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Devising IoT based Healthcare Medical Container for Transportation of Organs and Healthcare Products using Unmanned Aerial Vehicle †

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Abstract: Every second counts when a patient who requires an organ transplant is finally matched with a donor. The organ's post-transplant performance declines with increasing time between the organ's removal and transplantation into the recipient. Organs must be transported from point A to B as quickly and safely as possible to improve the chances of success or delivering medical goods or vaccines to hard-to-reach places, drones can help us to save lives across the world. But there are some issues to address in which one of them is maintaining container temperature & humidity and monitoring it. Further, the drones carrying medical containers flying at different altitudes causes temperature changes, which may affect the organs. To tackle such difficulties, in this work a smart container embedded with a Peltier module (Thermoelectric cooler) and a temperature sensor has been developed to maintain the temperature thereby providing safety for healthcare products or organs. Further, the relay module is utilized to control the Peltier module and ESP8266 WIFI Microcontroller (MCU) it also enables the user to send live data to the cloud and also allows the user to monitor and control the temperature remotely. The Blynk Internet of Things (IoT) platform is used to monitor the temperature. Results show that the proposed system is highly efficient for monitoring and controlling the temperature changes accurately according to the user defined values. For demonstration purpose, the temperature of the container is maintained at 12 degree Celsius and the performance of the system is presented. The medical cargo drone carrying healthcare products is tested in real time and at different altitude levels to examine the performance of the developed system.

Keywords: drone; healthcare; humidity; internet of things; Peltier; temperature; transportation

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1. Introduction

Recent years, the healthcare industry has undergone tremendous technological advancements. The scope of these advancements have no limitations, ranging from Internet of Medical things to advancements in the point of robotic surgeries. Even after undergoing such remarkable development, traditional methods are still adopted to transport healthcare products or organs in the majority of nations [1]. Developed nations have adapted the usage of unmanned aerial vehicles for transportation of organs as to speed up the delivery process and enhance the chances of successful medical outcomes, maintaining the organ's function until transplanting it into the patient is ensured through effective organ conservation and protection, which is a crucial part in transplantation and also these UAV's or Medical Cargo Drones are able to deliver medical goods at hard to reach places which could help us to save lives during calamities [2–4].But these UAV's or Medical Cargo Drones are subjected to various external factors such as temperature, pressure, humidity etc. due to the varying altitudes at which these UAV'S or Medical Cargo Drones operate these changes would have a great impact on the healthcare products or organs which are being carried [3,5].

The various storage temperatures of healthcare products and organs are as follows: RBC (Red Blood Cells) or whole blood 2–10 °C, FFP (Fresh Frozen Plasma) 2–6 °C, Cryoprecipitate 2–4 °C, Platelets 20–24 °C, Frozen vials transport −25 °C to −15 °C, Refrigerated vials transport 2 °C to 8 °C, Organs 4 °C to 8 °C, as temperatures below 2 °C significantly increase the risk of cold injury with some proteins denaturing below 0 °C, at temperatures above 12 °C the higher metabolic demand for oxygen leads to irreversible hypoxic injury and thus significantly impairs organ function [6–8].Temperature ranges of 2 to 8 °C or 4 to 8 °C are recommended for use with organ preservation solutions [6,9,10]. Medicines are transported in 3 different temperature ranges based on them < −20 °C, 2–8 °C, 15–25 °C [8].

To maintain these temperature ranges and to ensure the safety of healthcare products and organs this problem needed to be addressed. The aim and objective of this work is to design and develop an IoT Based Healthcare Medical Container for Transportation of Organs and Healthcare Products using Unmanned Aerial Vehicle.

2. Literature Survey

Over the recent years, organ and vaccine preservation has been a challenging work during transportation, Liao et al. (2021) [5] have presented the study on blood preservation during storage and transportation. Further, the authors discussed the various factors that affects the quality of stored blood, such as temperature fluctuations, oxygenation, and the presence of certain additives. Also, the authors have described various methods for monitoring the temperature and oxygen levels of stored blood, including temperature-sensitive labels and oxygen sensors. Jing et al. (2018) [7] have discussed an overview of organ preservation techniques, highlighting the importance of temperature control during organ preservation. Nyemba et al. (2019) [14] authors have discussed the evaluation and feasibility assessment of refrigeration systems devoid of harmful refrigerants for the storage of vaccines.

The authors have discussed the demerits of traditional cooling methods and suggested better preservation techniques of organs and vaccines below, Minasian et al. (2015) [3] have discussed the state of the art in heart preservation technology which highlights the importance of temperature control during organ preservation. Also, the authors have discussed the limitations of traditional cooling methods and suggested that Peltier cooling modules could provide a better solution for organ preservation. Nyemba et al. (2019), the authors have discussed the performance characteristics of various refrigeration systems, including the cooling capacity, the power consumption, and the temperature stability. Also, the authors have concluded that the Peltier cooling is a promising technology for vaccine storage due to its low power consumption, compact size, and lack of harmful refrigerants. Sathyan et al. (2021) [1] have discussed the importance of efficient organ transportation, highlighting the challenges faced in the preservation of organs during transportation. Further, the authors have designed a 3D CAD model of a novel approach that utilizes a combination of Peltier cooling technology and a vacuum insulated container for organ transportation.

Chang et al. (2019) [13] have reported on the development and testing of a thermoelectric air-cooling module for electronic devices. The authors have tested the performance of the system in terms of the cooling capacity, the power consumption, and the temperature drop across the module. The results of the study showed that the thermoelectric air-cooling module had a cooling capacity of up to 17.7 W, a power consumption of up to 31.5 W, and a temperature drop of up to 14.5 °C. The study also showed that the cooling performance of the system was affected by various factors, such as the ambient temperature, the air flow rate, and the geometry of the heat sink. Afshari et al. (2020) [12] have presented a review of Peltier cooling devices and their applications. The authors have discussed the basic principles of Peltier cooling and the factors that affect their performance, such as the thermoelectric materials used, the temperature difference across the device, and the electrical input power. Zeng et al. (2020) [16] have presented a theoretical analysis of temperature control for a thermal insulation box. The authors have demonstrated the various factors that can affect the temperature stability of the box, such as the thermal conductivity of the insulation material, the thermal conductivity of the surrounding environment, and the heat transfer coefficient and also described the various temperature monitoring devices that can be used to ensure proper temperature control during transportation. Remeli et al. (2020) [11] have conducted an experimental study of a mini cooler using a Peltier thermoelectric cell. The authors have utilized a Peltier thermoelectric cell as the cooling mechanism and tested its performance in terms of the cooling capacity and the coefficient of performance. The authors also investigated the effects of various parameters, such as the input power, the heat load, and the ambient temperature, on the cooling performance of the system. The results of the study showed that the mini cooler had a cooling capacity of up to 7.38 W and a coefficient of performance of up to 0.07. Also, the study showed that the input power, the heat load, and the ambient temperature all had significant effects on the cooling performance of the system. Here the authors have discussed about the performance and factors affecting the peltier module giving an analysis how to get a better performance.

Schubert et al. (2019) [18] have discussed an overview of sensor technologies for monitoring the cold chain during transportation. The authors have discussed the various types of sensors that can be used to monitor temperature, humidity, and other factors that can affect the quality and safety of perishable goods during transportation.

3. Materials and Methods

3.1. Proposed System

In this work, a IoT based smart healthcare medical box with a temperature control mechanism is designed and developed. Figure 1 shows the overall block diagram of IoT based smart healthcare medical box. It is observed that the proposed system consists of various components such as temperature sensor, Peltier module, battery, microcontroller and relay units.

3.1.1. Temperature Sensor

In this work, a LM35 temperature sensor is utilized to measure the temperature of the medical box. LM35 is a commonly used temperature sensor which can be used to measure temperature in degree Celsius. Also, it measures the temperature more accurate than the thermistors. The LM35 is very cheap, compact and a three terminal device which operates on the voltage range of 4–30 V. Further, it produces 10-mV per degree Celsius which is linear and directly calibrated in Celsius. Also, the LM35 temperature sensor can measure the temperature range of −55 degree Celsius to 150 degrees Celsius which is more suitable for the proposed work.

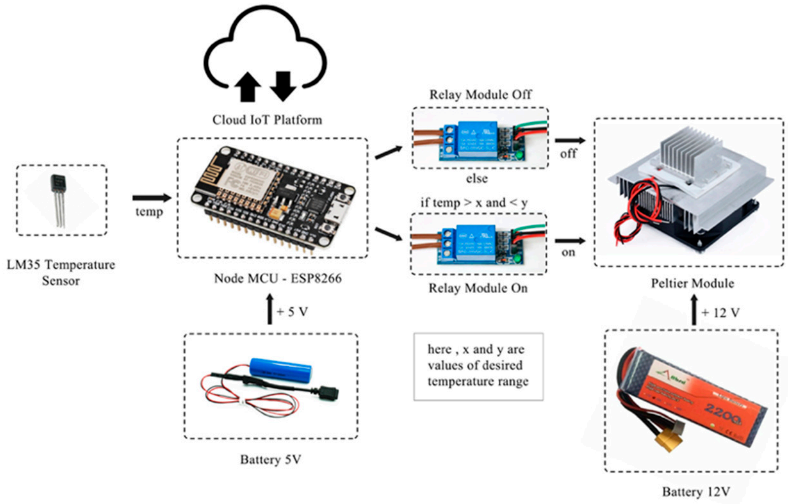


Figure 1. Overall block diagram of IoT based smart healthcare medical box.

3.1.2. Node MCU-ESP8266

In this work, a ESP8266 node MCU microcontroller is utilized. Further, the ESP8266 has an inbuilt WiFi (WiFi protocol—IEEE 802.11 b/g/n) and operates on 5 V supply which can be supplied using batteries. Also, the microcontroller has an analog to digital converter pin in which the LM35 is connected and the analog signals from the temperature sensor is converted into digital signal for further processing. Once the input signal is converted into digital, the microcontroller calibrates the signal directly to Celsius by properly coding it. Also, the ESP8266 microcontroller is capable to feed/read the data's directly to/from the IoT cloud with the help of read/write API keys.

3.1.3. Freezer Arrangement

The freezer arrangement is constructed with a help of Peltier which is otherwise called as thermoelectric coolers. Peltier operates on the supply voltage of 12 V to 15 V and it draws the maximum current of 10A. Once the Peltier is powered, it creates the temperature difference namely hot side and cool side on each side of it. The heat produced at the hot side of the Peltier is continuously removed with the help of fan arrangement and on the cool side, the continuous cooling is utilized by the medical box of the proposed system.

3.1.4. Relay Unit

In general, the relay module acts as an automatic switch which can be switch ON/OFF without any manual intervention by control electrical control signals. In this work, a 3.3 Volt relay module is utilized to drive Peltier module, Coolant fan arrangement. The relay module is capable of switching ON/OFF the Peltier module and coolant fan by applying a 3.3v/5v control signal which shall be supplied by the microcontroller.

3.1.5. Power Supply

The power supply of this work is simply a battery technology. Two different batteries are used for the proposed system whereas one battery is utilized to power Peltier module and another battery is utilized to power microcontroller a other electronic components. Also, the battery utilized to power microcontroller and other components provides 5 V supply which can be commonly seen in smartphone battery banks. A Lithium Polymer battery utilized to power Peltier module has the charge capacity of 2200 mAh and voltage range of 11.1 V which is more sufficient to source the Peltier module.

Firstly, the temperature of the medical box is read by the LM35 sensor and the temperature values are given to the ESP8266 microcontroller. Since, the ESP8266 microcontroller is a WiFi controller, the temperature values are updated to the Blynk page. Blynk is an IoT (Internet of Things) platform that allows users to remotely control and monitor their devices over the internet. Blynk provides an API that allows developers to integrate their devices and applications with the Blynk platform it also provides a range of functionalities, including device authentication, data streaming, and it consists of a mobile app and a cloud-based server that communicate with each other to enable remote device control.

Figure 2 shows the flowchart for working of smart healthcare medical box. Also, the microcontroller checks the medical box temperature with the set temperature whereas the set temperature can be set with the help of Blynk IoT platform. Further, if there is any decrease/increase in medical box temperature than the set temperature, the microcontroller switches ON/OFF the Peltier module with the help of relay unit and the medical box temperature will be maintained in line with the set temperature. The medical box is fixed to the readymade drone. This drone aided thermo-regulating medical container provides a reliable and efficient system for transporting medical products, ensuring the safety and efficacy of medical products, ultimately saving lives across the world.

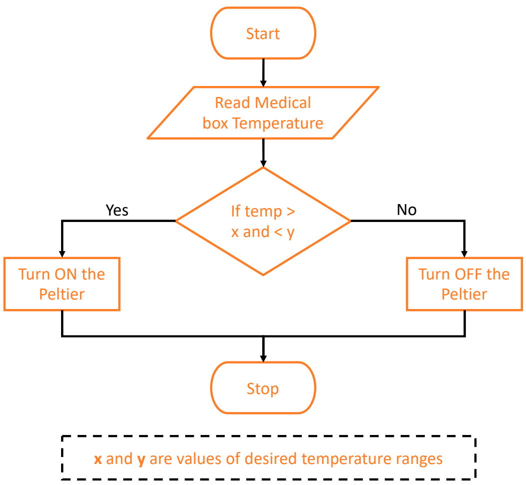


Figure 2. Flowchart for working of smart healthcare medical box.

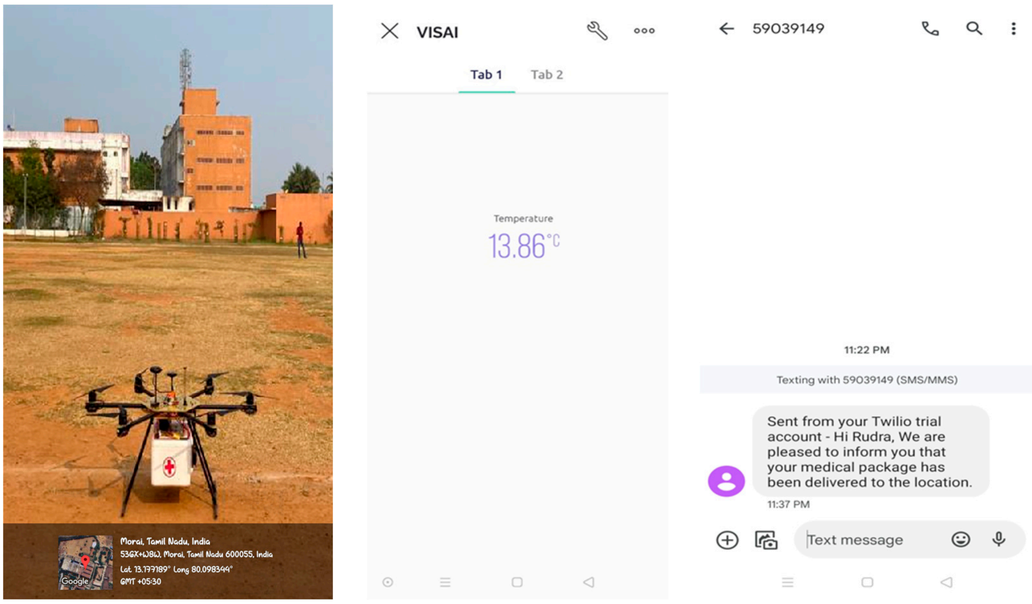
3.2. Internet of Things Framework

In this proposed work, a custom designed Blynk page is developed and it will act as a user interface using the internet. Further, the Blynk page is used to monitor and control the temperature of the medical compartment. The medical compartment is capable of carrying any healthcare products/organs etc. and the appropriate menu has to be set through a user interface. The various storage temperatures are: RBC (Red Blood Cells) or whole blood 2–10 °C, FFP (Fresh Frozen Plasma) 2–6 °C, Cryoprecipitate 2–4 °C, Platelets 20–24 °C, Frozen vials transport −25 °C to −15 °C, Refrigerated vials transport 2 °C to 8 °C, Organs 4 °C to 8 °C, as temperatures below 2 °C significantly increase the risk of cold injury with some proteins denaturing below 0 °C, at temperatures above 12 °C the higher metabolic demand for oxygen leads to irreversible hypoxic injury and thus significantly impairs organ function. To balance the two tendencies, 4 °C to 8 °C is said to be ideal. The page is designed such a way and for the aforementioned temperature ranges, the appropriate menu has to be selected.

Generally, the Raspberry PI and other advanced microcontrollers have the capability to transmit/update the data to the Blynk page. So, the designed page can be accessed with the help of Application Programming Interface (API) keys and it can be accessed from anywhere. The page has the option to select the type of healthcare product/organ accordingly the compartment temperature is maintained. Also, the present compartment temperature, humidity, vibration, altitude and GPS can be monitored in the developed webpage. Since, the microcontroller is connected to the internet, with the help of open access communication platforms such as Twilio etc. the mail/Short Messaging Service (SMS) can be sent to the sender of the medical healthcare products once it is delivered to the receiver.

4. Results and Discussion

Figure 3a shows the prototype of a smart medical box integrated with an Unmanned Aerial Vehicle.



(**a**) (**b**) (**c**)

Figure 3. (**a**) Smart medical box integrated with an Unmanned Aerial Vehicle (**b**) User page of Blynk IoT platform (**c**) Twilio Messenger Service.

The container box is attached to a drone, and trial tests are conducted at high altitudes to simulate the actual delivery conditions is shown in the Figure 3a. Figure 3b shows the custom designed user page of Blynk IoT platform. The proof of concept is evaluated and it is evident that by using the Peltier module, the temperature of the medical compartment can be maintained at the set values. The Peltier module is used to maintain a constant temperature within the container during delivery. Also, the trial tests are conducted to assess the efficiency of our container. The temperature inside the container are recorded continuously with the help of the Blynk IOT platform. The trial tests showed that the container with the Peltier module successfully maintained the temperature range for 6 to 8 h. This indicates that the container is suitable for transporting medical goods that require a constant temperature during delivery.

The proposed system is integrated with Twilio API. The Twilio API sends a message to notify the user that the package has been successfully delivered at the destination. The container with the Peltier module proved to be efficient in maintaining a constant temperature during delivery, which is crucial for medical goods that require specific temperature conditions. The integration of the Twilio API allows us to notify the user of successful delivery, which adds an extra layer of convenience and security to the system which is shown in the Figure 3c.

Also, the Figure 4 shows the QGround Control user interface which is used to monitor the drone parameters and control the drone. Further, it is demonstrated that the altitude, target distance and spacing of the drone can be fixed using QGround Control user interface. Also, it is clearly observed that the path of the drone can be configured using the same user interface whereas the drone will travel through the specified path as shown in the Figure 4. Hence, the QGround Control provides an efficient solution for path planning, mission planning and monitoring of drone.

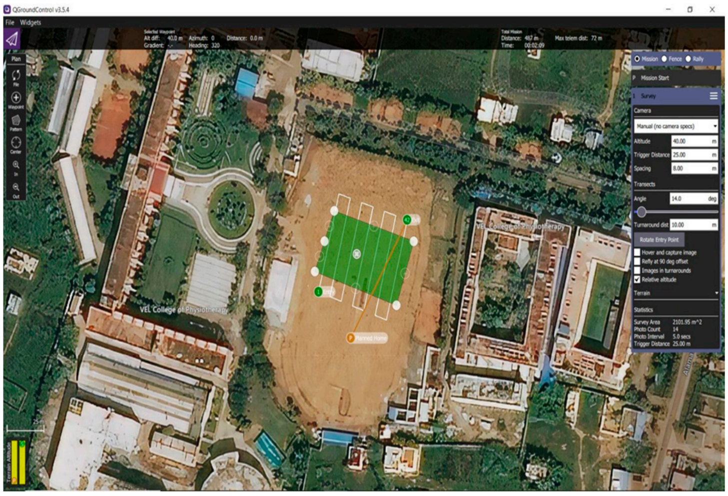


Figure 4. QGround Control User Interface.

Figure 5 shows the temperature data of the developed container box. It is observed that the temperature of the container is almost maintained constant. Further, the temperature values are recorded during flight and it is demonstrated that the temperature can be maintained constant with the help of Peltier. For demonstration purpose, the set temperature of 12 degrees is set and it is clearly seen that the Peltier module maintains the container temperature in line with the set temperature. The future work includes conducting trials in different environmental conditions to assess the container's efficiency and further improvements to the system, such as adding Humidity sensor and non-contact type temperature sensor. Also, the non-contact type temperature sensor would be highly beneficial to measure temperature of organs and liquids present inside the container.

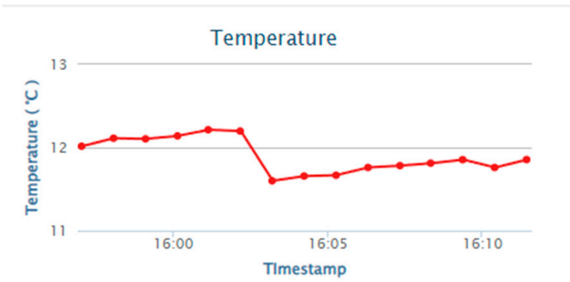


Figure 5. Temperature data**.**

5. Conclusions

A novel medical container box embedded with a Peltier module, temperature sensor, ESP8266 WIFI Microcontroller, relay board, and battery power banks to maintain and monitor the temperature is proposed. The integrated IoT framework of the medical container allows the user to monitor and control the temperature remotely. The entire module is included into a UAV and field testing is performed at various altitude levels and at a range of 2 km. The developed device is able to maintain the desired temperature and same being transmitted via IoT platform. The existing road transport is replaced by advanced drone technology, which results in less transportation time. Developed device ensures high-level safety for transportation of healthcare products, including organs, medical goods, and vaccines and also can quickly and safely deliver medical products to hard-to-reach places, saving lives across the world. Additionally, the proposed solution does not require cryogenic systems, which can be expensive and challenging to maintain. This helps to reduce the risk of product damage, spoilage, or loss during transportation. Overall, the developed device can have a significant impact on the healthcare sector, improving the quality of life.

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