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Mechatronics Design and Development of T-EVA: Bio-Sensorized Space System for Astronaut's Upper Body Temperature Monitoring During Extravehicular Activities on the Moon and Mars

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***Abstract*—The exploration of the universe is progressively increasing, within this inquiry, the planet Mars and the Moon remain a mystery and challenge, as well as its colonization and civilization. Thus, in the extravehicular activities (EVA) where the astronaut will be in extreme environments performing activities such as exploration, and collection of rock and soil samples for later analysis, it should be noted that when he performs these activities, he will be exposed to extreme environmental parameters such as radiation, temperature, gravity, and many other extreme conditions. Therefore, the Center of Space Emerging Technologies (C-SET) proposed a project called T-EVA, developed into the Research Line: Space Suits and Assistive Devices, and in the Research Area: Biomechatronics and Life Support Systems, with the aim of astronaut temperature monitoring during their work outside the base station, being able to know how much their body is measuring and if they are at risk of hypothermia or hyperthermia, which could cause irreparable damage. The electronic design was made for testing both in the laboratory and outside, as well as the implementation of the lycra to mount the design, resulting in a feasible prototype that can be implemented in real situations with easy access to temperature reports.**

Keywords—Extravehicular-activities astronauts; spacesuits; body temperature; Mars; space

I. INTRODUCTION

The journey to Mars is a major undertaking, as it is fraught with obstacles from the start of the mission to its completion, including challenges related to the atmosphere, geology, and distance involved (Fig. 1). This has motivated both governments and private space companies to be interested in sending manned missions to Mars or the Moon, investing resources, and sending robotic missions to explore solutions to make these planets habitable and safe for humans [1]-[3]. Among these solutions are space biomedical mechatronics projects developed by the Center for Space Emerging Technologies, on which the T-EVA Project is based [4]-[9].

Extravehicular activities (EVAs) are a fundamental part of space exploration and have been a regular feature of manned missions since the earliest days of the space program. EVAs are planned activities that take astronauts outside the spacecraft or space station to perform specific tasks in space, such as repairs, maintenance, science equipment installation, or sample collection Extravehicular activities are extremely complex and challenging due to the extreme environment of space. These activities are inherently dangerous because astronauts performing EVAs are exposed to many hazards, such as lack of gravity, extreme temperatures, cosmic radiation, and micrometeorites [15].

Successful EVAs require meticulous planning and coordination, as well as close collaboration between astronauts and the ground control team. As space exploration continues to expand to new horizons, EVAs will remain an essential part of our journey into the universe, allowing us to conduct scientific research and develop skills and technologies for future space missions, such as those planned to explore Mars and other celestial bodies [28].

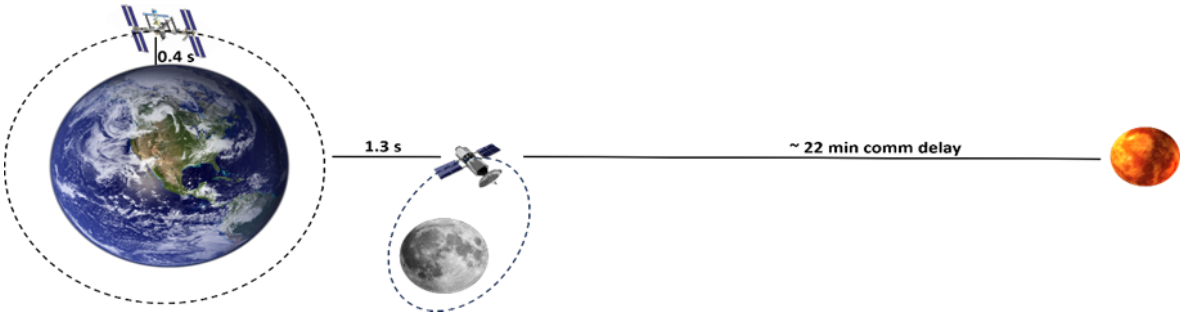


Fig. 1. Average communication delay between Earth, LEO, cislunar space, and Mars.

The lunar environment is characterized by approximately ⅙ Earth g, and surface temperatures ranging from -143°C to +127°C due to direct sunlight or shading in an ambient vacuum. The temperature Lunar [10], [11] seen in the image collected from Quickmap, selected Artemis 3: Candidate Landing Regions and LRD DIVINER, Polar Winter Max Temp and selected temperature range -173.1°C to 31.8°C and LOR WAC Basemaps, WAC+NAC+NAC_ROI_MOSAIC.

Space studies have determined that Mars has a thin atmosphere, which does not protect the surface from dangerous cosmic rays and micrometeorites, a problem for astronauts traveling on the surface. In addition, the presence of 95% CO2 and 0.17% O2 in the atmosphere also makes it difficult for astronauts to breathe outside their spacesuits. Extreme temperatures [12], Fig. 2(a) are also a problem for the astronauts because they range from -153.1 ºC near the poles to 19.8 ºC near the equator [13]. The cold climate of Mars is due to the low conductivity of the surface, the sparse atmosphere, and the great distance from the sun Fig. 2(b).

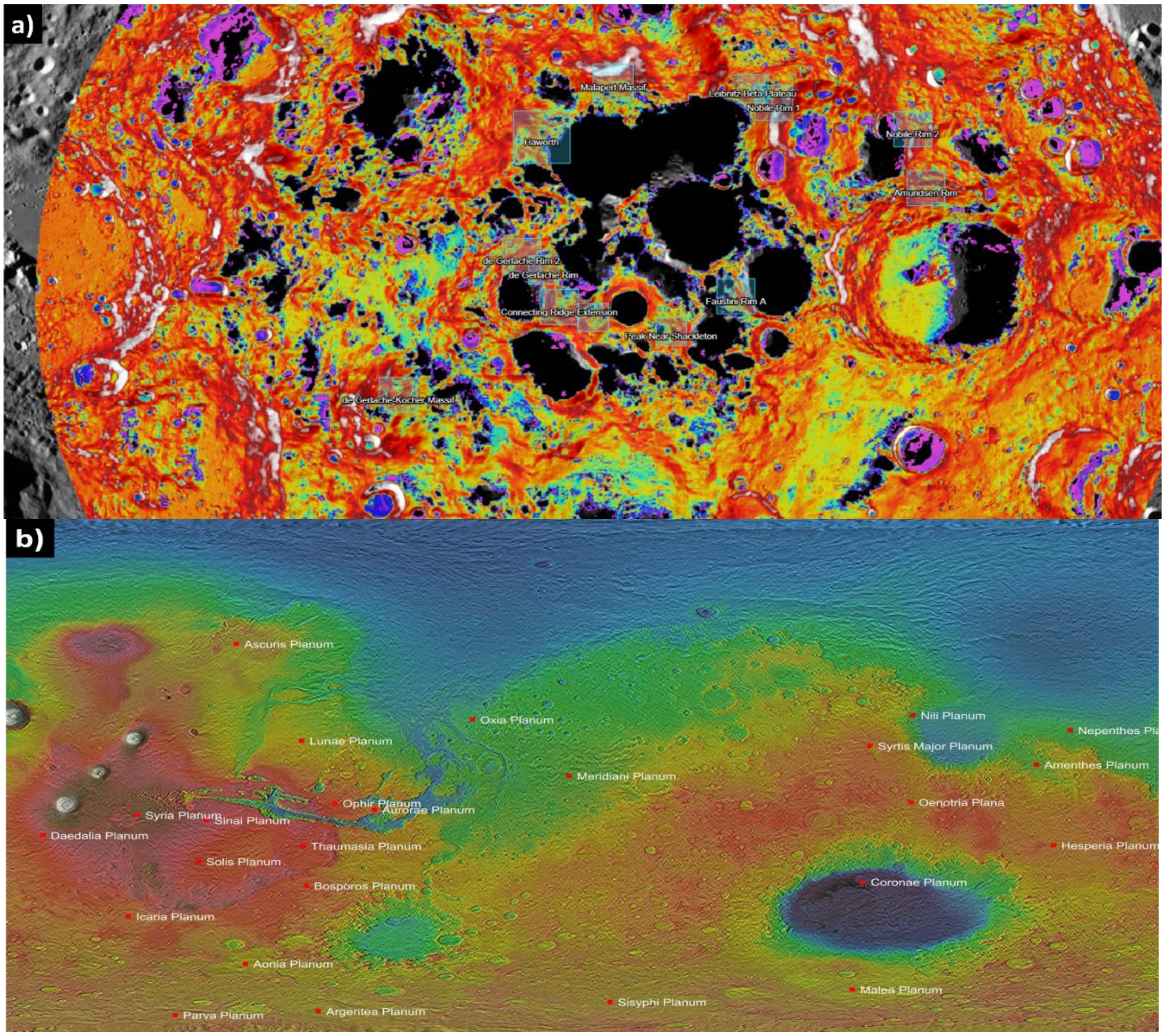


Fig. 2. (a) Temperature zones on the Moon from QUICKMAP and (b) Sea temperature from JMARS.

The human body can be conceptualized as a thermal machine that exchanges energy with its environment through moisture and heat. Likewise, thermal comfort implies a balance between the heat produced and the mechanisms of heat transfer through the effector system (vasoconstriction or vasodilation), depending on the constraints [14]. This means that exposure to adverse environments (environmental heat stress) can be detrimental to human health, especially when the environment is unknown [15]. As a result, in this temperature range in Fig. 3(a), it can be difficult for the crew to maintain the thermal stability of both habitat and internal body temperature to conserve heat against hypothermia and its effects [16]. To solve this problem, the Extravehicular Mobility Unit (EMU) was designed to provide the necessary functions to keep the user alive [17], during extravehicular activities (EVA). As shown in Fig. 3(b), research in simulated Mars EVAs has shown that surface temperature on the suit may spatially vary by as much as 50°C depending on the astronaut's orientation relative to the sun, and atmospheric effects.

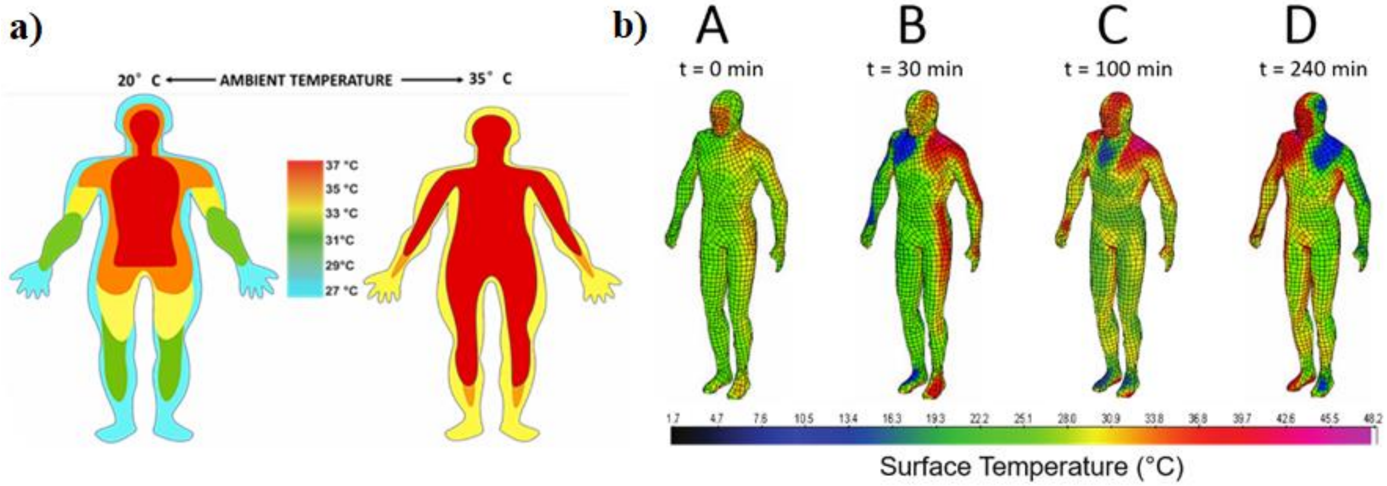


Fig. 3. (a) Thermoregulation in the human body and (b) Suit surface temperature varies throughout a simulated Martian EVA.

If the body's core temperature is exposed to extreme temperatures, it can develop hypothermia (<35.5 °C) or hyperthermia (> 37.5 °C), and in peripheral parts, these effects can also occur at different degrees (<10ºC), (>44ºC) which can manifest in multiple symptoms [18]. Also, Table I presents a quantitative range of peripheral (skin) and core (thoracic) temperatures in relation to effects on the body and limits of thermal comfort in a thermoneutral environment [19], [20].

TABLE I. THERMOREGULATION IN HUMAN BODY

Temperature		**Effects**
Periphery	***Body Core***	
> 44-46 °C	42 °C	Death
36-43 °C	41 °C	Hyperthermia
	38-40 °C	Evaporation
		Vasodilation
30 – 34 °C	37 °C	Thermal Comfort
24-28 °C	36 °C	Vasoconstriction
		Thermogenesis
	35 °C	Hypothermia
< 10 °C	25 °C	Death

II. PROPOSED APPLICATION FOR THE EARTH

A. *Firefighter Suit*

In firefighting, activities with different levels of intensity are performed such as: throwing ladders, climbing ladders with heavy loads, performing a search, advancing a line, applying water, ventilating a roof, forcing a door, and searching a room [21]-[23]. Firefighters regularly face stress in their work, and their job performance that is directly related to saving or losing human lives, including their own [24]. The magnitude of these heat effects depends on individual factors such as age, health status, hydration, and physical fitness.

1) Environmental conditions: In firefighting, conducted a study compared physiological responses to an overhaul task in ambient conditions with no fire (15°C) to the same task performed with live fires in the structure (90.5°C at chest level). Heart rate increased to an average of 139 bpm in the ambient conditions and to 175 beats per minute in the live-fire condition. Tympanic temperatures increased by slightly more than 5.4°F in the live-fire condition and less than 1°F in the ambient conditions as shown in Fig. 4(a), [25].

2) Personal protective equipment (PPE): Protects firefighters from burn and inhalation injuries; however, due to its weight and restrictive properties, a laboratory study comparing 15 min of treadmill walking in the firefighter's uniform and 15 min of walking in fully encapsulated PPE found that the heart rate was 50 beats per minute higher while wearing the fully encapsulated gear [26].

3) Individual characteristics: A firefighter’s age, gender, and body size all affect physiological responses to firefighting activities. In general, the risk of a heart attack while fighting a fire increase as the age of the firefighter increases.

4) Medical condition: High blood pressure, high cholesterol, and obesity are all well-established risk factors for cardiovascular disease. By prioritizing their cardiovascular health, firefighters can reduce their risk of experiencing cardiac events on the fire-ground and improve their overall quality of life.

5) Fitness level: A high level of physical fitness is necessary to successfully and safely perform demanding physical activities [27]. It increases the efficiency of the heart, improves thermal tolerance, provides cardioprotection by increasing the anticoagulant activity of the blood, and increases blood vessel dilation capacity to allow more blood to reach the muscles as shown in Fig. 4(b).

6) Environmental control and life support subsystem: Space is a hostile place, charged particles, solar radiation, vacuum, and free fall are potentially harmful, even fatal, to unprepared humans. Future space exploration missions will take astronauts far from Earth into extreme thermal environments, where temperature control of spacesuits will be a critical life support function. Due to wide oscillations of temperature swings, we need to balance the heat flow in, plus the heat generated internally, with the heat flow out humans, have their own, specific temperature range, where they function best. Existing thermal control technology relies on venting water to space to provide the required cooling. This approach is extremely costly, and possibly unsustainable, for future exploration missions [28].

The spacesuits have thermal regulation systems that ensure astronauts' comfort and protection by maintaining a stable internal temperature. These systems also allow the temperature of the suit to be adjusted according to external environmental conditions and the amount of heat generated by the astronauts during their metabolic activity. It has been observed that performance decrements manifest above 480 Btu/hour heat storage and tissue damage begins at 800 Btu heat storage. During the Apollo lunar surface EVAs, heat expenditure rates ranged from 780 to 1200 Btu/hour. It is important to understand and measure the estimated amount of heat expenditure prior to planetary spacewalks to ensure crew health, as the duration and requirements of the task can significantly affect heat output. Thermal management technology is an uncelebrated but nonetheless essential requirement for all spacesuits, spacecraft, and space habitats. During extravehicular activity (EVA), spacesuits must remove metabolic heat produced by the astronaut, residual heat from the suit’s electronics, and absorb heat from the external environment [29]. Spacesuit design encompasses both the material selection of the spacesuit, which is important to consider for radiation shielding and dust mitigation, as well as all the internal systems that support the regulation and monitoring of physiological health [30] as shown in Fig. 5(a).

In recent years, stretchable sensors for wearable applications have demonstrated their ability to continuously monitor health with a high level of fidelity and comfort (Table II) [31]. The integration of these elastic sensors into spacesuits could provide valuable information about astronauts' movements during EVA maneuvers, which could be combined with our proposed T-EVA to safeguard the astronaut's integrity [32]–[33] as shown in Fig. 5(b).

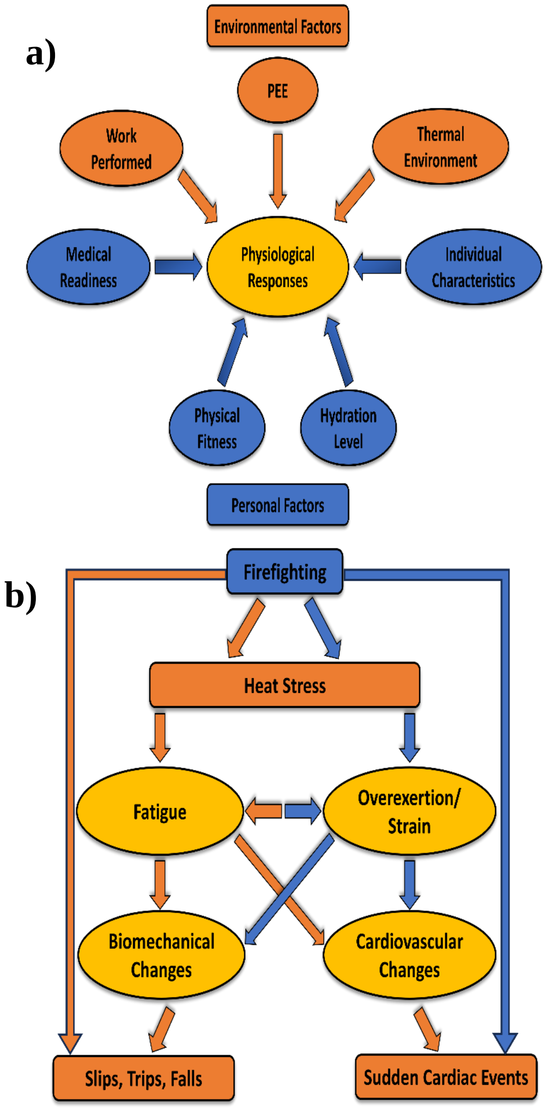


Fig. 4. (a) Factors that affect the way the body responds to firefighting activities and (b) Risk of heat stress in firefighters.

TABLE II. PLSS FUNCTIONS, RECOMMENDED TECHNOLOGIES OF CHOICE, RATIONALE, AND STRENGTHS & WEAKNESSES

Functions	**Technology of Choice**	**Rationale**	**Strengths & Weaknesses**
Oxygen Supply	High-Pressure Gaseous Oxygen Storage	Rechargeable on orbit, lighter & fewer parts	**Strengths** Reduced Volume Reduced System Mass Robustness Operability Reliability Less logistic **Weaknesses** Poor on-suit Mass
Thermal Control	Suit Water Membrane Evaporator	Less water contamination & can operate on Mars	
CO2 & Moisture Removal	Rapid Cycle Amine	Reduce logistics and resupply	
Power	Li-ion Polymer Batteries	Increase battery life & higher energy density	

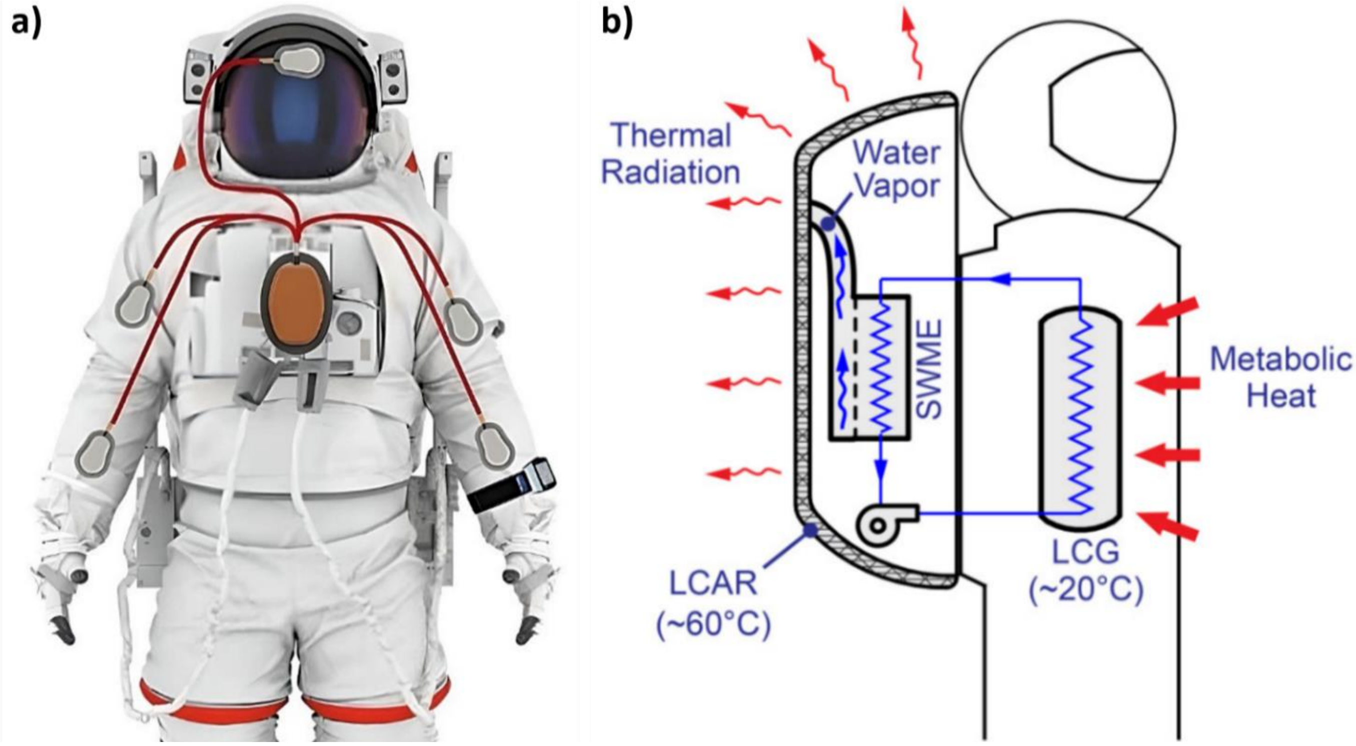


Fig. 5. (a) Spacesuit with the sensor of T-EVA and (b) The system can control the temperature inside a spacesuit without venting water.

III. PROPOSED METHOD

This section shall describe the steps for the development of the prototype of the temperature measurement system for extravehicular activities. The proposed methodology consists of 3 phases as shown in Fig. 6.

A. *Phase 1 / Inputs*

First, as it is very well described in the methodological diagram, it is a design project focused 100% on the user. As background, one could analyze and study the success that OMEGA watches have had in the space conquest, watches that NASA astronauts have used for more than 50 years in all their space explorations. Thanks to all these experiences, one was able to define the problems of visually assisted communication and control that astronauts currently lack information assistance systems that the astronaut will need to be able to carry out high-risk extravehicular activities, and more significant challenges unknown until now. One found three immediate needs that need to be resolved, such as:

1) Thermoregulation
2) Extreme temperatures
3) Monitoring of physiological parameters.

1) Project objectives:

a) General Analysis: Analysis of the context in which the project performance will be carried out, Environmental analysis, Background analysis of presented congresses and workshops, Package Evaluation, Material Evaluation, and Manufacturing evaluation.

b) Sensor Suit: Anthropometric Evaluation to see the anatomical shape of the sensor case. Points Location to get the temperature variation correctly.

c) T-EVA System: Electronic package analysis, Performance analysis, Sensor analysis, Temperature analysis, Network analysis.

d) T-EVA Bracelet: Electronic package analysis, Performance analysis, Visual communication analysis.

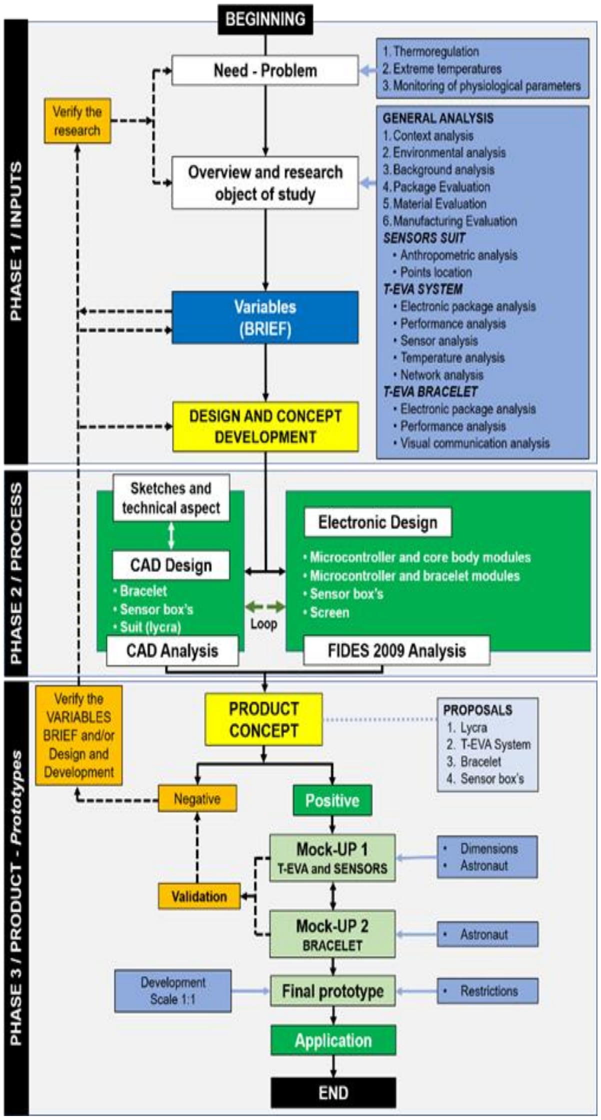


Fig. 6. Development diagram of T-EVA / I+P+p.

B. Phase 2 / Process

In this phase, designs such as Sketches and technical aspects were made, which included analysis and CAD design with feedback from electronic design (Microcontroller and core body modules, Microcontroller and bracelet modules, Sensor boxes, Screen) [Fig. 7(a)]. This phase is divided into 3 parts.

1) *Bracelet*: The first part is a bracelet where the astronaut will be able to visualize the temperature in real-time as well as several pre-established alarms [Fig. 7(b)].

a) Brushed titanium - Case – Grade 2.

b) Black ceramic coated titanium -Top Ring - Grade 5.

c) Special quartz - Glass Dome - that does not fragment.

d) Black-coated brushed titanium-Side Push Button-Grade

e) Titanium – Screws - Grade 2.

f) Brushed Titanium - Bracelet Ring - Grade 2.

g) Velcro Strap.

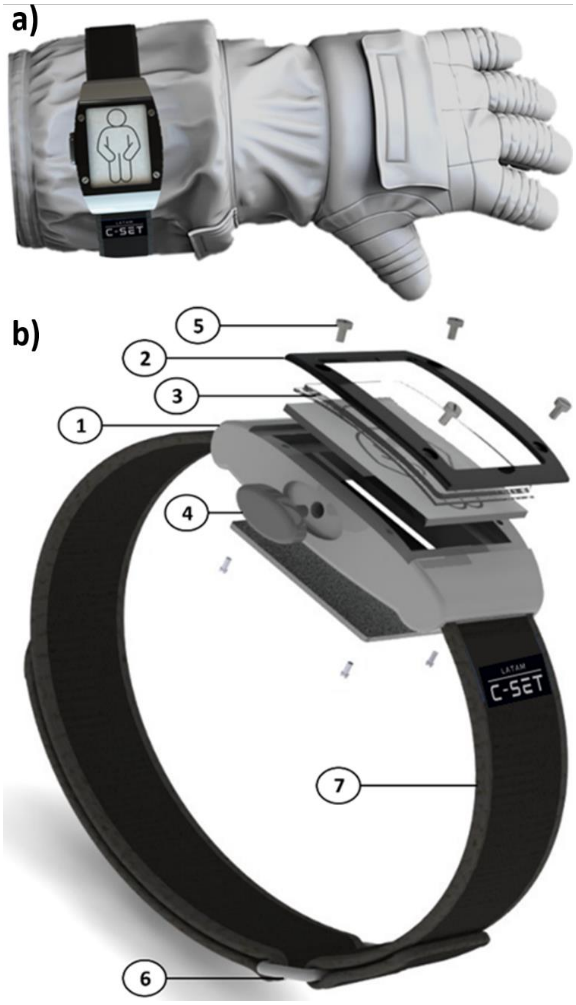


Fig. 7. (a) Bracelet in explosion view and (b) Bracelet implemented in a spacesuit.

2) *Sensors box*: The second part is the temperature sensor boxes (Fig. 8), which have an anatomical shape to capture any temperature variation, which is pretending to be manufactured based on FDA guidelines for medical devices [34], [35].

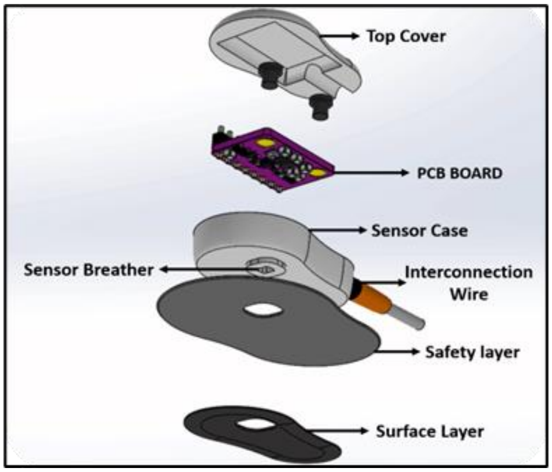


Fig. 8. Sensor Box.

3) Central box: The third part consists of the central box (Fig. 9), which contains the data processing board, a temperature sensor, and an RF module for sending the information to the bracelet and the base station.

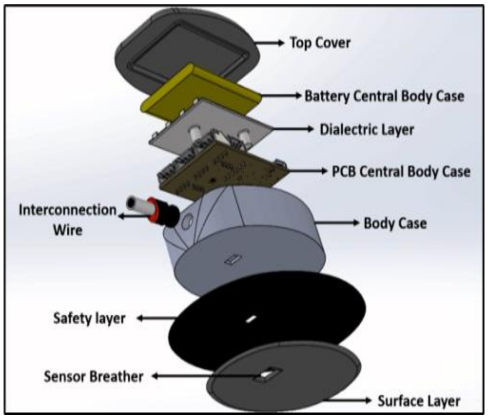


Fig. 9. Central Box.

C. Phase 3 / Product - Prototypes

1) Implementation specifications: Lycra being a flexible and adaptable material to the human anatomy, it is established that the measures of this would be the Latin American 95th percentile [36], Fig. 10(a) shows the location of the sensors and twisted pair wires in the lycra. In Fig. 10(b), one can see the connection. See Table III.

2) Electronics specifications

a) Sensor DS18B20: The analog temperature sensor DS18B20 [Fig. 11(a)] was used, whose voltage output is linearly proportional to temperature, generates 10mV for every 1ºC, has an accuracy of ±3/4°C in the configured range of -55ºC to 150ºC [Fig. 11(b)] and has a power consumption of 60 µA, generating a self-heating of less than 0.1ºC, Fig. 11(c) [37].

TABLE III. SENSOR LOCALIZATION IN HUMAN BODY

	PERIPHERY – UPPER LIMBS				***BODY CORE (THORACIC)***	***FOREHEAD***
	LEFT SIDE		**RIGHT SIDE**			
SENSOR	Upper Arm	Fore Arm	Upper Arm	Fore Arm		
CODE	L-UA	L-FA	R-UA	R-FA	BC-T	FH

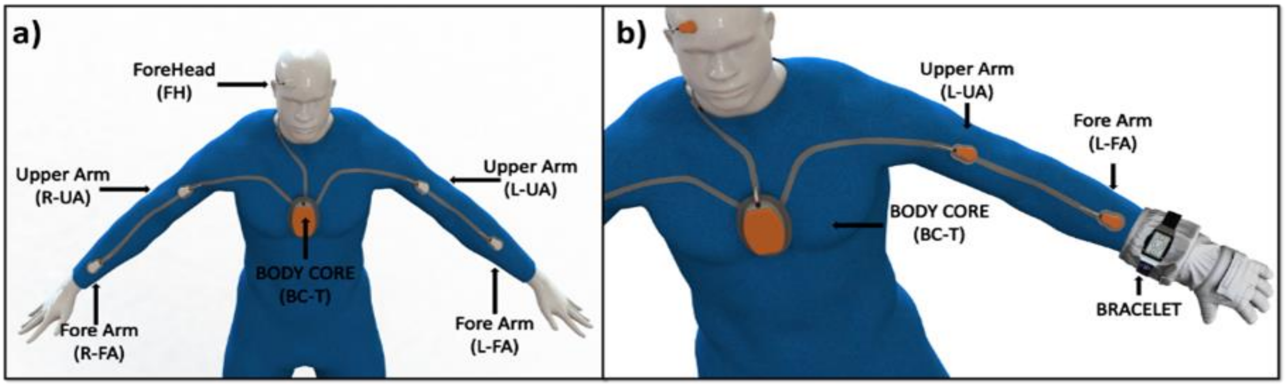


Fig. 10. (a) Sensors in the body and (b) a Bracelet mounted on the arm of the space suit.

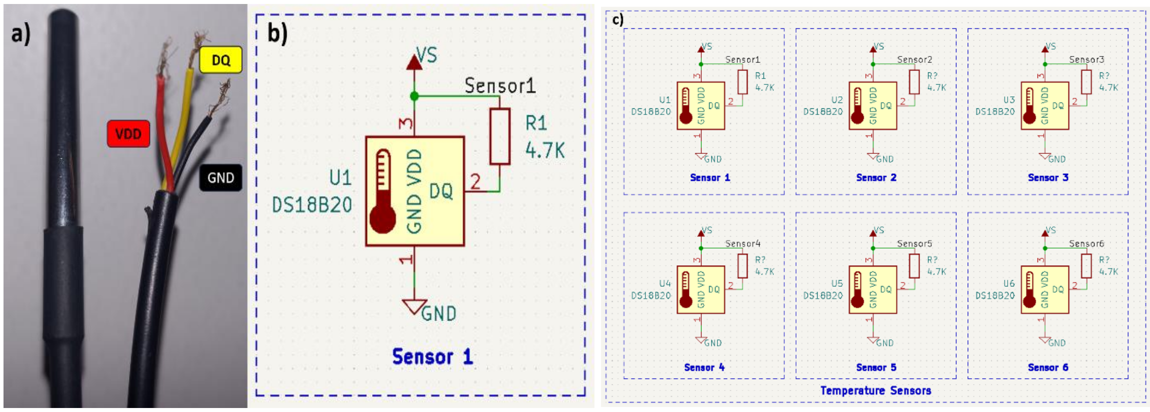


Fig. 11. (a) Sensors in the body and (b) a Bracelet mounted on the arm of the space suit.

b) Microcontroller ESP32: The ESP32 microcontroller was selected [Fig. 12(a), 12(b)], it has integrated wireless connectivity (WiFi and Bluetooth) to generate a communication network, has an operating temperature range of -40°C to 125°C, 30 pinouts, 512 KB RAM and the consumption specifications are shown in Table IV [38]–[41].

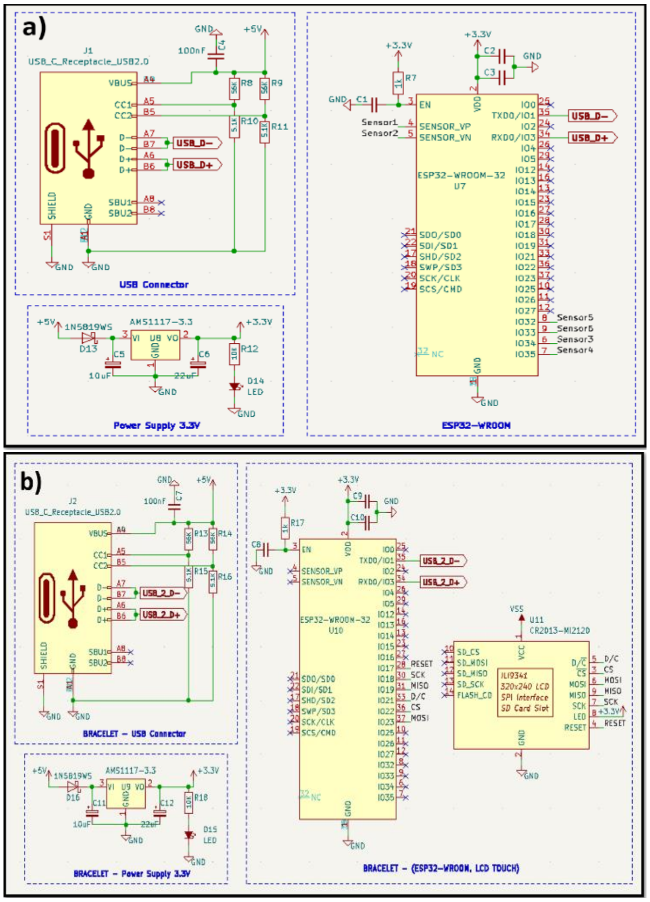


Fig. 12. (a) Schematic body core (ESP32, power supply, USB connector), and (b) Schematic bracelet (ESP32, power supply, USB connector).

TABLE IV. ELECTRONIC DESIGN OF T-EVA

Nº	Components and Consumption		
	Body Core Sensor Box	***Consumption***	***Total***
1	ESP 32 (SENDER)	180 mA	180 mA
2	DS18B20 (6)	5 mA	30 mA
3	Battery 3.7V DC – 1.4 A	Autonomy: 7.5 horas	
	Bracelet		
1	ESP32 (RECEIVER)	80 mA	80 mA
2	TFT 2.4” – ILI9341	150 mA	150 mA
3	Battery 3.7V DC – 1A	Autonomy: 6 horas	

3) Communication protocol: ESP-NOW is a protocol invented by Espressif that allows connecting many devices without Wi-Fi. It is very versatile and can have unidirectional or bidirectional communication in different low-power 2.4 GHz wireless configurations. It is comparable to WiFi in the sense that pairing takes place before communication. After pairing, it becomes a secure peer-to-peer connection that does not require a handshake. This means that if one of the boards suddenly shuts down or reboots, it will automatically connect to the other board at that time and continue to communicate. In addition, ESP-NOW can carry a payload of up to 250 bytes and can be configured to inform the application layer of the success or failure of transmission through the functions listed in Table V [42].

TABLE V. FUNCTIONS ESP-NOW

Nº	ESP-NOW PROTOCOL	
	Functions	***Description***
1	esp_now_init()	Wi-Fi must be initialized before initializing ESP-NOW.
2	esp_now_add_peer()	This function is used to pair a device and pass the MAC address of the peer as an argument.
3	esp_now_send()	Sends data with ESP-NOW.
4	esp_now_register_send_cb()	Registers a callback function that is triggered when sending data. This function returns whether the delivery was successful or not.
5	esp_now_register_rcv_cb()	Registers a callback function that is triggered when data is received. A specific function is called when data is received.

The configuration of an ESP32 "RECEIVER" (R) microcontroller receiving data from an ESP32 "SENDER" (S) microcontroller has been used. The communication network is unidirectional, which means that the information flows only from the sender to the receiver.

With this configuration, it is possible to collect the data from the four temperature sensors (1_L-FA, 2_L-UA, 3_R-FA, and 4_R-UA) from the sender ESP32 microcontroller and send it wirelessly to the receiver ESP32 microcontroller. After receiving the four temperature readings from the sending ESP32 microcontroller, the receiving ESP32 microcontroller displays the values on a 2.4" LCD display, as shown in Fig. 13.

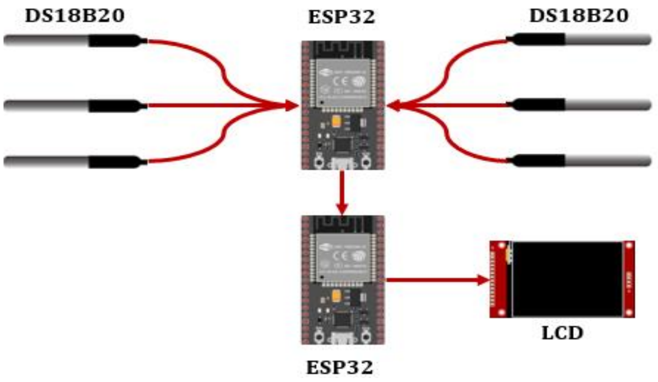


Fig. 13. Diagram of connection.

IV. RESULTS AND DISCUSSIONS

Once the connections and operation of the sensors and microcontroller were verified, tests were performed on a breadboard to check the code and then the system was mounted on a lycra where first one sensor was inserted and then 4 sensors (Fig. 14 and 15).

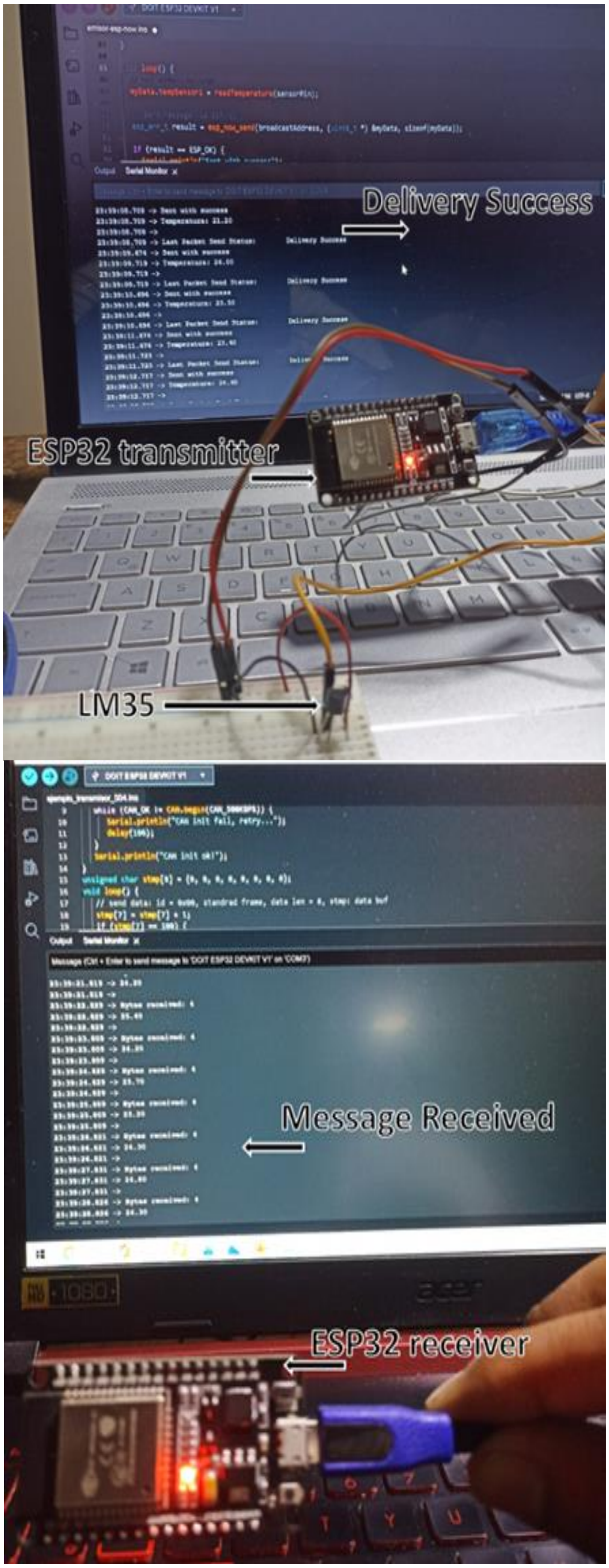


Fig. 14. (a) ESP32 mode Transmitter sending a message and (b) ESP32 mode Receiver.

Fig. 15. Mounting of a DS18B20 sensor on the rash guard.

Within the tests, we included several temperature sensors such as the BMP280 and LM35, where the first due to its modular board design was difficult contact with the skin and sweat, and the second was less difficult, but since the design when adapted to the lycra was not very safe, so the DS18B20 was our best choice because its probe type shape does not bother the human body in activities and is resistant to sweat which favors us a lot for extravehicular activities such as mineral extraction, sample collection, etc.

Finally, the assembly of the 4 sensors located in LEFT SIDE: Upper Arm (L-UA), Fore Arm (L-FA). RIGHT SIDE: Upper Arm (R-UA), Fore Arm (R-FA), as shown in Fig. 16. Four tests were performed to send and receive data at room temperature (25ºC) to see if it arrives in good condition, it is observed that due to the short distance between the transmitter and receiver, the time is almost immediate.

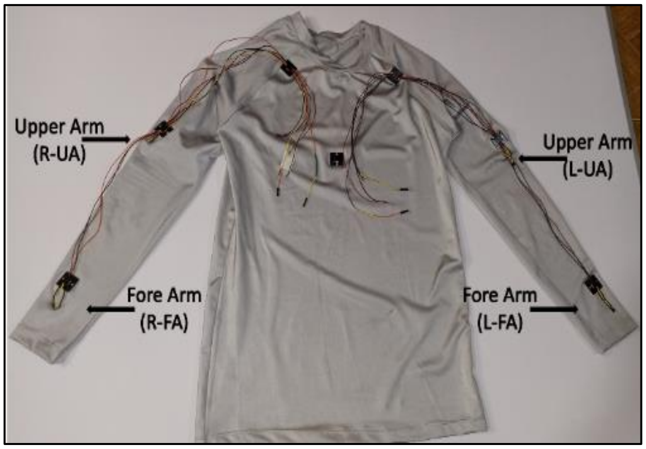


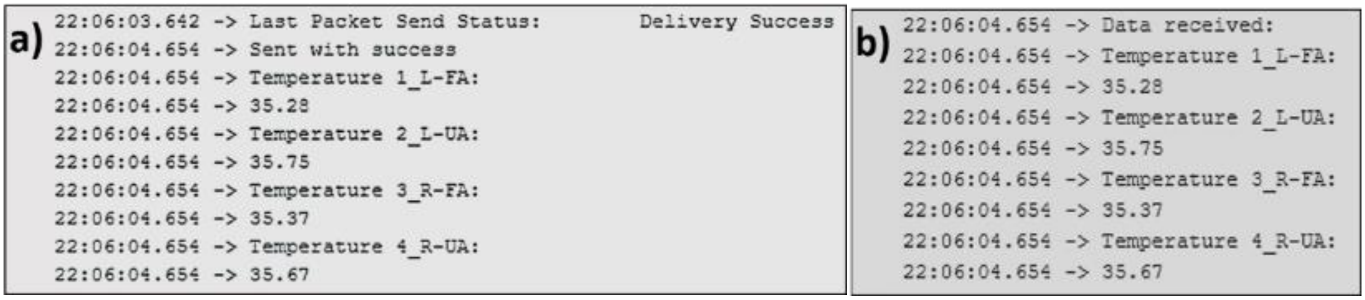
Fig. 16. Mounting of the 4 DS18B20 sensors.

a) First Test: Fig. 17(a), (b) shows the sending and receiving of the 4 temperature values using the ESP-NOW protocol and the Arduino IDE serial monitor. It is observed that the data (1_L-FA = 35.28°C, 2_L-UA = 35.75°C, 3_R-FA = 35.37°C and 4_R-UA = 35.67°C) reach their destination without loss of information.

b) Second Test: Fig. 18 shows the sending and receiving of the 4 temperature values using the ESP-NOW protocol and the Arduino IDE serial monitor. It is observed that the data (1_L-FA = 35.35°C, 2_L-UA = 35.77°C, 3_R-FA = 35.41°C and 4_R-UA = 35.68°C) reach their destination without loss of information.

c) Third Test: Fig. 19 shows the sending and receiving of the 4 temperature values using the ESP-NOW protocol and the Arduino IDE serial monitor. It is observed that the data (1_L-FA = 35.39°C, 2_L-UA = 35.79°C, 3_R-FA = 35.44°C and 4_R-UA = 35.73°C) reach their destination without loss of information.

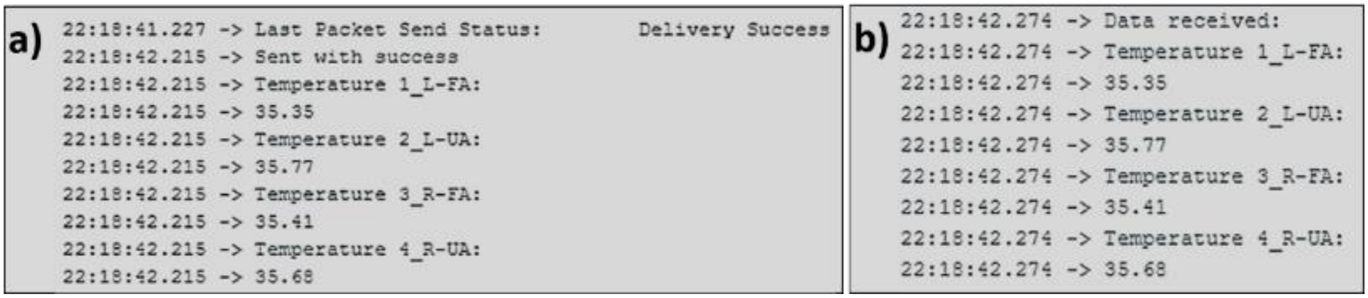
d) Fourth Test: Fig. 20 shows the sending and receiving of the 4 temperature values using the ESP-NOW protocol and the Arduino IDE serial monitor. It is observed that the data (1_L-FA = 35.45°C, 2_L-UA = 35.76°C, 3_R-FA = 35.46°C and 4_R-UA = 35.72°C) reach their destination without loss of information.



```
22:06:03.642 -> Last Packet Send Status:       Delivery Success
22:06:04.654 -> Sent with success
22:06:04.654 -> Temperature 1_L-FA:
22:06:04.654 -> 35.28
22:06:04.654 -> Temperature 2_L-UA:
22:06:04.654 -> 35.75
22:06:04.654 -> Temperature 3_R-FA:
22:06:04.654 -> 35.37
22:06:04.654 -> Temperature 4_R-UA:
22:06:04.654 -> 35.67
```

```
22:06:04.654 -> Data received:
22:06:04.654 -> Temperature 1_L-FA:
22:06:04.654 -> 35.28
22:06:04.654 -> Temperature 2_L-UA:
22:06:04.654 -> 35.75
22:06:04.654 -> Temperature 3_R-FA:
22:06:04.654 -> 35.37
22:06:04.654 -> Temperature 4_R-UA:
22:06:04.654 -> 35.67
```

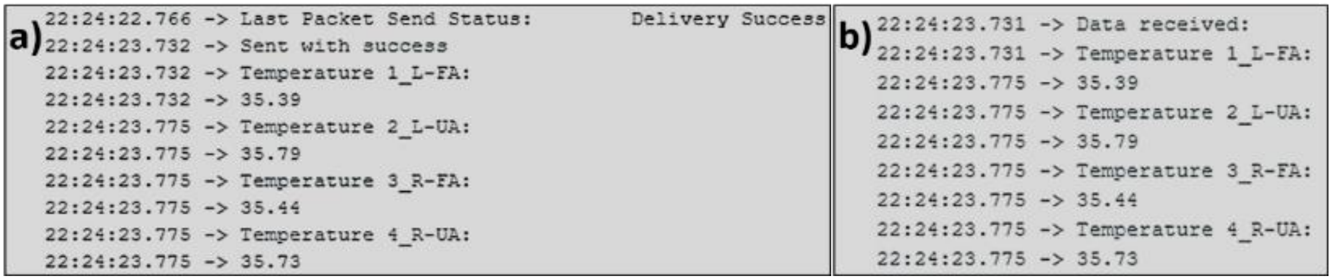
Fig. 17. (a) Transmitter - Temperature data from the DS18B20 and (b) Receiver - Temperature data from the DS18B20.



```
22:18:41.227 -> Last Packet Send Status:       Delivery Success
22:18:42.215 -> Sent with success
22:18:42.215 -> Temperature 1_L-FA:
22:18:42.215 -> 35.35
22:18:42.215 -> Temperature 2_L-UA:
22:18:42.215 -> 35.77
22:18:42.215 -> Temperature 3_R-FA:
22:18:42.215 -> 35.41
22:18:42.215 -> Temperature 4_R-UA:
22:18:42.215 -> 35.68
```

```
22:18:42.274 -> Data received:
22:18:42.274 -> Temperature 1_L-FA:
22:18:42.274 -> 35.35
22:18:42.274 -> Temperature 2_L-UA:
22:18:42.274 -> 35.77
22:18:42.274 -> Temperature 3_R-FA:
22:18:42.274 -> 35.41
22:18:42.274 -> Temperature 4_R-UA:
22:18:42.274 -> 35.68
```

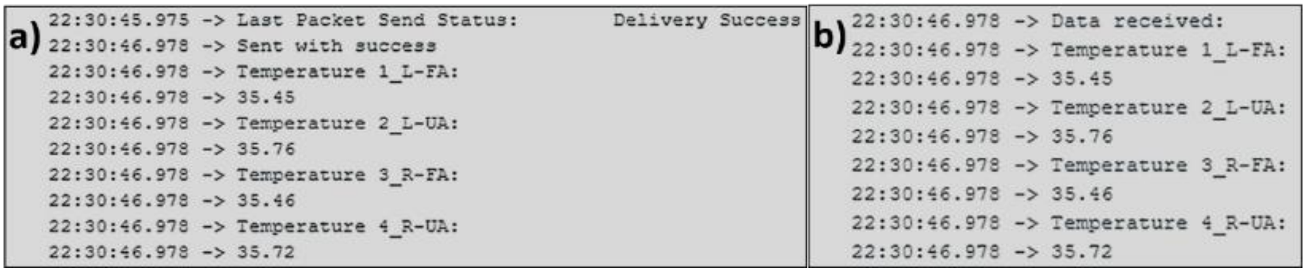
Fig. 18. (a) Transmitter - Temperature data from the DS18B20 and (b) Second test of receiving temperature data from the DS18B20.



```
22:24:22.766 -> Last Packet Send Status:       Delivery Success
22:24:23.732 -> Sent with success
22:24:23.732 -> Temperature 1_L-FA:
22:24:23.732 -> 35.39
22:24:23.775 -> Temperature 2_L-UA:
22:24:23.775 -> 35.79
22:24:23.775 -> Temperature 3_R-FA:
22:24:23.775 -> 35.44
22:24:23.775 -> Temperature 4_R-UA:
22:24:23.775 -> 35.73
```

```
22:24:23.731 -> Data received:
22:24:23.731 -> Temperature 1_L-FA:
22:24:23.775 -> 35.39
22:24:23.775 -> Temperature 2_L-UA:
22:24:23.775 -> 35.79
22:24:23.775 -> Temperature 3_R-FA:
22:24:23.775 -> 35.44
22:24:23.775 -> Temperature 4_R-UA:
22:24:23.775 -> 35.73
```

Fig. 19. (a)Transmitter - Temperature data from the DS18B20 and (b) Receiver - Temperature data from the DS18B20.



```
22:30:45.975 -> Last Packet Send Status:       Delivery Success
22:30:46.978 -> Sent with success
22:30:46.978 -> Temperature 1_L-FA:
22:30:46.978 -> 35.45
22:30:46.978 -> Temperature 2_L-UA:
22:30:46.978 -> 35.76
22:30:46.978 -> Temperature 3_R-FA:
22:30:46.978 -> 35.46
22:30:46.978 -> Temperature 4_R-UA:
22:30:46.978 -> 35.72
```

```
22:30:46.978 -> Data received:
22:30:46.978 -> Temperature 1_L-FA:
22:30:46.978 -> 35.45
22:30:46.978 -> Temperature 2_L-UA:
22:30:46.978 -> 35.76
22:30:46.978 -> Temperature 3_R-FA:
22:30:46.978 -> 35.46
22:30:46.978 -> Temperature 4_R-UA:
22:30:46.978 -> 35.72
```

Fig. 20. (a) Transmitter - Temperature data from the DS18B20 and (b) Receiver - Temperature data from the DS18B20.

V. CONCLUSION AND FURTHER WORK

The results of this study demonstrate the feasibility of designing and implementing a prototype to measure astronaut body temperature during extravehicular activities (EVA). Body temperature ranges remained stable under normal conditions, and although problems arose with the LM35 temperature sensors, the choice of the DS18B20 sensors proved to be more successful, providing more stable and reliable readings. These sensors feature encapsulated probes that are ideal for skin contact and are water resistant, which increases their robustness when astronauts sweat. Constant temperature monitoring translates into easy-to-read reports, which is essential for preserving astronaut health during EVAs.

As a part of future work, it is intended to carry out further tests, in addition to those already performed, and to optimize the 3D printed prototype. These tests will be conducted at the Mars Desert Research Station (MDRS) in the deserts of Utah, USA, and in environments with lunar-like conditions.

The Center for Space Emerging Technologies (C-SET) is known for pursuing dual applications in every project. In this case, the T-EVA device could be employed on Earth to monitor the upper body temperature of firefighters when they face extreme heat exposure in urban or rural environments. This would provide them with real-time readings of their temperature, which would be crucial to take safety measures and protect their life and health in these challenging situations.

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