DETAILED DESIGN OF THE OPERATING TEMPERATURE OPTIMIZATION SYSTEM FOR ELECTRONIC DEVICES

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ABSTRACT: The research addresses the technical solutions chosen for the systems that make up the temperature optimization device that is the subject of the paper. The temperature monitoring and augmentation, thermal insulation and structural subassemblies work together to perform the primary function of the product. Multiple technological solutions have been considered for the design of each subassembly and the most advantageous from a technical, economic, ergonomic and environmental point of view have been selected.

KEYWORDS: electronic device; temperature; thermal insulation; sensor; microcontroller

1. Introduction

The main role of the product is to keep the temperature of the phone above the minimum optimal operating threshold [>0°C]. The designed product consists of three main sub-assemblies: the heating system [Fig. 1], the structural sub-assembly and the heat-insulating case [Fig. 2]. This research is a continuation of the scientific research 3 [1] presented in the scientific communication session of 2021 in which we addressed the issues to be considered for fulfilling the main function of the product and the possible technological options to address these issues.

2. State of the art of the domain

The heating system monitors the phone's temperature and activates a set of battery-powered resistors that will operate until the minimum optimal operating temperature threshold (0°C) is exceeded. It also monitors the temperature of the electrical resistors to prevent overheating that could damage the product. When the temperature recorded by the resistor control sensor exceeds a certain value, the resistors will be deactivated.

The heat insulating cover consists of a flame retardant cotton cover that both thermally insulates the heater and the phone, as well as accommodates them and ensures the correct position of the phone in relation to the heater. Both sub-assemblies have been designed to be easily removable to allow quick intervention and repair of the product.

Fig.1. Heating system

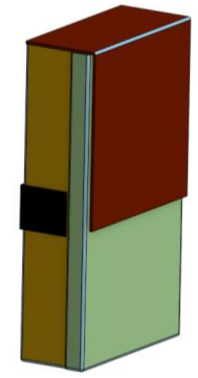

Fig.2. Heat-trapping pouch

Table 1 includes the operating parameters of the device.

Table 1. Working parameters

Item No.	Parameter	Value	Observations
1	Charging time	3.85h	At maximum charging capacity 1000mAh with 10% efficiency loss
2	Continuous functioning time	3.5h	At 0 °C
3	Start-up temperature	5°C	-
4	Overheat prevention temperature value	40 °C	-
5	Maximum temperature	35 °C	-
6	Minimum working temperature	-20°C	-

3. The problem analysed and research objectives

The objective of the research is to arrive at a final prototype design that will establish the fundamentals of the functioning of an eventual market-ready product. The problem lies in the multiple existing options for addressing each of the requirements imposed by the main purpose of the product: optimising the operating temperature of electrical devices. [1]

To achieve its primary purpose, the product must have a set of critical characteristics:

- Temperature monitoring of the electrical device;
- Heating of the electrical device once its temperature falls below the optimal threshold for operation;
- Thermal insulation of the electrical device to avoid heat loss;
- High portability;
- Use of a battery that powers the monitoring system and increases the temperature of the electrical device;

Currently, all solutions on the market that address the problem of keeping the temperature of electrical devices, specifically smart phones, within the indicated parameters are based on the principles of thermal insulation or high thermal conductivity and ventilation.

Most typical phone housings have no influence on smartphone temperature.

The best example of a case based on the principle of thermal insulation is the ClimateCase (Fig.3.) [2], which is made of 8 layers of synthetic material that insulate the phone from both high and low temperatures. This case can also be heated in the microwave or cooled in the freezer when emergency cooling or heating of the phone is needed.

A typical example of a case that works on the basis of heat dissipation and ventilation is the Mixneer case (Fig.4), [3] made of thermoplastic polyurethane. This material is cheap, durable and easily injectable, and its geometry ensures a constant airflow to the phone, thus preventing overheating.

Fig.3. ClimateCase Phonecase [2]

Fig.4. Mixneer Phonecase[3]

The product covered in this research will be the only device on the market that fulfils the role of active temperature optimisation of small electrical devices.

4. Theoretical aspects

There are two main theoretical aspects that have influenced the design process of the electrical device operating temperature optimization system:

- The Steinhart-Hart equation [4];

- Magnetic saturation of the inductor in the voltage booster [5];

The sensors chosen for monitoring the temperature of the electrical device are thermistors. Thermistors are electrical resistors whose electrical resistivity depends on their temperature. As the resistivity varies, so does the current flowing through them. The Steinhart-Hart equation is used to convert the current flowing through thermistors into degrees Kelvin:

$$\frac{1}{T} = a + blnR + c(lnR)^3 \quad (1)\ [4]$$

where: R is the resistance of the thermistor;
T is the absolute temperature
a, b and c are Steinhart-Hart parameters and are specified by the manufacturer for each thermistor.

This equation is used in the code uploaded into the microcontroller to determine the temperature of the electrical device.

The heating elements used to regulate the temperature of the electrical device operate based on electrical resistance. In order for them to reach their maximum temperature of 55 °C, they need a power of 3W and must be connected to a voltage of 12V. The battery used in this project can output a maximum voltage of 3.7V. In order to generate the voltage required for the correct operation of the heating elements, the system must contain a voltage booster module integrated circuit. This voltage booster incorporates a metal core inductor. When current flows through the inductor coil, the metal core generates a magnetic field which increases the voltage at the current output of the coil. Magnetic materials, such as the inductor core, have a property called magnetic saturation, which is directly proportional to the strength of the magnetic field generated by the current passing through the coil. Magnetic saturation imposes an upper limit on the intensity of the magnetic field, and therefore on the current flowing through the coil. If the saturation threshold of the inductor core is exceeded, its impedance increases rapidly, causing a rise in inductor temperature, which can cause accidents or circuit destruction. This principle limits the amount of voltage rise the voltage booster can provide to increase the efficiency of the heating elements. [5]

5. The proposed solution

The system for optimising the operating temperature of electrical devices is composed of 3 sub-assemblies: the temperature monitoring and raising system, the heat-trapping pouch and the structural assembly.

The temperature monitoring and raising system is structured according to the sketch in [Fig. 5]:

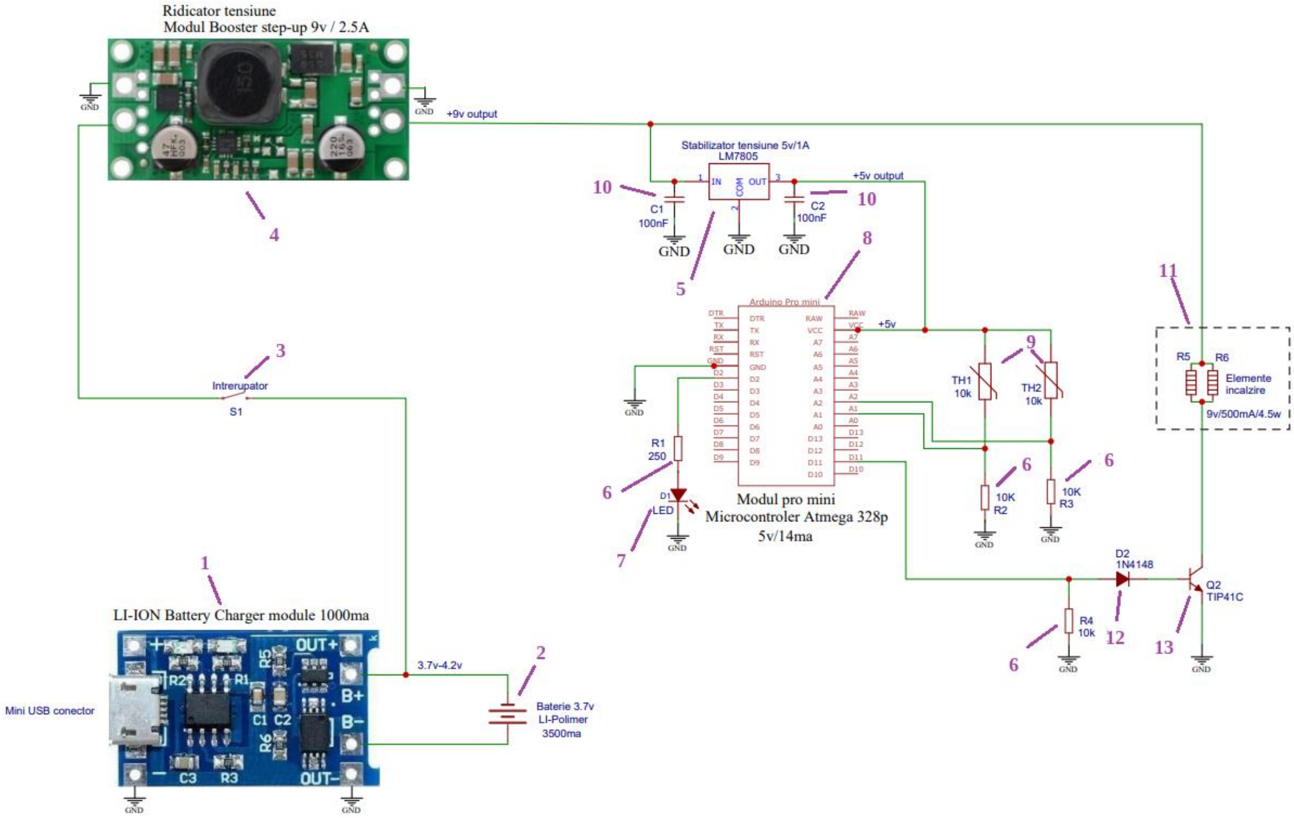

Fig.5. Electrical scheme

The main purpose of the electrical system is to heat the phone when its temperature falls below the optimal operating limit. The temperature of the phone is monitored by one of the thermistors (9) and the second thermistor monitors the temperature of the heating elements (11).

If the temperature of the heating elements becomes dangerously high, the thermistor monitoring the temperature will send a signal to the microcontroller (8) to turn off the power.

Thermistors are electrical resistors that have the property of changing their resistivity as a function of temperature. The current flowing through them changes inversely with the resistivity of the thermistor. Both thermistors are connected to the microcontroller. The microcontroller is programmed so that if the current received through the thermistors exceeds a preset value, it will send current to the transistor (13) to open the circuit branch containing the heating elements. If the current intensity from the thermistors read by the microcontroller exceeds a certain value, the microcontroller will send current to the LED branch (7) to signal the operation of the heating elements.

The microcontroller requires an operating voltage of 5V and the heaters require a maximum operating voltage of 12V. The battery (2) generates a maximum voltage of only 3.7V. For this reason it is necessary to implement a voltage booster (4) to generate the required operating parameters for the heating elements. The 12V voltage resulting from the voltage booster is too high for the microcontroller to operate. A 5V voltage stabiliser (5) will be used to bring the voltage back to the 5V value required by the microcontroller.

To facilitate charging of the battery operating on DC power from an AC power source, a battery charging module (1) used in most applications involving lithium-ion batteries is required.

The circuit breaker (3) is intended to allow the user to close and open the electrical circuit.

Capacitors (10) are designed to take up residual current fluctuations in the circuit remaining after charging from an AC source.

Diodes (12) and resistors (6) are intended to prevent reversal of circuit polarity and to protect components.

The heat-trapping pouch (Fig. 6) performs the following roles:
- thermally insulates the phone and heater against low temperatures;
- maintains the correct position of the phone in relation to the heater;
- protects the phone against mechanical shocks or abrasions;

Cotton has been chosen as the material for the heat-trapping pouch because it is the most effective thermal insulation material readily available on the market. The fabric is flame retardant due to the risks associated with housing an electrical heating system.

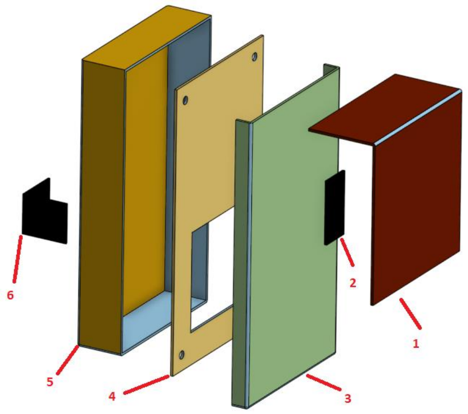

Fig.6. Heat-trapping pouch


Fig.7. Heating system housing

The structural assembly consists of the housing, the fasteners and the copper heat transfer plate. The enclosure cover [Fig. 9] and the enclosure base [Fig. 10] can be seen in the construction drawings attached to the work as well as in [Fig. 7]. The housing is manufactured by FDM additive manufacturing technology from PETG material. The material and manufacturing method were chosen due to the low cost, PETG properties of mechanical strength and high melting point compared to alternatives and low electrical conductivity of the material which does not create a short circuit hazard of the electrical system. Assembly of the cover and housing base is done with M2.5 screws and nuts to provide easy access for modifications and maintenance. The enclosure is secured in the thermal insulation cover by passing the head of the screws through the holes in the inner membrane. Afterwards, the screw heads will be covered with cotton patches to prevent scratching the electrical device. The fixing solution will be modified once the product passes the prototype stage to generate a small footprint and a pleasing appearance. The heat transfer plate will be installed in the housing next to the window to prevent direct contact between the resistors and the electrical device or user.

6. Conducting experiments and interpreting results

Initially, a design variant of the temperature monitoring and raising system was considered that would be purely electronic (Fig. 8), without being controlled using a microcontroller.

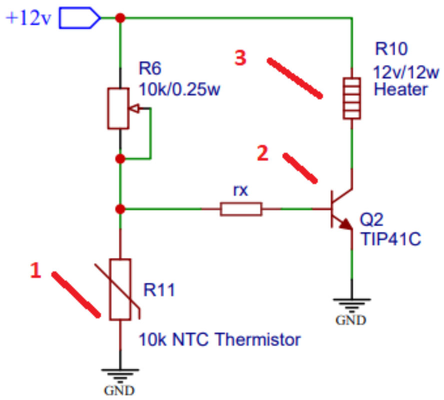

Fig.8. Tranzistor based electrical scheme

Both operating variants perform exactly the same role of monitoring the temperature of the electric device and activating the heating system under the necessary circumstances. The difference between them is that the variant with the transistor-based operating principle controls the heating of the resistors (3) by means of a transistor (2) which allows current to flow through the resistor branch only when the thermistor (1) allows a current of a specific transistor current to flow.

The microcontroller-based version was preferred because of its high versatility. If it is desired to change the operating parameters of the system, the operating code uploaded in the microcontroller can be easily modified. In the variant without microcontroller it would be necessary to change the resistivity of the variable resistor R6 and measure the current intensities after each change to calibrate the circuit.

7. Conclusions

The temperature measurement and augmentation system will operate according to the microcontroller-controlled design version due to the high degree of versatility it offers, without imposing a significant cost increase. The housing will be made by FDM manufacturing technology, using PETG material due to the design-suitable properties of the plastic material. The heat-trapping pouch will be made of flame retardant treated cotton due to its good thermal insulation properties and to avoid accidents or damage to the product.

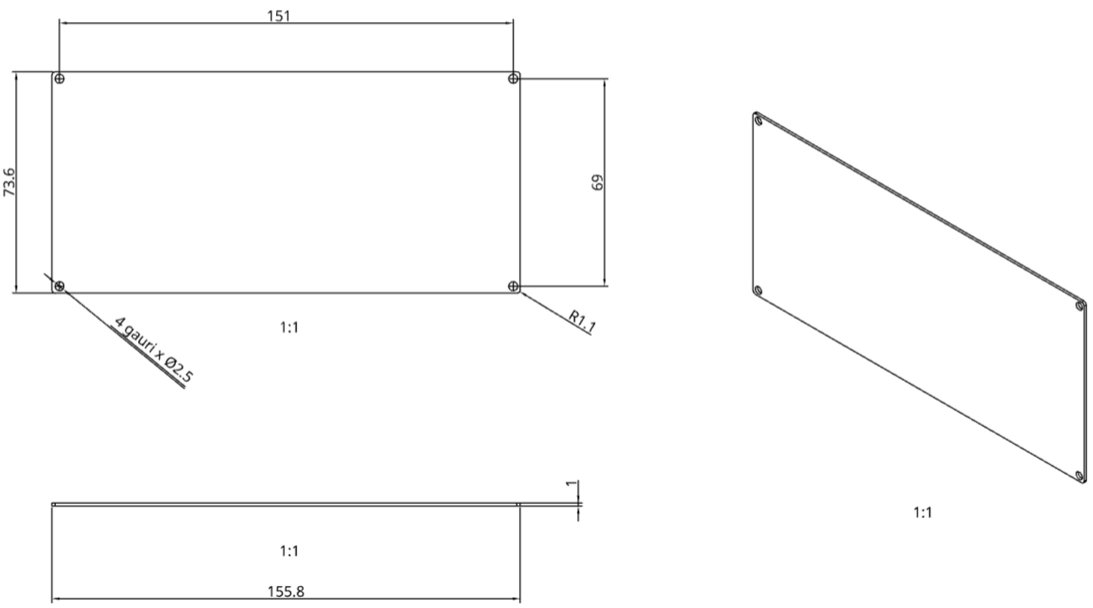

Fig. 9 Case lid drawing

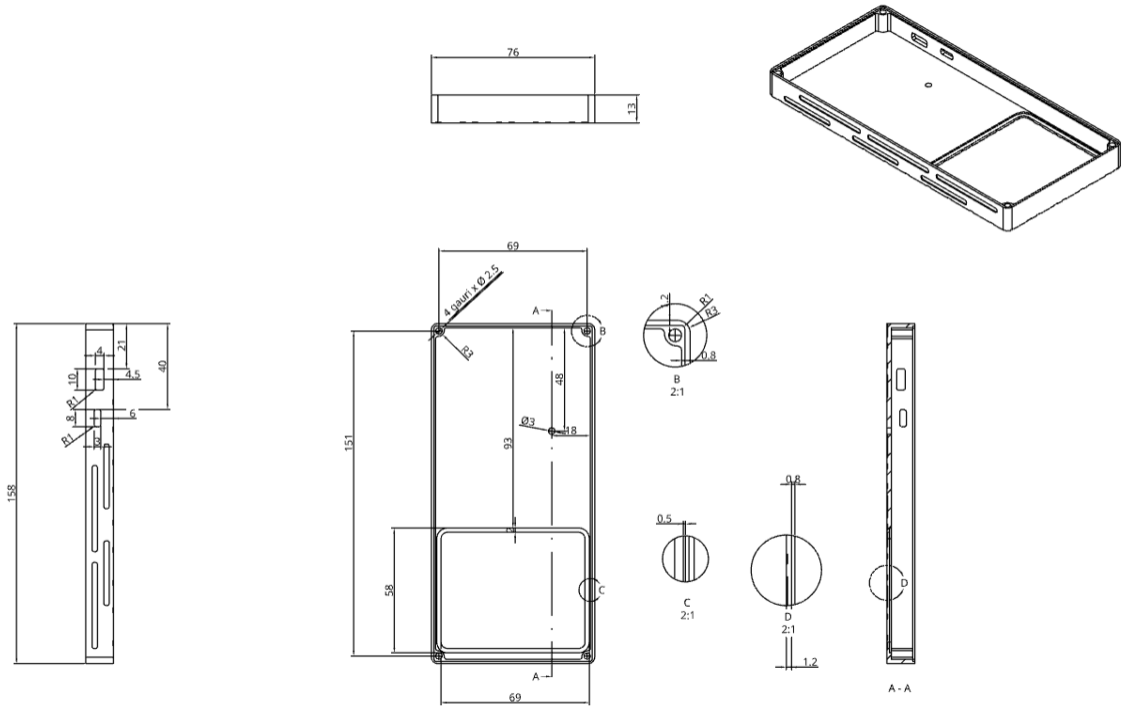

Fig. 10 Case base drawing

7. References

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