RESEARCH ON IMPROVING THE AUTONOMY OF MISSIONS EXECUTED BY UNMANNED AERIAL VEHICLES – UAV

CERCETARI PRIVIND CRESTEREA AUTONOMIEI MISIUNILOR EXECUTATE DE CATRE AERONAVELE FARA PERSONAL UMAN LA BORD - UAV

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Abstract. In order to increase the autonomy of missions executed by unmanned ships – UAV, an experimental stand was created to serve in automatically charging Li-Po batteries that charge-up drones with multiple engines, without disconnecting them from the drone support. Generally speaking, the electrical current necessary even for a standard mission is quite high, and a professional charger has a weight of over 800 grams, weight that will diminish a lot the useful weight of the drone. So the solution found will be to create an automatic charger with two modules, that will also include a personalized BMS for charging/discharging the batteries safely. In this paper we will present the research done on various specialized chargers with different powers and various configurations of batteries in order to find an optimal algorithm to be implemented on the experimental stand created.

Rezumat. Pentru cresterea autonomiei misiunilor executate de catre aeronavele fara personal la bord – UAV, s-a realizat un stand experimental pentru incarcarea automata a bateriilor Li-Po ce energizeaza dronele multimotor, fara deconectarea acestora de pe drona suport. In general puterea electrica necesara pentru o misiune standard este destul de mare, iar un incarcator specializat are o greutate de peste 800 grame, greutate care ar diminua foarte mult greutatea utila a dronei. Astfel ca solutia gasita este proiectarea unui incarcator automat format din doua module, care include si un BMS personalizat pentru incarcarea/descarcarea bateriilor in siguranta. In aceasta lucrare se prezintă cercetarile realizate pe mai multe incarcatoare specializate cu puteri diferite si mai multe baterii cu configuratii diferite pentru identificarea unui algoritm optim care sa fie implementat pe standul experimental realizat.

I. INTRODUCTION

During the research carried out the process of charging and discharging of Lithium – Polymer batteries was studied, batteries specific for charging electric drones. Because the energy consumption of a drone is quite high, Lithium – polymer rechargeable batteries are being used that can store a large volume of energy into a very small space. This kind of batterie can be of a cell or a series of cells placed in parallel or in sequence with very cell having a nominal energy of 3.7 V. During the charging process it is vital that the temperature does to exceed 5-60 degrees and that the voltage / cell does no increase more than a few millivolts over 4.2 VDC. In this case the battery will self-destroy, burning sometimes with an open flame or just exploding which can cause fires. At discharge, there is minimum limit where the voltage cannot go under, because in that case the battery can deteriorate fast. In case of Lithium-Polymer batteries that limit 2.5 VDC for each cell. Going under this threshold can damage the cells forever and of course the battery, because these can sulphur, increasing internal resistance and thus decreasing its total capacity. Another situation that affects this type of batteries is storing them for too long, without periodic control, fact that can lead to internal short-circuits of the battery and in the end its destruction. Thus, it is imposed that the experimental stand created especially for automatic charging of Li-Po batteries can manage all these limitations and protect the battery by adjusting parameters of charging and discharging according to the situations occurring during this process.

II. PRESENTATION OF THE EXPERIMENTAL MODULE.

For selecting the best solutions but also the safest methods for charging these batteries, the managed process for charging on various chargers on two batteries with different characteristics and capabilities was studied: one with two cells in sequences - 2S1P, 7.4 Vdc, 5300 mAh, 30C and one with three cells in sequences - 3S1P, 11.1 Vdc, 10,000 mAh, 15C, both consisting of a single string in parallel. For tests, three chargers of different powers were selected: 50 W, 200 W and 300 W, respectively, among the most used in the field, for the two types of batteries selected. These chargers have also implemented specialized circuits for automatic charge management focused on the passive controlled balancing of the load level on each cell.

For this, an experimental module was developed (Fig. 1) that monitors all the parameters from the battery level but also from the charger terminals, during the whole period of the charging / discharging process. The components of the experimental module are simple and do not interfere at all in the charging / discharging process, being mounted transparently between the charger output and the battery terminals.

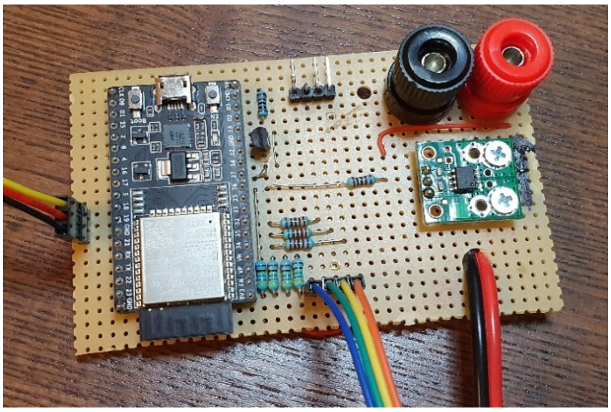
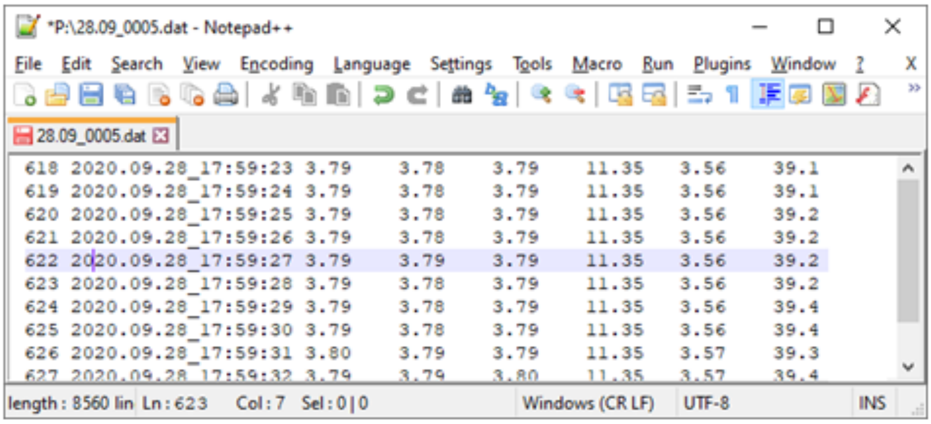


Fig. 1 Experimental module for monitoring battery / charger parameters.

A 32-bit microcontroller is used to acquire and monitor the data: ESP32-DEVKITC-32D produced by ESPRESSIF. It has several communication interfaces: GPIO, 2xI2C, Wi-Fi, Bluetooth, Bluetooth Low Energy, 2xI2S, 3xUART, micro-USB, SDIO, 3xSPIO. On these microcontrollers a program written in C++, which reads the data using analog inputs, processes them and transmits them on the serial to a PC that feeds this experimental module via the USB interface.

On the PC with the help of the PUTTY program the data from the serial is written in a file of type ".dat" in a simple and easy format to read and interpret later and has the following structure:

"Index data_timp tensCell_1 tensCell_2 tensCell_3, tensIncarcator, curentIncarcare"



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2020.09.28_17:59:23 3.79     3.78     3.79     11.35    3.56     39.1
2020.09.28_17:59:24 3.79     3.78     3.79     11.35    3.56     39.1
2020.09.28_17:59:25 3.79     3.78     3.79     11.35    3.56     39.2
2020.09.28_17:59:26 3.79     3.78     3.79     11.35    3.56     39.2
2020.09.28_17:59:27 3.79     3.79     3.79     11.35    3.56     39.2
2020.09.28_17:59:28 3.79     3.78     3.79     11.35    3.56     39.2
2020.09.28_17:59:29 3.79     3.78     3.79     11.35    3.56     39.4
2020.09.28_17:59:30 3.79     3.78     3.79     11.35    3.56     39.4
2020.09.28_17:59:31 3.80     3.79     3.79     11.35    3.57     39.3
2020.09.28_17:59:32 3.79     3.79     3.80     11.35    3.57     39.4
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Fig. 2 File of gathered data.

Also, in order to gathered more precisely the analog signals an external resistance voltages source was needed, so we added the TL1431IZ stabilized voltages source. This offers a reference voltage of 2.5 V with a tolerance of -40 +/- 105 ^{0}C.

The monitored parameters are the following:

- Electrical voltage for every cell of the battery
- Electrical voltage for the battery terminals
- Current for charging / discharging
- Battery temperature

In order to read the voltages for each cell that form the battery voltage dividers were used with precision resistance. Practically these voltages range from 2.5 VDC and 4.2 VDC, respectively from being charged and discharged. The acquisition of these voltages is very important because their variation and the way of working the balancing system is very important. The decrease of these voltages below the threshold of 2.5 VDC makes the battery impossible to recharge at optimal parameters, and exceeding these voltages even by a few tens of millivolts will cause the battery condition to deteriorate quickly, reaching a very rapid rise in temperature over 60 degrees Celsius and immediately on visible swelling of the battery. At this stage the battery is already compromised but if no quick action is taken the battery will overheat, burning with an open flame and in some cases even exploding violently.

Reading these voltages using a microcontroller that uses a 12-bit ADC for analog inputs has an advantage over other classical solutions because the measurement range is divided into 2^{12} discrete values, for example 4096 samples, and the measurement is much more accurate. in this case. Basically, the measurement resolution is:

$$(3.3\ \text{V} - 0\ \text{V}) / 4096 = 3.3\ \text{V} / 4096 = 0.000805\ \text{V} = 0.805\text{mV}$$

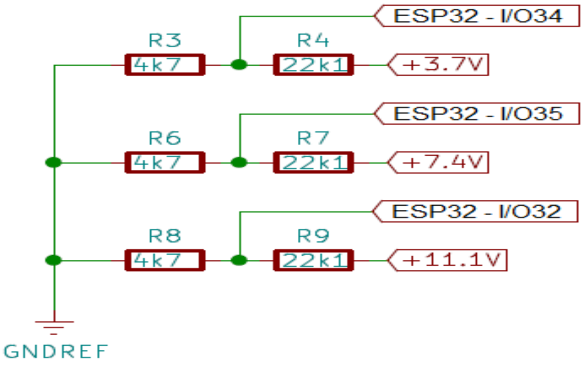

Fig. 3. Voltage divider used to read the voltages on the battery cells.

As we can see in the previous figure, the inputs used to measure these voltages are GPIO34, GPIO35 and GPIO32. In order to increase the measurement accuracy, all these values are correlated with the calibration made previously using the reference voltage source mounted especially for this purpose.

- *Electrical voltage at the battery terminals.*

This voltage coincides with the previously measured voltage Ucell_2 (GPIO35) from the 2-cell battery in sequence - 2S or coincides with the voltage Ucell_3 (GPIO32) in the case of a 3-cell battery - 3S. When the charger is connected to the battery, it will coincide with the value of the voltage at the charger terminals which is generally about 10% higher than the maximum battery voltage of 13.5 VDC for a 3S battery and 9 VDC for a battery with a 2S configuration.

- *Current charge measurement*

To measure the charging current, it was decided to use an electrically isolated Hall current sensor, which can measure the current on the main circuit compared to the rest of the measuring circuit, up to 3 kV RMS, which allows the sensor to be inserted anywhere along the current path. The ACHS-7121 sensor used, is manufactured by Pololu and is a bidirectional sensor with a measuring range that covers the entire current required in the range (-10 A ÷ + 10 A) with high accuracy and reliability: with a typical total output error equal to ± 1,5% at room temperature, with factory calibration, extremely stable output voltage and magnetic hysteresis close to zero. The sensor provides 185 mV data output for each ampere measured on the main current path, centered at 2.5 V. The supply voltage is in the range of 4.5 V ÷ 5.5 V.

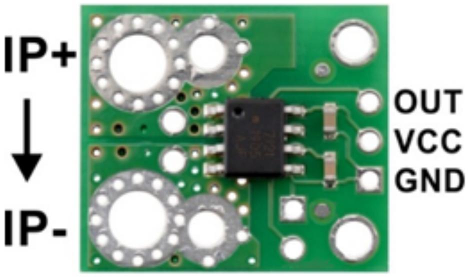

Fig. 4. ACHS-7121 bidirectional current sensor

The sensor is robust enough for such applications and can tolerate transient increases of up to 100 A over a maximum period of 100ms. Also, another important feature for this sensor is the wide operating temperature range offered: (-40 °C ÷ 110 °C).

- *Battery temperature*

One of the most important parameters in the process of charging a battery is the temperature of the battery or batteries during the charging / discharging process. In the case of the BMS implemented on the drone, the temperature reading is done with the digital temperature sensor DS1820, which has a measuring range of -55 °C ÷ + 125 °C, sufficient for monitoring lithium technology batteries and have a resolution up to 12 bits. Each sensor has a unique address in the network, 64-bit, assigned by the manufacturer, and for reading the temperature it uses the "1-wire" protocol and a digital input on the microcontroller, so on the same 3 wires: GND, VDC, Data-Pin a multitude of such sensors can be installed, if you want to increase the number of measuring points or the number of batteries.

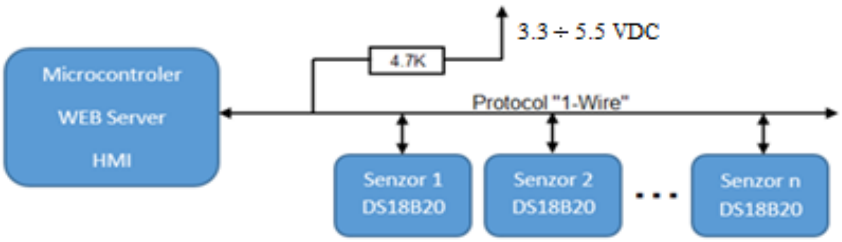

Fig. 5. Principle of temperature measurement using DS18B20.

Fig. 6 shows some images from the tests highlighting the specialized chargers and the batteries used.

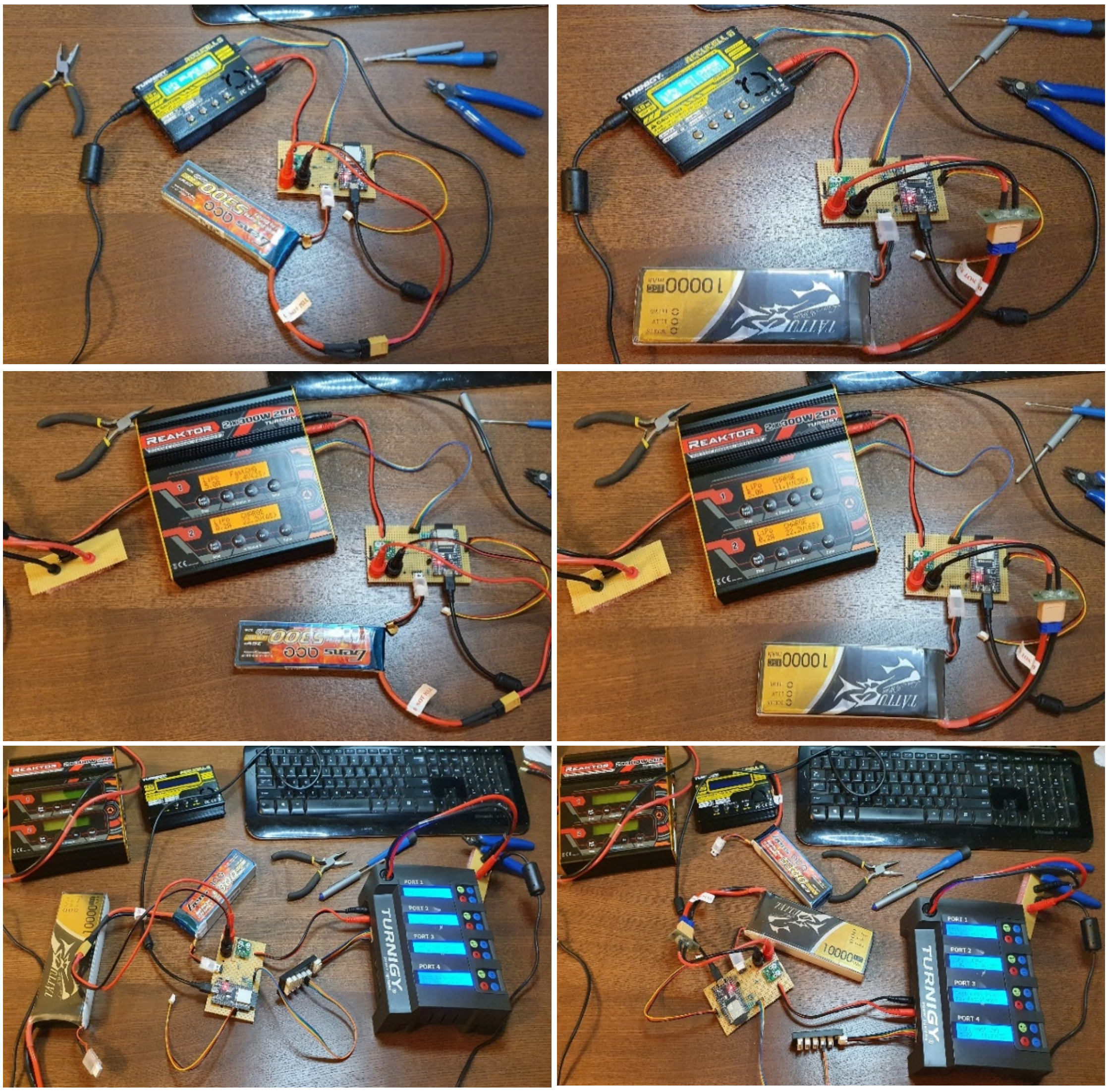

Fig. 6 Images during the acquiring of data for the process of charging / discharging.

3. INTERPRETING THE RESULTS AND FORMING ALGORITHMS

From the analysis of the preliminary results at the end of tests, the architecture and algorithm that is implemented at the experimental stand is created. In fig. 8 we see the mobile module placed o nthe drone that includes a specialized BMS. The algorithm developed through this research used to charge Li-Polymer batteries, that power-up the drone’s multi engines, is based on the most widely used method of charging, that following the charging cubature in

Fig.7. This method has three initial phases: pre-charging, charging with constant current and charging with constant voltage [1] [2] [3].

Phase I. In the preload phase, first of all, the temperature of the environment and of the cell pack that forms the battery are tested. If the temperature is not in the optimal temperature range (0 ÷ 50) ºC, the beginning of the charging process at low temperatures favors the appearance of metal lithium which means the significant degrading of the electrodes forming a cell, and in case of a temperature above the limit accelerated degradation of the cell and thus the battery. If the cell temperature is within the accepted limits then the charging process begins, charging the battery at a rate of 10 % of the rated charging capacity, up to a voltage of 3.0 V on each cell. Basically, in this phase the integrity of the cells is tested, thus the passive layer is regenerated, which is affected if the battery has been stored for a longer period of time, and if the cell voltage does not reach the value of 3.0 V in a predetermined time (30 minutes), then the loading process ends with an error, because structurally or chemically the cells are compromised. If the voltage on each cell exceeds the 3.0 V threshold then the charging process enters phase 2.

Phase II. In this phase the charging current is kept at a constant, limited from 0.5C to 1C, in order to avoid heating the batteries and thus the degradation of the cells. From the tests, the charging rate was set to 1C, the temperature remaining within acceptable limits for the test battery. The charging process remains set on these parameters until the voltage on each cell reaches the maximum prescribed by the battery manufacturer equal to 4.2 V. And in this phase the evolution of the temperature is followed. If the temperature exceeds the maximum threshold, the charging process is suspended until the temperature drops below 45 °C. When the voltage reaches the prescribed value, we enter phase III.

Phase III. In this phase of the charging process the current begins to decrease exponentially at a predetermined minimum current and the voltage is adjusted to remain the maximum reference values mentioned in phase II. The current decreases naturally due to the internal resistance of the battery up to a value of (5 ÷ 10 %) of the charging current specified on the battery.

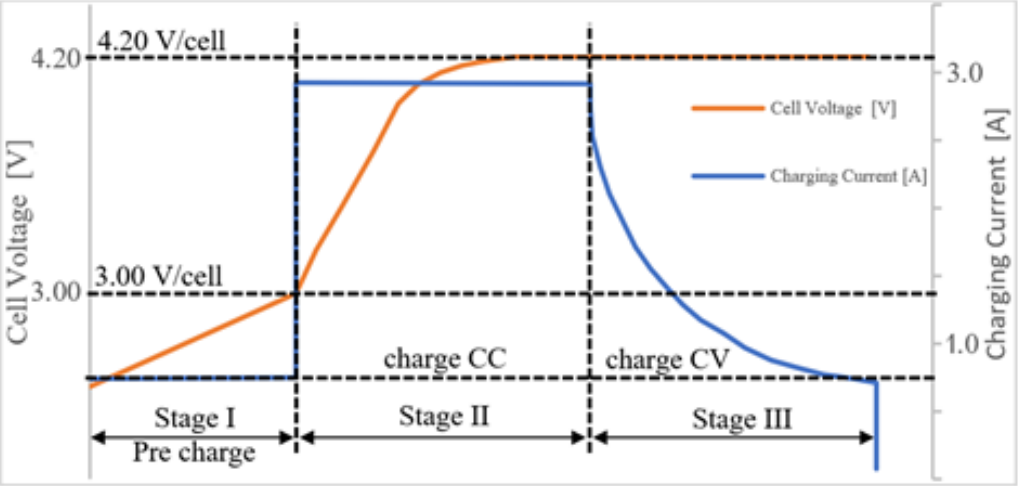

Fig. 7 The charging scheme for the Li-Po battery, using the method of constant voltage / voltage [1].

As a percentage the second phase is about 70 % of the total charging time, and phase three is 30 %. Generally speaking, the lower the internal resistance of the battery, the lower the charging time, and setting a stronger charging voltage makes going though the two phases II and III a lot faster. Increasing the charging voltage above the limit specified by the manufacturer causes the battery life to decrease substantially as it leads to the appearance of metal lithium that deposits on the anode. This is an aggressive metal that reacts easily with the electrolyte leading to loss of lithium, which shortens the battery life.

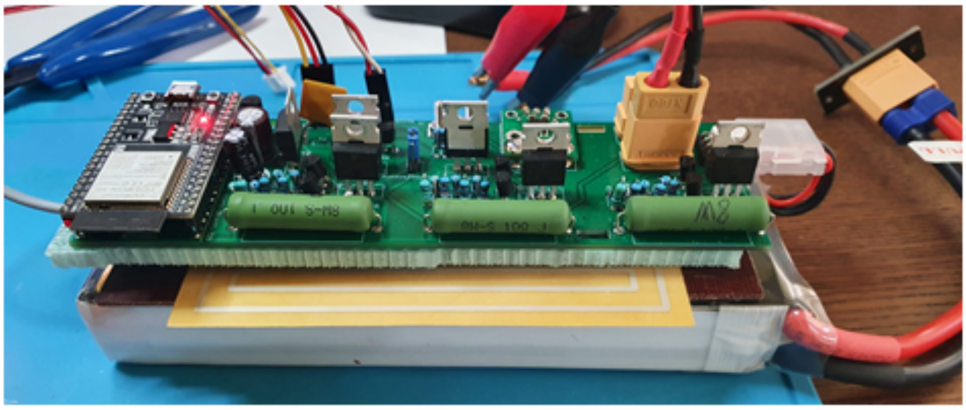

Fig. 8. Mobile module that includes BMS, placed on the battery that energizes the multi-engine drone

The system implemented in this paper detects when the battery has been charged 100%, by continuously monitoring the charging current, which in the last phase gradually decreases until it reaches the value of C/20. This value is associated with the end of the charging process, but for safety reasons it can be doubled by measuring the voltage on each cell of the battery. If all cells have a voltage of 4.2 V, then the charging process is complete.

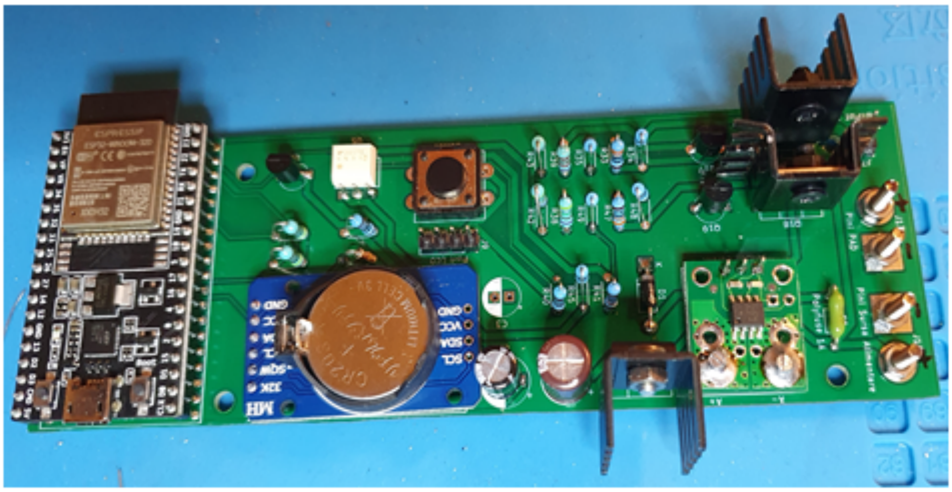

Fig. 9. Fixed module placed on the charging pad

In addition, as mentioned above, during the entire charging process, the battery temperature is continuously monitored, and if it leaves the safety range, the charging process is suspended by the microcontroller. If the charging time is not a critical one then, in order to eliminate the effects that could appear on the battery structure, it is possible to set the charging process to be a slower one, but not longer than 3 to 5 hours, depending on the parameters. battery, but especially its wear and tear, and condition.

Another function implemented in the charging stand algorithm is to detect the discharge rate of Li-Po batteries. This is a rather important initial parameter, as it was imposed by their manufacturer depending on the application it serves and can vary quite a lot. For this, manufacturers use thicker or thinner active materials depending on the desired application, the thin layers have a higher charging rate but lower energy density. The discharge rate decreases a lot when the temperature drops below 0 °C, but also with the accumulation of a significant number of charging / discharging cycles.

4. CONCLUSIONS

Drones are beginning to impose themselves in many activities, in the civil or industrial field, as it is a field that is constantly developing. Unfortunately, their autonomy depends very much on the useful weight at takeoff but especially on the quality of the batteries, which have failed to keep up with the development of this field.

An autonomous multi-engine drone battery recharging system, without the need for a human operator to be present at the site and replace these batteries with charged ones, can greatly expand the areas in which they can operate and can improve and automate most missions that have as a scenario objective monitoring or predictive maintenance achievements supervised remotely by a human operator.

The idea of creating an automatic loading system consisting of two synchronized modules, one mobile containing a specialized BMS, mounted on the drone and another fixed located on a loading PAD mounted at a fixed point on the ground, helps to increase the autonomy of missions ensuring the energy autonomy of the drone by automating the charging process, located on the route of the drone.

5. Acknowledgements

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