systems in Precision Agriculture Mogili and Deepak established that the use of UAVs in precision agri-

Doi: https://doi.org/10.54216/IJNS.190306
Received: April 13, 2022 Accepted: October 28, 2022

culture began with a Yamaha RMAX aircraft model designed for pest control and crop monitoring, after this model ([2]). The concept was extended to improve productivity, irrigation, fumigation, especially crop monitoring through multispectral cameras mounted on UAVs. Cameras mounted on aircraft can take photos during the flight and relate them to geographic points so that, in later analysis, experts can accurately find and geolocate areas marked for irrigation, treatment or fumigation, drastically reducing the waste of inputs and increasing the effectiveness of treatments.

Agricultural technologies are constantly evolving and constitute the resources that offer the most opportunities to increase productivity and safety in the field. One of the tools that in recent years has begun to be used is the "Drone" or UAV. And these have managed to position themselves as a very helpful tool, becoming allies for global agricultural production. Variations in plant cover on the earth's surface are an important environmental indicator that has been used in different fields, in precision agriculture, from studies related to the dynamics of ecosystems, to guidance in decision-making on issues of planning of the territory linked to development, on the other hand, remote sensing has been used as a determining tool to establish indicators of degradation and conservation of natural resources, especially in evaluating dynamics in changes in land use and vegetation cover. Among the techniques derived from the use of multispectral satellite data, the indices used are: the Normalized Difference Vegetation Index (NDVI), the Water Stress Index (WSI) and the Vegetation Index Adjusted to the Soil (VIAS), applied to images from multispectral and thermal cameras located in the "drone".

Remote sensing has been used as a valuable and determining tool when it comes to establishing indicators of degradation and conservation of natural resources, especially in evaluating dynamics in changes in land use and vegetation cover.

Therefore, a viable solution is the use of "Drones" or Unmanned Aerial Vehicles (UAV), equipped with multispectral cameras for these purposes, for which they become important and interesting, since they fulfill multiple functions in agriculture, such as field mapping, surveillance and monitoring of crops, pests and diseases, irrigation efficiency, and pesticide application, among others. Additionally, they bring multiple benefits, such as precise, localized application and in areas of difficult access, less exposure of the applicator, saving water and time, and increased productivity of the farmer, which implies an adequate use of the drone for these purposes. There are a wide variety of these devices on the market.

According to Adam C. Watts, Vincent G. Ambrosia and Everett A. Hinkley in their article "Unmanned Aircraft Systems in Remote Sensing and Scientific Research: Classification and Considerations of Use" states that the utility of UAVs currently finds a large niche in natural resource management and remote sensing applications with applications ranging from forest monitoring, land quality air, until agriculture depreciation, [3].

The implementation of a drone for the analysis of these soil data and vegetation indices of Pitahaya crops requires the search and redesign of a UAV that allows efficient data collection in large areas of Pitahaya crops.

The redesign of a Chinese-made SKYWALKER (X8) flying wing was proposed, with characteristics similar to those currently on the market, with the difference in some aerodynamic and flight control aspects for greater autonomy in spectrographic and thermographic analysis tasks, similar to the one illustrated in Figure 1.

Figure 1: Fixed-wing FPV drone.

This article aims to redesign a "Drone" capable of performing analysis and estimation of soil data and vegetation indices in Pitahaya crops, efficiently for the rational use of the ecosystem, biodiversity, entrepreneurship and economic sustainability to the community.

Within the collection of agricultural data, vagueness, inaccuracy, contradictions, indetermination can be found, among other characteristics that we decided to assume in this research instead of ignoring. That is why the Neutrosophic Control is applied, which consists of the neutrosophication of the collected data, for the evaluation of inference rules and then the de-neutrosophication, [4]. Which will allow better decision-making regarding the flight of the redesigned drone.

This paper is divided into a section that offers a background of the techniques and theories used in the research, both related to drone design and neutrosophy. The following section explains the features of the drone redesign and the use of Neutrosophic Control and uninorms in the neutrosophic framework [5,6]. The last section contains the conclusions of this paper.

2 Background

2.1 Technical characteristics of the Drone

The "Drone" in the form of an airplane has a maximum flight height of 180 meters, with an expected autonomy of 1 hour or 60 minutes, a time that allows it to fly over an average of 500 hectares (Ha). The flying wing made of carbon fiber, with a wingspan of just over a meter and a weight of 700 grams, makes precise turns along a previously defined path, by means of software controlled from the ground. Like a tiny airplane, it takes off and lands with precision, although the runway in this case is a small area outside the plantation. It is a “drone” or unmanned aircraft, whose use is now gaining strength in the agricultural sector. With a cost that exceeds USD 35,000.00 in the international market.
This "drone" incorporates a spectrographic or thermal camera that takes high resolution aerial photographs in the field, through these images useful information is obtained for different purposes, data that cannot be obtained from the ground. The analysis of the images taken by the device allows us to determine where there is the population of plants and the areas that change color due to diseases. The change of color of a plantation can mean problems in the soil, deficit or excess of irrigation, or a deficient fertilization. This photographic analysis is carried out periodically and allows control of the state of the plantation in a given time.
For the construction, a wing platform (X 8 SKYWALKER) of Chinese origin and not a multi-rotor was used, since better performance indicators per hectare would be obtained in the data analysis, see Figure 2.

Figure 2: Platform X 8 SKYWALKER of the drone.

Original Product Features
This is the X-8 FPV Wing from Skywalker Technology. The Great FPV Wing, the X-8 (Figure 2) has been designed specifically for FPV and UAV, custom for stabilizer systems, an impressive and fantastic flying FPV/UAV platform, molded from EPO so it is almost inductible. This model offers great amount of space under the canopy, excellent gliding performance, fast low power cruising speeds in the region of 80-90 km/h, the fuselage was designed from the ground up to take FPV and other video devices, the equipment docks. They have been designed to suit FPV and UAV applications. There is a camera mount on the nose and there is a forward oblique mount to fit a Gopro. Transporting the fuselage is easy, both the wing panels and vertical blades are bolted on. Nice design points are the wing reflex molding, removable vertical stabilizers, window launch grips, nasal camera bay, retained canopy via strong magnets, molded stacks and FPV trays and 2 spars to the fuselage - plus a molded strap on each wing panel.
It has a very large size cockpit for FPV equipment, compatible with the GoPro Hero 3 camera, detachable main and rear wings, no glue required for assembly, just a screwdriver, carbon tubes and wood construction inside the body to improve the fuselage, full size engine mount, suitable for upgrading the engine for more power, the fuselage/wings are made of reinforced shock resistant EPO material, it is an impressive 2120mm wingspan airframe.

Product Details
Article no.: X-8 white,
Wing reach: 2120mm,
Fuselage length: 790mm,
Wing area: $80dm^2$,
Flying weight: 2500-3000g,
CG: Head to back 430-440mm,

Take off: Catapult shot from molten cat or by hand,
Landing: slide down or parachute landing,
Maximum anti-wing capacity: Level 4,
Air speed: 65-70km/h,
Maximum flight time: 25min,
Maximum flight level: 200m,
Engine: Sunnysky4250KV500 / OS5010KV810,
Propeller: 12080F /12060E,
Servo: 17g*2pcs,
EXH: 60A/100A,
Battery: 22.2v5000mah-6500mah,
Radio: 4CH 4SERVO.
1*2820 (3548) or larger brushless motor.
Foldable prop 12*6 or 12*8 foldable prop set.
2*20g servos (the hole size on the servo plane is 40*40mm).
ESC 60A or larger.
4S 6000---10000mah batteries 2pcs.
Skywalker X8 FPV Airplane Flying Wing 2122mm EPO RC Airplane Empty frame.
Radio control futaba 6 channels with receiver.
Pinguave controller with gyroscope.
Multispectral Camera.
Thermal camera.
Wing profile diameter and curvature of the extrados.
Vertical stabilizers at the limits of the airfoil.
Wing load, more than 30 g/dm^2 of surface.
3-cell battery to be used with more than 50 cycles 5500 mA 12 V.
Static thrust of more than 2 Kg.

2.2 Neurosophy

One of the challenges of classification for decision-making is how to aggregate the raw data obtained. This requires the use of a convenient aggregation operator, in this article the neutrosophic uninorms are used.
Definition 1 ([6]). A *neutrosophic uninorm* $\mathbf{U}_N$, is a commutative, increasing and associative mapping, $\mathbf{U}_N$: $(]^-0,1^+[\times]^-0,1^+[\times]^-0,1^+[)^2 \to]^-0,1^+[\times]^-0,1^+[\times]^-0,1^+[$, such that:
$\mathbf{U}_N\left(x(T_x, I_x, F_x), y(T_y, I_y, F_y)\right) = (\mathbf{U}_N T(x,y), \mathbf{U}_N I(x,y), \mathbf{U}_N F(x,y))$, where $\mathbf{U}_N T$ means the degree of membership, $\mathbf{U}_N I$ the degree of indeterminacy and $\mathbf{U}_N F$ the degree of non-membership of both, x and y. Additionally, there exists a neutral element $e \in]^-0,1^+[\times]^-0,1^+[\times]^-0,1^+[$, where $\forall x \in]^-0,1^+[\times]^-0,1^+[\times]^-0,1^+[$, $\mathbf{U}_N(e, x) = x$.
This concept was generalized to the Neutrosophic Offuninorms for domains outside the interval [0, 1] or offsets ([7,8]). In particular, the formula of the PROSPECTOR combining function is used ([5,9]).
Uninorms have been applied in the resolution of a multiplicity of problems [9].
A special type of uninorm defined on the interval $[-1,1]$ is the combining function in Prospector P: $[-1,1]^2 \to [-1,1]$ with neutral element 0, as it is shown below:

$$P(x,y) = \frac{x+y}{1+xy} \quad (1)$$

This function is the aggregator in the mining expert system of this name. The interpretation of x <0 is that the expert believes that he/she has evidence against the hypothesis that is evaluated; whereas x > 0 means that the expert has evidence in favor of the hypothesis. x = 0 is used when the expert has no evidence either for or against the hypothesis. The absolute value of x means the degree of belief in the evidence, where -1, 1 are the maximum degrees, the former one against the evidence and the second one in favor. $P(x,y)$ is a function that aggregates two evaluations. This is an Archimedean uninorm, that is $P(x,y) < min(x,y)$ if $x, y < 0$ and $P(x,y) > max(x,y)$, if $x, y > 0$. -1 and 1 are the two veto values.
Two separate cases are $P(-1,1)$ and $P(1,-1)$, where it is evident that there is a contradiction because this means there is absolute evidence for and against the hypothesis at the same time. In some texts, it is defined by $P(-1,1) = P(1,-1) = 0$, since Equation 1 is undefined for this pair of values.
Here we use the following formula [5-7]:

$$P(x,y) = \begin{cases} \frac{x+y}{1+xy}, \text{if } (x,y) \notin \{(-1,1),(1,-1)\} \\ -1, \text{otherwise} \end{cases} \quad (2)$$

3 The new drone model

The different stages of redesign of the drone were as follows:
Conceptualization of the proposal: It consisted of the conceptualization of the implementation of "Drones" technologies for improvements in the yield parameters of Pitahaya crops. In this sense, presentations and exchanges were made with the producers of Pitahaya.
Diagnosis: This stage was oriented to the study and improvement of the performance variables in the Pitahaya crops, as well as their incidence in the final results of contaminating agents of the soil and of the fruits, based on which the analysis of the data for running the application.
In this stage, the conditions of the crop fields are also evaluated for the definition of flight route parameters, as well as the performance parameters and contents in the computer application developed for the control of flight routes.
Proposal: The "Drone" was redesigned and developed, taking into consideration the use of the different types of materials to be used, the design and construction of the prototype structure where the wing profile was modified through software to increase its flight autonomy and improve the performance parameters of these devices, in comparison with those currently existing in the international market.
A self-sustaining profile was used instead of a straight profile, modifications were made to the wing profile with carbon fiber, thermal cameras and a multi-spectral infrared camera were adapted.
In this design, important modifications were made to the X8, of aerodynamics to obtain better flight performance indicators, among them there are elements in the design that it was proposed to modify the original characteristics of the product.
To introduce the aerodynamic changes in the airfoil and perform simulated tests, before the field tests, the XFLR5 computer application was used, which is an application specifically designed for the analysis of the airfoil. Other programs, such as EasyPlan, DesignCAD Express or AllyCAD, which could be similar to XFLR5, were not used since the latter has very friendly graphical environments and high precision in calculations given the low Reynolds number coefficient, which is excellent in the analysis of small airfoils.
The Windows version of XFLR5 states that XFLR5 is an analysis tool for airfoils, wings, and aircraft operating at low Reynolds numbers, [10]. Includes XFoil forward and inverse analysis capabilities and wing design and analysis capabilities based on lift line theory, vortex lattice method, and 3D panel methods.
The primary purpose, for which the XFLR5 software application was developed, was to provide:

- A friendlier interface for XFoil.
- Change the original Fortran code to C++.
- For all programmers who might require it, this was done in accordance with the work of Mark Drela and Harold Youngren, who were very generous in making their project free to use under the General Public License.
- This computer application made it possible to carry out a 2D and 3D analysis of the main parameters of the wing, with high precision, the calculations of which are based on the use of the well-known Reynolds number, see Figures 3 and 4.

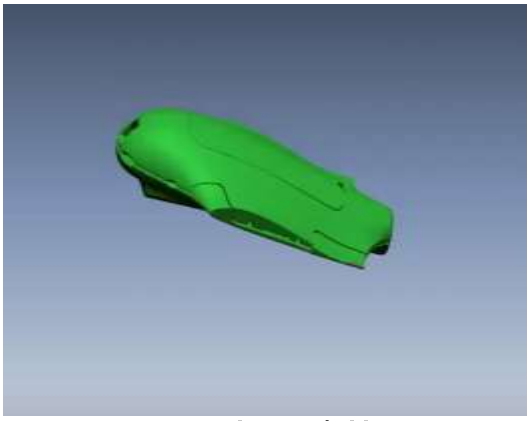

Figure 3: Structure without airfoil limits.

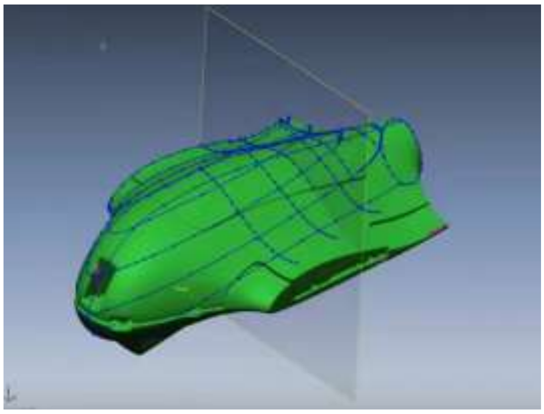

Figure 4: Fuselage with airfoil limits.

This is a free software application, which has an extensive community that keeps this application updated, its latest release being version 6 on June 28, 2017.
Below, in Figure 5 and Figure 6 we can see images of the experimental simulated flights to which the X8 wing was subjected and the potential of this computer application.

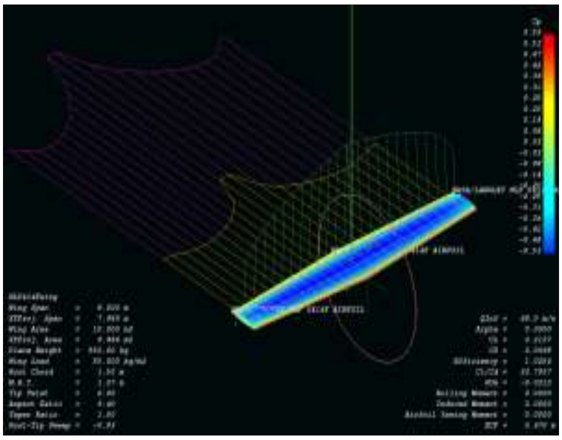

Figure 5: Simulation to which the X8 wing was subjected

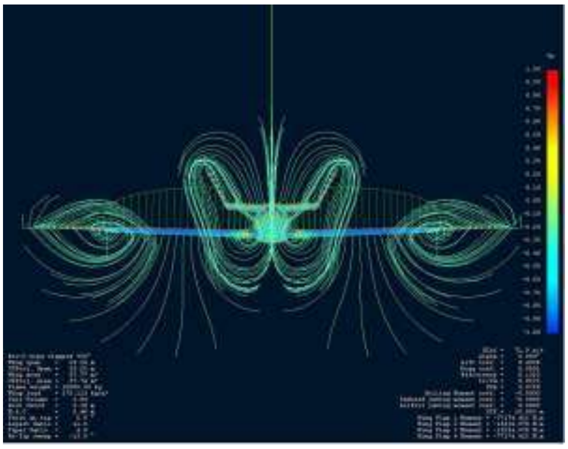

Figure 6: X8 Vortex Pattern Analysis

A control system based on the use of neutrosophic logic for UAVs is also proposed. The proposed neutrosophic controller algorithm is as indicated in the following:

- Record the measurements,
- Neutrosophication,
- Make inference,
- De-neutrosophication.

Neutrosophic control

Step 1: Record the measurements of all the variables that represent the relevant conditions of the controlled process.

Step 2: The acquired measures are converted to appropriate neutrosophic ensembles to capture the true, false, and indeterminate measure using true, false, and indeterminate membership functions respectively.

This step is called the neutrosophication step.

Step 3: The neutrosophication measurements are then used by the inference engine to evaluate the control rules stored in the neutrosophic rule base. This evaluation will result in a neutrosophic set or several neutrosophic sets to be defined on the universe of possible actions.

Step 4: This neutrosophic set is then converted, in the last cycle step, to a single (sharp) value since the triplet formatted as x(t,i,f); which would be the best representative of the derived neutrosophic set. This process is called de-neutrosophication.

This algorithm allowed the handling of uncertainty, vagueness, ambiguity, imprecision, incompleteness, inconsistency, redundancy and contradiction in the data.

Below we explain some important details of the applied neutrosophic control.

Because there are multi-spectral images, one or more colors are chosen to perform the particular study. For example, the prevalence of green is important to study the state of the vegetation, while in other cases the image converted to its black and white equivalent is studied. We can also study the pixel values for more than one color. These pixels that are in a range of 0-255 are fuzzified using membership functions such as those shown in Figure 7, where they are classified as "High", "Medium", and "Low", in accordance with the prevalence of a given color.

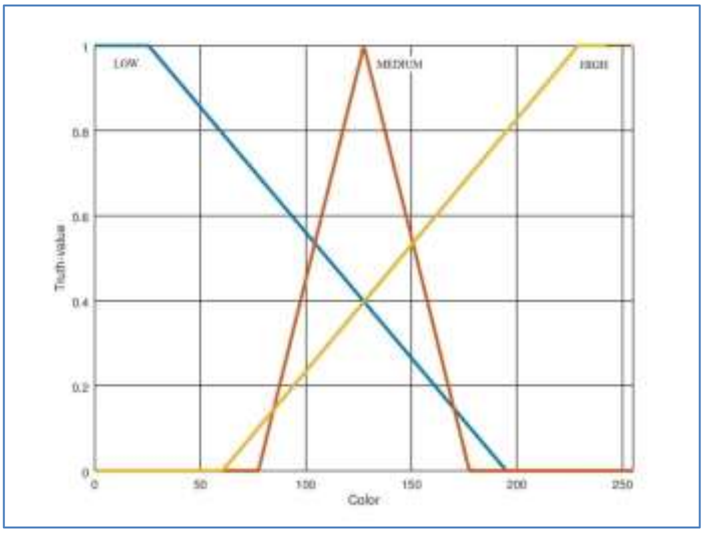

Figure 7: Hypothetical membership functions to fuzzify the pixel data of the captured image.

Each data (pixel) is first converted to a neutrosophic number by determining the label that is used to measure within the inference rule. If, for example, the prevalence of a color in a high degree of pixel x is measured, the truth-value of the pixel is taken in the membership function "HIGH" that constitutes its truth-value for truthfulness, its membership value for "LOW" which will be its truth-value for falseness and its truth-value for indeterminate is measured by the evaluation in the "MEDIUM" membership function. On the other hand, if little prevalence of such a color is measured, it is done by the neutrosophic negation of the above values.

The neutrosophic values in a single pixel may not be significant to yield to a conclusion, which is why the values in a complete determined area can be aggregated by using formula 3, for each T, I, F value of the pixels that make up the region studied, as is indicated below:

If G is the region under study, for example it is a square within the geography, of certain dimensions, we obtain $\bar{x}_G = \langle U_T(G), U_I(G), U_F(G)\rangle$, where $U_T(G), U_I(G), U_F(G)$ is the recursive evaluation of the elements (pixels) of G in its components Truth, Indeterminate, and False, respectively, by using the uninorm defined in [0, 1], given by Equation 3 ([5,6,11-15]), which is the variant of formula 2 on this interval, through an algebraic transformation.

$$U(x,y) = \begin{cases} \frac{xy}{xy+(1-x)(1-y)}, \text{if } (x,y) \notin \{(0,1),(1,0)\} \\ 0, \text{otherwise} \end{cases} \quad (3)$$

To apply the de-neutrosophication process these triads, the following formula is used ([16]):

$$S(\langle x_T, x_I, x_F\rangle) = \frac{1}{3}(2 + x_T - x_I - x_F) \quad (4)$$

There is a set of inference rules of the type IF A_1 AND IF A_2 ... AND IF A_m THEN B. Where the arguments of the IF are the elements obtained from the de-neutrosophication. For example, IF "in zone G there is a prevalence of green" THEN "the zone is healthy". Then, these results are processed by the defuzzification methods of well-known fuzzy systems, [17].

Finally we summarize the results obtained on the redesigned drone.

In Figure 8, the redesigned "drone" for research purposes at the University of Guayaquil is shown. The product obtained was a drone with improved characteristics and to which 22 flight tests were carried out in the open field and on real crops.

Figure 8: Redesigned drone from the University of Guayaquil

The last specific objective that was raised in the present investigation was fulfilled, since the "drone" was implemented in conjunction with the company Pitasol of Guayaquil and subjected to flight tests with the following results:

All the flights were of an experimental nature, 22 directed flights were carried out with a Futaba radio transmitter and various hardware components were used, such as the battery built into the drone.

Conclusion

According to the results of this study, with the redesign of the drone, improvements were obtained in the characteristics of the final product, using the XFLR5 software and it is summarized in the following 5 aspects:

1. **Simplicity**: A very standard product was established in terms of operational simplicity. Simply it defines the terrain or region we want to recognize using the software and launch the "Drone" into the air. It can fly, capture images and land automatically. No in-depth piloting knowledge is required.
2. **Efficiency**: Thanks to its modified fixed-wing design and precisely optimized cruise speed, and changes made to the X8 platform, tens of hectares of crops could be photographed in a single flight: coverage far superior to that of multi-rotor platforms and the original version of it.
3. **Confidence**: This reliability is achieved thanks to its light and robust construction, as well as the integration of state-of-the-art robust electronics. In addition, it has a technical assistance service, both for Hardware and Software by researchers from the University of Guayaquil.
4. **Versatility**: The "Drone" was easily modified to support a wide range of camera options, allowing it to fit any agricultural application: NIR (Near Infrared), RGB (Visible).
5. **Flight autonomy**: This was one of the main features modified to the original platform, which allowed obtaining relevant results in terms of distances traveled in crop fields. The introduction of solar panels or folding solar panels for upper wing skin (This last element will be studied, its economic feasibility and its specific weight / contribution ratio, so its use may be feasible and it was decided to study it in future research projects.

An important novelty was the introduction of a neutrosophic control method that allowed the data obtained to be classified with greater accuracy, although with less precision. For this, uninorms were successfully used in the neutrosophic framework.

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