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DEPARTMENT OF PHYSICS

DEVELOPMENT OF GRAPHICAL USER INTERFACE AND PREDICTION PROGRAMS FOR HIGH ALTITUDE BALLOON (HAB) USING MACHINE LEARNING (ML)

Indian Institute of Astrophysics

PROJECT REPORT

SUBMITTED BY,

BHAVANA THILAKAN

210011023194

UNDER THE GUIDENCE OF

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Indian Institute of
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In partial fulfilment of the requirements for the degree of
Master of Science in Space Science
2021-2023

BHARATA MATA COLLEGE
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Affiliated to MG University, Re-accredited by NAAC with 'A+' Grade, ISO 9001-2015 Certified

DEPARTMENT OF PHYSICS

CERTIFICATE

Certified that the minor project work titled "DEVELOPMENT OF GRAPHICAL USER INTERFACE AND PREDICTION PROGRAMS FOR HIGH ALTITUDE BALLOON (HAB) USING MACHINE LEARNING (ML)" is carried out by Ms. Bhavana Thilakan (210011023194) who is a bonafide student of Bharata Mata College, Thrikkakara in partial fulfilment for the award of degree of Master of Science in Space Science of the Mahatma Gandhi University, Kottayam in the year 2020-2022. It is certified that all corrections indicated for Internal Assessment have been incorporated in the report deposited in the departmental library. The project report has been approved as it satisfies the academic requirement respect of project work prescribed by the institution for the said Degree.

Signature of Internal Guide
Dr. Manesh Michael

Signature of External Guide
Dr. Binu Kumar

Signature of HoD
Dr. Shibi Thomas

Signature of Principal
Dr. Johnson K M

Indian Institute of Astrophysics
Block II, Koramangala
Bangalore - 560034
India

Ref: SPG/PCL/N./04/06 /23

CERTIFICATE

To whomsoever it may concern

This is to certify that Ms. Bhavana Thilakan, 4th semester M Sc Space Science student, Bharata Mata College, Thrikkakkara, Ernakulam (Affiliated to Mahatma Gandhi University, Kottayam) has completed her project work at the Indian Institute of Astrophysics, Bangalore during 14th April 2023 to 16th June 2023.

She has worked on the project titled "**Development of Graphical User Interface and prediction programs for High Altitude Balloon (HAB) using machine learning (ML)**". Objective of the project was to develop a Graphical User interface for recording and sorting the in situ data received during the HAB flight and processing the data with ML to predict and correct the trajectory. She used Python based libraries to develop an algorithm which can correct the preflight prediction based on in situ measurements from HAB. She had a self-driven attitude to venture into new arena of contemporary research in the field of High altitude ballooning and trajectory predictions. Her performance was par excellence.

We wish her best of luck for all her future endeavors.

30/06/2023
Bangalore

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DECLARATION

I, BHAVANA THILAKAN (210011023194), a student enrolled in the fourth semester of MSc Space Science at Bharata Mata College, Thrikkakara, Department of Physics, hereby confirm that the project titled "Development of Graphical User Interface and prediction programs for High Altitude Balloon (HAB) using machine learning (ML)" was carried out by us and submitted as a partial fulfilment of the requirements for the degree of Master of Science in Space Science at Mahatma Gandhi University, Kottayam, during the period of 2021 - 2023.

Furthermore, we affirm that the content of this project has not been submitted to any other university for the purpose of obtaining any degree or diploma.

I also declare that any Intellectual Property Rights resulting from this project, conducted at IIA, will be the property of Bharata Mata College, and I will be one of the rightful author of such property.

Place: Thrikkakara BHAVANA THILAKAN

Date: 27/07/2023 (210011023194)

ACKNOWLEDGEMENT

The success of any accomplishment, whether academic or otherwise, is not solely attributed to individual efforts but also to the guidance, encouragement, and cooperation received from intellectuals, elders, and friends. Numerous individuals, each contributing in their own unique way, have assisted us in completing this project. I would like to seize this moment to express my gratitude and extend my heartfelt thanks to all of them.

I would like to take this opportunity to express my sincere appreciation and gratitude to my project guide Binukumar sir and my teachers for their exceptional guidance and mentorship throughout this project. Their expertise and dedication have been instrumental in shaping my skills and knowledge in the subject matter.

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To everyone mentioned above, thank you from the bottom of my heart for being a part of my journey and for your invaluable contributions. I am truly blessed to have such amazing individuals in my life.

ABSTRACT

High altitude balloons are crucial for atmospheric and space science research, collecting data from the tropospheric and near stratospheric regions. They have a long history, dating back to military tasks and atmospheric weather studies. Proper flight predictions are crucial for safety and locating payloads. But as the atmosphere is constantly evolving, the already existing pre-launch prediction can give a larger error

This study mainly focuses on developing graphic user interface and implementing the technologies of machine learning for the post launch Real-time trajectory prediction which utilizes the existing models to determine the balloon's path and current location. The payload, consisting of sensors, cameras, data loggers, GPS receivers, and other scientific instruments which are integrated together, is used to extract data like altitude, latitude, longitude, humidity, and temperature used for the real time trajectory prediction. Later the comparison on the pre-predicted path, actual path and the post predicted path are done and analysed.

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1 INTRODUCTION

In the field of atmospheric science and space science, high altitude balloons are one that are indispensable. High altitude balloons are of great importance for experimental as well as observational research in the respective fields. It's been highly used to collect data from the tropospheric and near stratospheric region. In the current era of large modern observatories and satellites, they are still relevant due to their advantages such as affordability, availability, maintainability, easiness for recovery and reusability of payloads.

High altitude balloons have long term history in the early stages of military tasks and purposes and for atmospheric weather studies. They used the fact about hotter air that are lighter can raise. Thus, early scientist worked with hydrogen filled balloons and later they worked on crewed high-altitude balloons and placed human altitudes records. US government even worked on balloon project with hydrogen which is highly inflammable and risk. This was the reason later they used less flammable helium in their next work. Later High-Altitude Balloons came into use as an essential scientific instrument.

HABs are used mainly for the studies in troposphere and stratosphere. Depending on the purpose, it varies in size. Larger HABs are scientific balloons which include payload weighing up to 3600 kg or more. The smaller HABs only use payloads with few kilograms of weight. These are used for meteorological purposes. Even smaller balloons are used for amateur purpose.

One of the many factors to consider in a balloon launch is the trajectory prediction of the flight. It is a prerequisite factor for the implementation of the successful balloon launch and payload recovery. The balloon can fly in the troposphere region of atmosphere and it get burst at stratosphere at certain conditions. Most of the atmospheric phenomena are observed in troposphere like vertical currents. These along with pressure, temperature and other factors can get affect the trajectory of the balloons. Due to that a deviation is observed from the already predicted path of the balloons. The real time trajectory predictor helps in finding the trajectory of the flight path from an existing model. And most importantly it helps in predicting the current location and path of the balloon with the help of real time data that are collected with the help of different sensors connected with the payload.

1.1 ATMOSPHERE- composition and layers.

Atmosphere is a helpful layer of gases that envelops the Earth that makes our planet habitable. The whole atmosphere is about hundreds of kilometers with a majority composition of Nitrogen-78.08%, Oxygen-20.95%, Argon-0.93%, Carbon Dioxide-0.04% and traces of other gases. The composition varies in different part of the atmosphere and based on the composition, temperature, pressure and other physical processes it is classified into different atmospheric layers. Lowest of this is the *troposphere*. It has an average height of 18 km and the temperature decreases with the height. Most of the phenomena we observe like wind, rain, snow is observed here. Vast majority of the mass of the atmosphere is concentrated here especially there is a higher concentration of oxygen and water vapour. The molecules like CO_2, O_3 and water vapour are responsible for the radiative heat transfer between layers and regulation of the heat for a habitable surface. About 1% of water vapour content is seen at the sea level and about 0.4% is seen over the atmosphere. Changing weather is a feature of this layer and the gases gets jumbled due to this changing weather. Vertical currents, both upstream and downstream, in this layer is beneficial in mixing up the minute particle thereby refreshing the air.

In early time it was believed that the temperature exponentially decreased in the other layers. Later experiments with the balloon-borne thermometers showed a temperature inversion in the above layer. In next higher layer from ground is the richest place of the eminent ozone layer. These ozone layer absorbs the most detrimental ultraviolet (UV) rays from the Sun and due to this action, there is an elevation in the temperature in this layer. One of the main features of this layer is the stratified temperature layers, with the lighter warm air at high and denser cold air at low sky. This layer is called *stratosphere*. It extends upward from tropopause to about 50 kms. The transition region between the troposphere and stratosphere is called *tropopause.*

Above stratosphere, present the *mesosphere*. Mesosphere does not have a clearly defined lower base. Mesosphere is almost 50 to 85 km in distance and the temperature drops with altitude. The upper boundary mesopause is the coldest region of the entire atmosphere. Due to the lower temperature, ozone gets dissociate easily by the photochemical reactions.

Again, a temperature rise is observed in the above layer, *thermosphere*. Here the shorter UV rays gets absorbed and the photoionization of molecules are high. Thus, the major constitution of ionosphere is given by thermosphere. The outer most *exosphere* extends and gradually merges with the interplanetary space. International space station (ISS) and many other satellites are orbiting here and below. The particle in this region travels in a curved path without collision and is later influenced by the gravitational force.

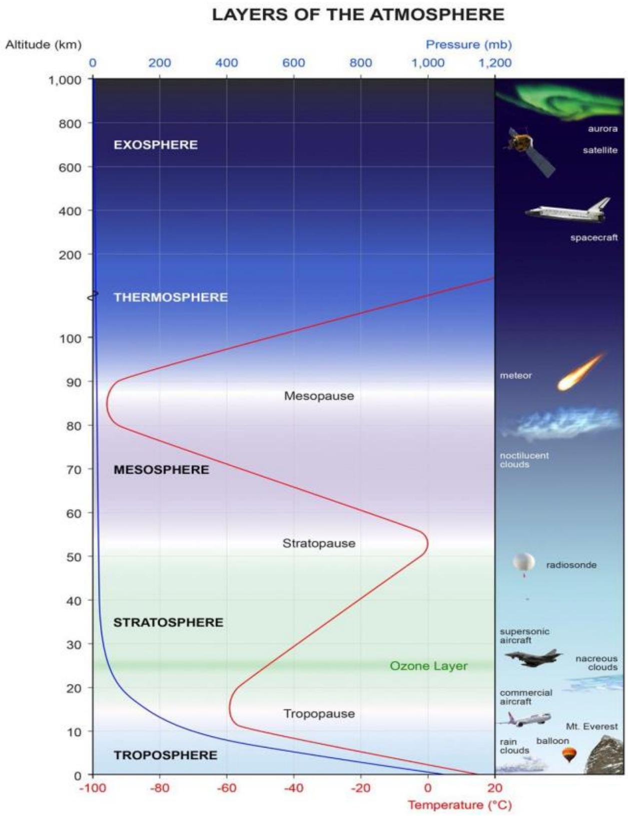


Figure 1: Different atmospheric layers and their temperature and pressure profiles

Earth's atmosphere is said to be in hydrostatic equilibrium. For the volume element of atmosphere we consider, the weight as being balanced by the upper and lower forces of the fluid. Pressure of course depends on the temperature. The combination of hydrostatic equilibrium and ideal gas law suggest the exponential decrease of pressure and density in the isothermal atmosphere. But in reality, the temperature of atmosphere is different in different layers as mentioned above and the atmospheric pressure become 1/3 less for almost every 7 km moving upward.

In atmospheric studies, thermodynamic principles and kinetic theories has a very important role. First law of thermodynamics helps to study the atmospheric heating and cooling processes while the second law helps to study different atmospheric behaviors. The wind formation and motion of wind is altered by the presence of Coriolis force.

There are two atmospheric model to study and explain the complex behaviors and characteristics of atmosphere; one is the model with a non- absorbing atmosphere which is a seriously defective one**,** second one is related to greenhouse effect that clarifies the defect by the former one.

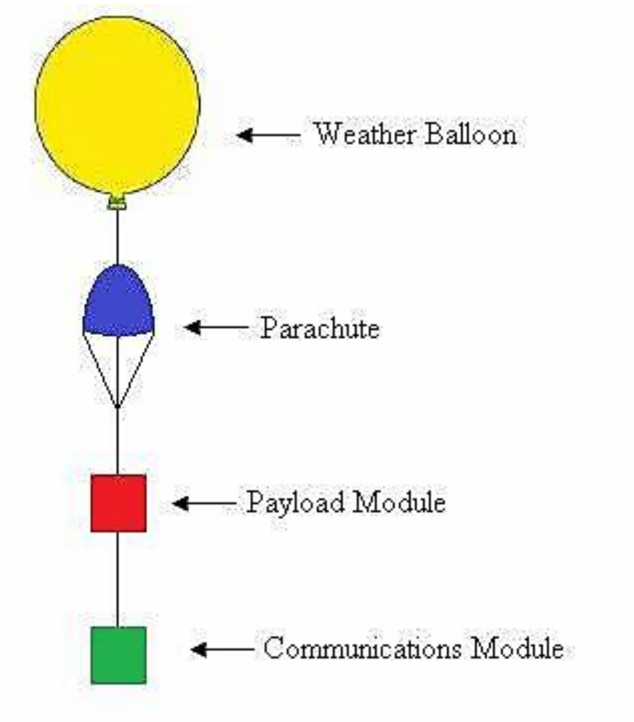
1.2 HIGH ALTITUDE BALLOON (HAB)

In scientific field, high altitude balloons are mainly used for weather studies and prediction. Depending on the usage, they vary in size. larger HABs are used for scientific purposes. Their payload can vary up to 3600 kgs. For meteorological purpose, smaller HABs with payload weighing up to few kilograms. The fuel to be used can be either hydrogen or helium. Each one has their own advantages. Hydrogen is the lighter one while helium is less inflammable. The white latex material is used for balloon which can be filled with 115 ft^3 of fuel to inflate the balloon. The total weight of payload is of 1.4 kg. The payload contains several sensors including UV sensor, temperature sensor, barometric sensor, NO2 sensor, CO2 sensor, ozone sensor. The launching requires clearance from respective governmental authorities of aviation. Power system, GPS Tracker and Radar reflectors are other important parts of the balloons. GPS tracker updates the location of the payload every 5 minutes and it is useful to locate the payload for its track and recovery.

Figure 2 high altitude balloon launch at CREST campus
IIA, Bangalore

1.3 HAB TRAJECTORY PREDICTIONS

The popularity of high-altitude balloons has surged due to their affordability and benefits in terms of learning and error correction. Predicting the balloon's trajectory is essential to guarantee its safety. Researchers use tracking hardware like APRS and GPS to monitor high altitude balloon trajectories. Redundant systems are recommended for reliability. Accurate flight predictions aid in locating payloads. Variables such as balloon size, time of day, launch and ascent velocity, and solar angle impact burst altitude. UV radiation and vertical velocity near burst altitude affect balloon performance. More research is needed to understand the relationship between variables and burst altitude changes.

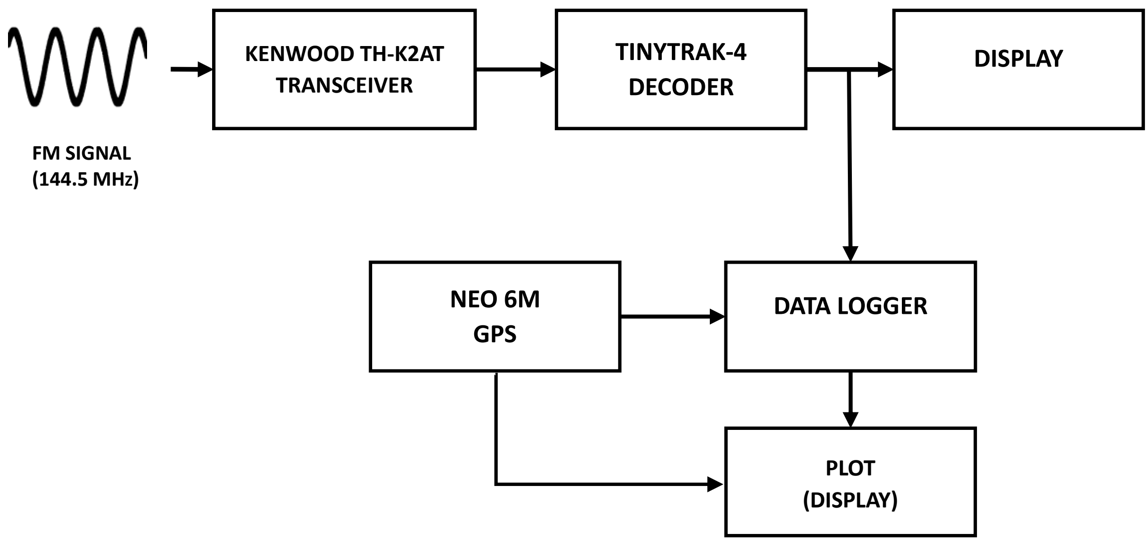


The prediction of a balloon's flight trajectory is a crucial factor in its successful launch and payload recovery. Balloons typically traverse the troposphere before bursting in the stratosphere under specific conditions. The troposphere, where atmospheric phenomena like vertical currents occur, is influenced by variables such as pressure and temperature, which can impact balloon trajectories. These factors often lead to deviations from the initially predicted paths. To address this, real-time trajectory prediction utilizes existing models to determine the flight path and current location of the balloon. This is achieved by collecting real-time data through various sensors connected to the payload.

2 GROUND SEGMENT

In the high-altitude balloon trajectory prediction mission, the ground segment typically refers to the components and systems on the ground that support and aid in predicting and tracking the balloon's trajectory during its flight.

2.1 FUNCTIONAL BLOCK DIAGRAM



2.2 DEVICES

2.2.1 KENWOOD TRANSCEIVER

Kenwood is a Japanese manufacturing company founded in 1946. They are leading manufacturer of high-quality audio and radio equipment including two-way radios, amateur radio transceivers, mobile radios, marine radio equipment and audio equipment for home and professional use.

Kenwood transceivers are devices that are cable of both transmitting and receiving radio signals. The company offers many types of transceivers that differ by their application of use. The 144 MHz Transceivers are used mostly in balloon experiments as the 144 MHz is well-suited for line-of-sight communication. Since it is an amateur radio band, and the equipment availability, it is the most convenient band of use. The 144 MHz FM Transceiver models includes TH-K2AT, TH-K2E, TH-K2ET.

2.2.1.1 TH-K2AT

The Kenwood TH-K2AT is a compact and lightweight handheld transceiver designed for use in amateur radio applications. It operates on VHF frequencies (144-148 MHz) and provides up to 5 watts of transmit power. The TH-K2AT is a popular choice among amateur radio operators due to its compact size, robust construction, and advanced features. It is suitable for a wide range of applications, including outdoor activities, emergency communications, and casual amateur radio use

2.2.1.2 TH-K2E

The Kenwood TH-K2E is a handheld transceiver that is similar to the TH-K2AT in many ways. Like the TH-K2AT, it is a compact and lightweight device that operates on VHF frequencies (144-148 MHz) and provides up to 5 watts of transmit power. Even though they have similarities, there are some differences between the TH-K2E and the TH-K2AT like a different style of antenna, and it may have slightly different dimensions and weight.

The TH-K2E is a reliable and versatile handheld transceiver that is suitable for a wide range of amateur radio applications.

2.2.1.3 TH-K2ET

The Kenwood TH-K2ET is a handheld transceiver that is similar to the TH-K2AT and TH-K2E in many ways. Like these models, it is designed for use in amateur radio applications and operates on VHF frequencies (144-148 MHz). It provides up to 5 watts of transmit power, making it suitable for both indoor and outdoor use. The way it differs from other models are the TH-K2ET includes an extended transmit frequency range of 136-174 MHz, which makes it suitable for a wider range of applications. It may also include different accessories or be marketed in different regions than the other models.

2.2.2 THE BYONICS TINYTRAK-4 DECODER

The Byonics TinyTrak4 (TT4) is a versatile radio interface that enables the transmission and reception of position and various digital information through a two-way FM radio system. This device is designed for tracking and decoding Automatic Packet Reporting System (APRS) packets. APRS is a communication protocol commonly used by amateur radio operators for real-time tracking and data transmission. The TinyTrak4 Decoder is specifically designed to receive APRS packets transmitted on the 144 MHz band. It incorporates a receiver module that captures the signals and demodulates the data packets. The device then processes the received packets, decoding the information contained within.

The TinyTrak4 connects to a radio using the microphone and earphone inputs, while it interfaces with computers and GPS receivers through serial ports. It can be updated with new features by downloading firmware updates from the TinyTrak4 website and loading them onto the device using a computer.

The Byonics Tinytrack-4 Decoder

2.2.3 DISPLAY

The display in a high-altitude balloon experiment integrates hardware and software components to provide real-time information about the balloon's trajectory and other relevant data.

The trajectory predictions and real-time position of the balloon are typically overlaid on a map. The map may include various features like landmarks, and geographical boundaries to provide reference. The predicted flight path is usually represented on the map.

Along with the position information, the display also includes telemetry data gathered from sensors onboard the balloon payload. This data might include parameters like temperature, pressure, humidity, or any other measurements relevant to the experiment. Telemetry values are frequently shown as numerical values or plotted on graphs to monitor trends and thereby analyze the collected data.

A critical role of the display is the landing zone prediction. By combining the balloon's current position and other valuable information, the display can estimate the probable landing area. The display system typically includes data logging capabilities to record the balloon's trajectory and other relevant data for later analysis. This recorded data can be used for post-flight evaluation, refining prediction models, and further research purposes.The display may also incorporate alert mechanisms to notify operators of significant events or deviations from the predicted trajectory

2.2.4 DATA LOGGER

A data logger is an essential device employed in experiments and scientific research to chronicle and retain data throughout a duration of time. It functions as a standalone unit with the ability to interface with external sensors or transceivers. Data loggers are designed to measure and capture various types of data. Data loggers are commonly utilized in high altitude balloon experiments to capture and record critical data throughout the flight. In such experiments, data loggers play a crucial role in monitoring and collecting various parameters as the balloon ascends to high altitudes. Through the utilization of a data logger during a high-altitude balloon experiment, researchers can acquire valuable data pertaining to atmospheric conditions, temperature fluctuations, pressure fluctuations, altitude profiles, and other pertinent parameters. This data not only offers insights into the performance of the balloon but also provides an understanding of the environmental conditions experienced at various altitudes. Furthermore, it aids in the analysis of the experiment's outcomes, enabling researchers to draw meaningful conclusions. The data logger securely stores recorded data for analysis and interpretation, enabling researchers to evaluate the experiment's success and draw informed conclusions after the balloon lands.

2.2.5 ARDUINO

Arduino is a project initially developed in 2005 by Design Institute Ivrea, Italy. They aimed to create an easy-to-use and affordable platform for artists, designers, hobbyists, and anyone interested in electronics and programming.

The Arduino platform is an open-source electronics platform that enables the creation of interactive projects and prototypes by combining hardware and software components. It comprises a microcontroller board, programmed with the Arduino programming language (can be C/C++ language), and the Arduino IDE (Integrated Development Environment) software, facilitating code writing and uploading to the Arduino board.

Based on the purpose of use, different types of Arduino boards are available today such as Arduino Mega, Arduino UNO, Arduino Leonardo, Arduino Nano, Arduino Micro and so on.

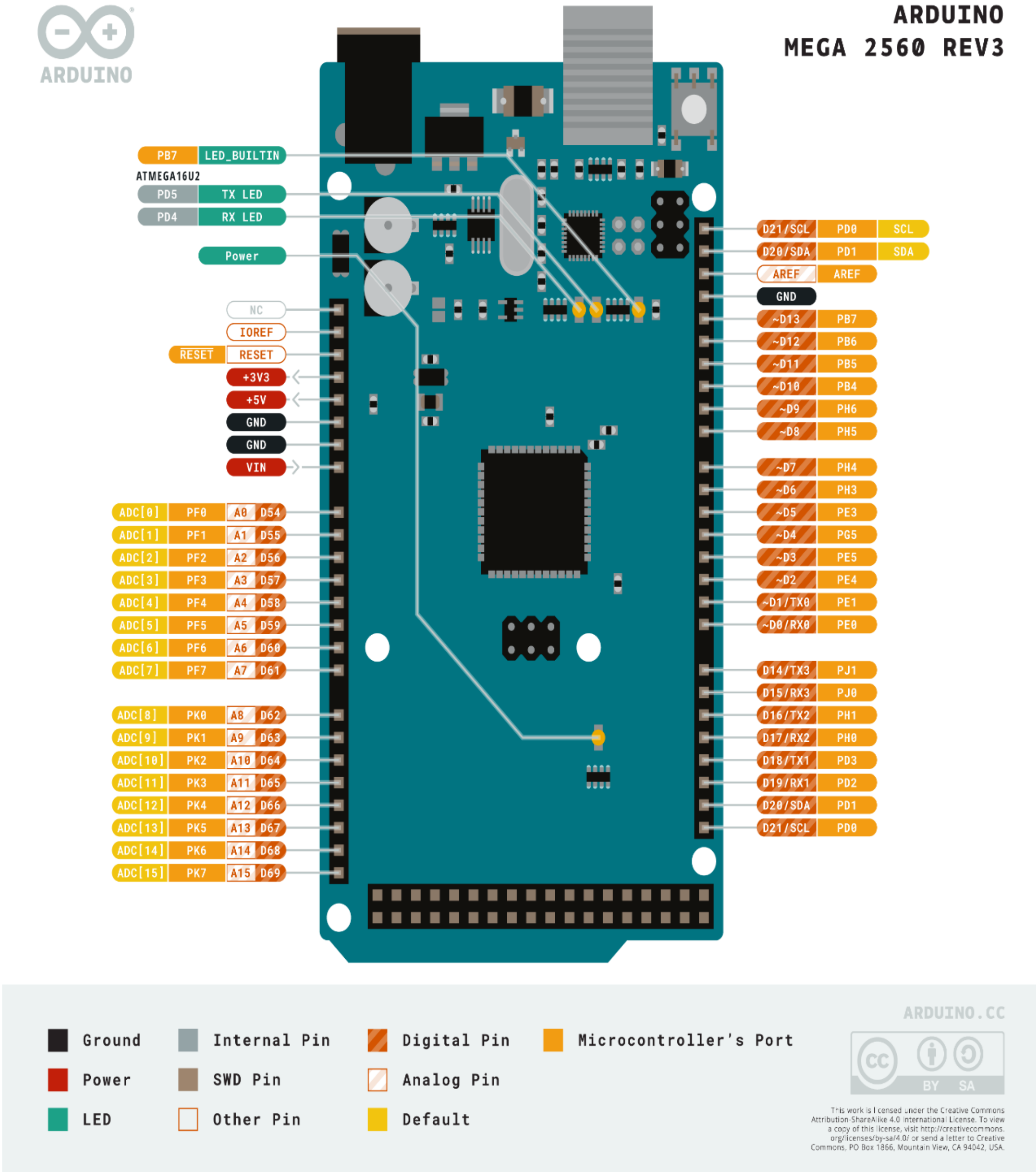
2.2.5.1 ARDUINO MEGA

A microcontroller board is a hardware platform that integrates a microcontroller chip, along with other necessary components, onto a single board.

The Arduino Mega is a microcontroller board based on the ATmega2560. It is an enhanced version of the on-demand Arduino UNO board and thus the Arduino Mega possess advantages over Arduino UNO like it offers more input/output pins and memory.

Some of the important features of the Arduino Mega are given below:

FEATURE	DETAILS
Microcontroller	ATmega2560 microcontroller with 54 digital I/O pins (14 PWM outputs), 16 analog inputs, and 4 hardware serial ports
Memory	256 KB flash memory, 8 KB SRAM, and 4 KB EEPROM
Communication	USB, UART, SPI, I2C, and ICSP header for programming
Power	Can be powered via USB or external power supply, with voltage regulator for 5V or 3.3V operation
Compatibility	Compatible with Arduino software (IDE) and libraries for easy programming and peripheral integration



FIGUER 4: The pinout diagram of Arduino mega-2560

2.2.6 RASPBERRY PI

Raspberry Pi is a series of single-board computers (SBCs) developed by an UK based organization the Raspberry Pi

Foundation. These small, affordable, and versatile computers are designed to promote computer science education and provide a platform for various projects and applications. the Raspberry Pi boards themselves have distinct hardware characteristics, one significant factor that sets them apart from other computers is the operating system (OS) they can run.

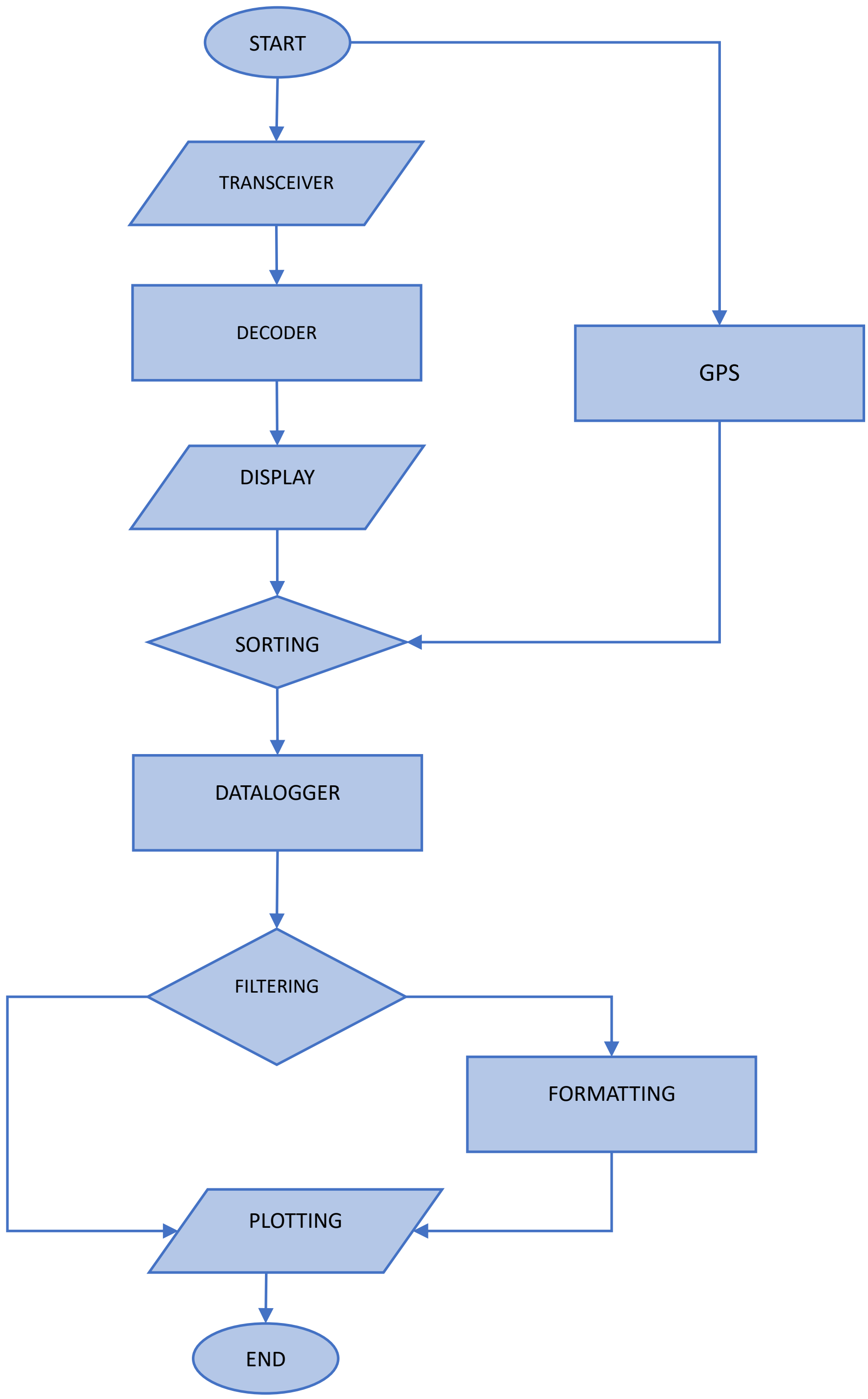
Some features of the Raspberry pi are as follows:

FEATURE	DETAILS
Microprocessor	Raspberry Pi boards feature a microprocessor for processing tasks.
Memory (RAM)	The boards have RAM for temporary storage of data during program execution.
Input/Output (I/O) Ports	Raspberry Pi boards have various I/O ports for connecting peripherals and external devices.
Power	They include a power supply to provide electrical power to the board.
Operating System	Raspberry Pi boards can run different operating systems, such as Raspberry Pi OS and others.

2.2.7 NEO 6M GPS

GPS, which stands for Global Positioning System, is a satellite-based navigation system that provides precise positioning, navigation, and timing information to users worldwide. The "NEO-6M" is a popular GPS module commonly used in various applications for obtaining accurate positioning and timing information. The production of the GPS module is carried out by u-blox, a Swiss company that specializes in the development of GPS and wireless communication technologies. The NEO-6M module establishes communication with a microcontroller or computer via a serial communication interface. Through this interface, it transmits GPS data, including latitude, longitude, altitude, velocity, and satellite information. This enables the connected device to accurately determine its location and track its movement.

2.3 FLOWCHART



2.4 ALGORITHM

Step 1: Start

Step 2: Frequency modulated signal of 144.5 MHz is received via Transceiver.

Step 3: The data we received is decoded by using the Tinytrack4 decoder.

Step 4: The decoded data will be displayed through the monitor.

Step 5: The required data will be sorted out.

Step 6: The sorted data will be saved as .csv or .txt file format.

Step 7: From the sorted data, the two required data for plotting is filtered out.

Step 8: If filtered data is in correct format, step 10 happens, else step 9.

Step 9: If filtered data is not in a correct format, formatting takes place.

Step 10: Plotting the map using latitude and longitude.

Step 11: End

2.5 GUI and MI DESIGNING

Graphic User Interface or GUI is a user interface that helps the user to interact with various electronic devices with the usage of various graphical elements. These graphical elements may include various icons, buttons, windows instead of text-based commands. The discovery of the first GUI was on 1981 at Xerox PARC by Alan Kay, Douglas Engelbart and other various brilliant minds which revolutionized the field of technology. The major components of a GUI include:

1. **WINDOWS:** The helps primarily to display information or any other applications on a display. We can open, close, resize and in modern technology we can even use multiple windows at a time.
2. **ICONS:** These are small graphical representations that basically gives a visual shortcut to access different functions quickly. They can represent different files, folders, applications or actions.
3. **MENUS**: Users can choose from a list of options or commands on menus to carry out particular operations. They are frequently accessed through a context menu or drop-down menu.
4. **BUTTONS**: Users can click or tap buttons to initiate specified actions or operations. Buttons are interactive elements.
5. **DIALOGUE BOXES**: These unique windows pop up to request input from users or to present messages, alerts, or warnings.
6. **TEXT FIELDS**: Users can enter text, numbers, or other types of data in text fields.
7. **CHECKBOXES AND RADIO BUTTONS:** Users can select items from a list using checkboxes and radio buttons, which are graphic components.

In the development of a real time trajectory predictor to predict the path of the balloon using real time data during flight, GUI-Graphic User Interface plays an important role in the work because it pave a major way for the user to easily interact with the electronic devices integrated together for the current purpose.

Machine learning is a branch of artificial intelligence (AI) that focuses on creating statistical models and algorithms that let computers learn and get better at a given task without having to be explicitly programmed. Machine learning algorithms use patterns and data instead of being explicitly programmed to follow a set of rules to make predictions, take actions, or complete tasks.

The main goal of machine learning is to give computers the ability to learn from examples or experience in a similar way that people do. The following steps are often included in the process:

1. Data Collection: Gathering a substantial and representative dataset relevant to the activity at hand. This dataset consists of the output labels (targets) that correlate to the input data (features).
2. Data Preprocessing: Data cleaning and preparation for training is known as data preprocessing. This procedure may entail encoding categorical variables, resolving missing values, normalising or scaling features, or any combination of these.
3. Model training: It is the process of teaching a machine learning model using the prepared dataset. The model is a mathematical representation that derives the intended output by learning patterns and relationships from the input data.
4. Model evaluation: Analysing how well the trained model performs on a different dataset known as the validation or test set. This process aids in determining how well the model generalises to fresh, untested data.
5. Model tuning: It is the process of modifying the hyperparameters (settings) of a model to enhance its performance on the validation set. Cross-validation and other approaches are frequently used in this procedure.
6. Model Deployment: Once the model is deemed satisfactory, it can be deployed to make predictions or decisions on new, real-world data.

There are three general categories can be used to classify machine learning:

1. Supervised Learning: The model is trained on a labelled dataset in supervised learning, where the input data is coupled with the appropriate output labels. The model must learn the relationship between inputs and outputs in order to be able to predict fresh data with accuracy.
2. Unsupervised Learning: The model is trained on an unlabelled dataset in unsupervised learning, and it must independently identify patterns and correlations in the data. Common unsupervised learning tasks include dimensionality reduction and clustering.
3. Reinforcement Learning: In reinforcement learning, an agent discovers how to make choices in a setting in order to accomplish a particular objective. Reward or punishment feedback is sent to the agent, allowing it to learn from its deeds and gradually improve its decision-making.

There are various uses for machine learning, including speech and picture recognition, natural language processing, recommendation engines, self-driving cars, fraud detection, and many more. It is a rapidly developing field with a lasting influence on many different businesses and technology.

3. HAB TRAJECTORY PREDICTION: MODELS AND PHYSICAL PARAMETERS

3.1 TRAJECTORY PREDICTION MODELS

There are different mathematical models that can be used for balloon trajectory predictions. These include wind, geometry, thermal dynamics, atmospheric, earth and exhaust models. Before going further several assumptions are to be made. They are

- The balloon is considered as a point mass while the external forces acting on the balloon is taken into account.
- The horizontal component of the balloon's speed is considered to be equal to the horizontal components of the wind's speed
- The high-altitude wind speed magnitude and direction are assumed to be constant for at least 24 h.

3.1.1 WIND MODEL

As there is an increase in the altitude, there occurs a change in the wind speed's magnitude and direction. Wind directions can be classified as latitude wind and longitude wind where for the latitude wind, the wind blowing from the west is positive and for longitude, the wind from south is positive. Here we use the sum of sines models. The wind data after processing it is curve fitted with a serious of continuous curves by this sum of sines model

$$y = \Sigma_{i=1}^{n} a_i * \sin(b_i * x + c_i)$$

Where a – amplitude

b – frequency
c – the phase constant for each sine wave term
n is the number of terms in the series, and 1≤n≤8

3.1.2 GEOMETRY MODEL

The geometric equations are

1. Diameter from the top view:

$$(4/3)\, \pi * Radius^3 = Volume$$

i.e $$Diameter = 1.383 * Volume^{1/3}$$

2. Projected area from the top view:

$$A_{top} = \pi * Radius^2$$
$$A_{top} = (\pi/4) * Diameter^2$$

3. The illuminated projected area (that varies with the solar elevation angle during the balloon flight process):

$$A_{projected} = A_{top} * (0.9125 + 0.0875 * cos\,(\pi - 2 * h))$$

4. Surface area of the balloon:

$$A_{surf} = 4\pi * Radius^2$$

i.e $$A_{surf} \approx 4.94 * Volume^{2/3}$$

5. When the balloon is not fully inflated, the surface of the balloon is presented in crenelated form. The maximum crenelated surface area is defined as follows:

$$A_{surf1} = 4.94 * Volume_{design}^{2/3} * (1 - cos(\pi * L_{goreB} / L_{goreDesign}))$$

6. To better approximate a realistic situation for convection and film mass calculations, $A_{effective}$ is used to describe the effective exposed surface area:

$$A_{effective} = 0.65 * A_{surf} + 0.35 * A_{surf}$$

7. The average pressure difference between the internal helium pressure and the surrounding atmospheric pressure is defined as

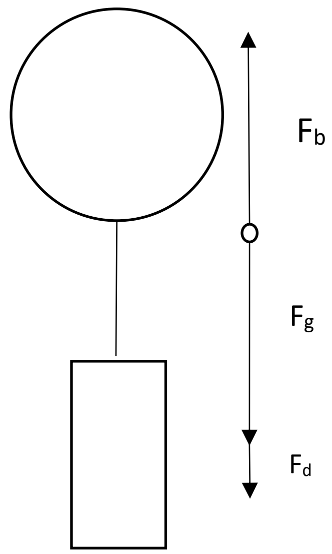
$$\Delta P = 0.517 * g * (\rho_{air} - \rho_{helium}) * Volume^{1/3}$$

Furthermore, based on the ideal gas law, the balloon's volume can be formulated as

$$Volume = \frac{m_{helium} * R_{helium} * T_{helium}}{P_{helium}}$$

$$P_{helium} = P_{air} + \Delta P$$

where Volume = $Volume_{balloon} = Volume_{helium}$, R_{helium} stands for the helium gas constant, T_{helium} represents helium temperature, P_{helium} refers to helium pressure, and P_{air} is the surrounding atmosphere pressure.



3.1.3 DYNAMIC MODEL

The motion of the balloon is divided into two as vertical motion and horizontal motion. Vertical direction is associated with the ascent module and descent module.

The ascent speed depends on the amount of gas that is used to provide lift. From figure, the balance of forces on ascent is

$$F_b + F_g + F_d = 0$$

Where,

1. Fb is the Buoyancy force given by,

$$Fb = (N * MHe - N * Mair) * g$$

with N is number of atoms of helium added to the balloon MHe is the mass of helium

$Mair$ is the mean mass of air

g is gravity

2. Fg is the weight of the payload train and the balloon:

$$Fg = (Mb + Mp) * g$$

With Mb is mass of balloon

Mp is mass of payload train

3. Fg is the drag force:

$$Fd = 0.5 * Ab * Cdb * \rho * Ua2$$

With Ab is projected area of balloon

Cdb is the drag coefficient of balloon

ρ is mass density of air

Ua is the ascent speed

Thus, the ascent speed is found using the equation,

The descent module works through a force balance equation. In this case the terminal velocity U_d is given by

$$U_d = \sqrt{\frac{2gM_p}{A_pC_{dp}\rho}}$$

Where the C_{dp} is the drag coefficient of the parachute and Ap is the area of the parachute

3.1.3 EXHAUST MODEL

3.1.3.1 AUTOMATIC EXHAUST MODEL

The balloon ascending process includes two phases: first is balloon partially expanded and the second is balloon fully expanded. The automatic exhaust process allows the balloon to expand to its designed volume, preventing it from exploding, resulting in helium mass loss. Then the helium loss is calculated to be

$$\frac{dm_{helium}}{dt} = -\rho_{helium} * \frac{Volume_{altitude} - Volume_{design}}{dt}$$

where ρ_{helium} stands for the density of the helium, and $Volume_{altitude}$ is the balloon volume with the corresponding altitude.

3.1.3.2 ACTIVE EXHAUST MODEL

The active exhaust process (a helium exhaust valve installed at the apex of the balloon can be opened to exhaust helium) is necessary for the balloon flight system to descend due to realistic flight mission requirements and emergencies. Then that helium loss is given by,

$$\frac{dm_{helium}}{dt} = -\rho_{helium} * c * A * \sqrt{\frac{2 * \Delta P}{\rho_{helium}}}$$

$$U_a = \sqrt{\frac{2g(N(M_O - M_{He}) - (M_b + M_p))}{A_b C_{db} \rho}}$$

3.2 REAL-TIME HAB TRAJECTORY PREDICTOR

High-altitude balloons experiment is an inevitable factor in the field of atmospheric studies. It is the most convenient method both in personal and scientific study purposes. After the flight, reaching a certain height the balloon will burst and the payload will descent with the use of attached parachute. For a complete and successful balloon launch, retrieving the payload is an important job. For that purpose, predicting the balloon trajectory is significant. There are many flights path and trajectory predictors available in the present day. They use the different data like the wind speed, humidity, temperature etc that affect the trajectory of balloon and use them to predict the path. But the difference of such predictors from this project is that we use the real time data from the sensors to predict the path on-time.

In the traditional method scientist predict the high-altitude balloon trajectory pre-launch using the already existing data set. The problem existing while following the traditional method is that 'the atmosphere is constantly changing'. The atmosphere is a dynamic system influenced by various factors such as weather patterns, temperature variations, air currents, and the presence of gases and particles. These factors cause continuous fluctuations in atmospheric conditions, including variations in temperature, humidity, wind speed, and air pressure. Thus, we can conclude atmosphere is complex and is ever-changing. So even though we pre-predict, the landing site may change from the already predicted site. That is why the new idea of predicting the balloon path with real time data makes relevance.

The payload is a equipment used in the balloon experiment usually used for the atmospheric measurements, photographic purposes, data collections during the balloon flight. It may consist of sensors, cameras, data loggers, GPS receivers, communication systems, and other scientific instruments. These instruments are securely attached to the balloon platform and protected with appropriate casings or enclosures to ensure their safety during the ascent, descent, and flight. These sensors include humidity and temperature sensors. So the required data like the altitude, latitude, longitude along with the humidity, temperature are extracted from the payload sensors.

The real time trajectory predictor is an integrated work of both the physical components and the graphical user interface with the help of machine learning. Data fed to the system is studied and analysed by the software, which later predicts the landing site of the balloon by its own.

4. HIGH-ALTITUDE BALLOON AND THEIR FLIGHT REQUIREMNETS

4.1 BALLOON DETAILS

The core factor to be considered for the high-altitude balloon experiment is the type of balloon used. The details of the balloon used are as follows:

- Dimensions of the Balloons:

Balloon type (kg)	Balloon condition	Volume (m^3)	Diameter (m)	Weight (kg)
2	Inflated	2.45	2.05	2.45
2	Deflated	nil	1.65	2

- Payload Weight : 2.2 kg + 1.9 kg + 2.45 kg (balloon weight)
- Maximum Altitude : 35-40 km
- Duration of flight : 2-6 hours
- Trajectory and rate of ascent : Expected to rise straight up in the sky at rate of 3.53-8.08 m/s
- Maximum lateral extent of balloon: 60-80 km (due to wind drift)
- Colour of the balloon : White latex
- Gas used for filling : Hydrogen

4.2 FLIGHT REQUIREMENTS AND PRE LAUNCH PREPARATIONS

I. PERMISSIONS REQUIRED – NOTAM (Notice to Airmen)

1. MOD (ministry of defence) permission
2. DCA-AAI (Director of Civil Aviation - Airport Authorities of India) Permission
3. NOTAM

II. PRELAUNCH PREPARATIONS

The activities included in the prelaunch preparations are as follows:

a. Testing the Radio – Purchase 'Dura cell AA size' batteries

Check the following Activities And the activity status is marked.

1 Antenna on the payload box
2 Longevity test-6-8 hours
3 LOS operational readiness test
4 Test the mobile decoder
5 Test Kenwood transceiver
6 Test the batteries for Kenwood transceiver
7 Test interchangeable antennas

b. Test batteries

Checking the following (Activities). Make sure they work. And the activity status is marked.

1 Charge and test all the Li-Po Batteries
2 Insulate and check the performance
3 Operate for 6-8 hours (Charge/discharge)
4 Total number of batteries needed

c. Test FTUs

1 Prepare new plastic boxes
2 Check the timer
3 Solder new Nichrome wire

d. Test Cameras

1 Test the performance
2 Integrate with other subsystems
3 Test after mounting in the box

e. Test data loggers

1 Prepare the data loggers
2 Check the storage

f. Test Payloads

1 Prepare new plastic boxes (Geiger-Muller Counter)
2 Check the timer (Particulate matter counter)
3 (Temperature and pressure sensors)
4 Charge the batteries and test the performance (IMU)
5 Not ready (CO2 Sensor)

g. Test ground station equipment at the launching site

1 Test the ground station antenna
2 Cable and connector to amplifier
3 Check the dipoles and the special connector

Then follows the following steps:

i. H2 Gas

1 Check and ensure the condition of cylinders
2 Check and test regulator

3 Order 4 cylinders (minimum)

ii. Balloon trajectory prediction
iii. Weather report
iv. Arrange Gate pass
v. Permission CREST
vi. Accommodation
vii. 7.checklist
viii. 8.inform outreach team
ix. launch
x. the launch
xi. the payload recovery
xii. prepare launch report and results

5.RESULT AND ANALYSIS

The major objective of the project is the creation of the graphic user interface followed by the development of the software for the real time trajectory prediction of high-altitude balloon. Based on the studies the following are the results to be discussed. First of all, the important parts of the ground systems are integrated together. The requirement of a python code in the data logger for saving incoming sensor data into a csv file is fulfilled. Then the data comparison plots are created. The GUI shows the post predicted flight path information. Their comparisons and their improvement in two different cases are analysed and improvements are taken into account.

Figure: components of ground segment

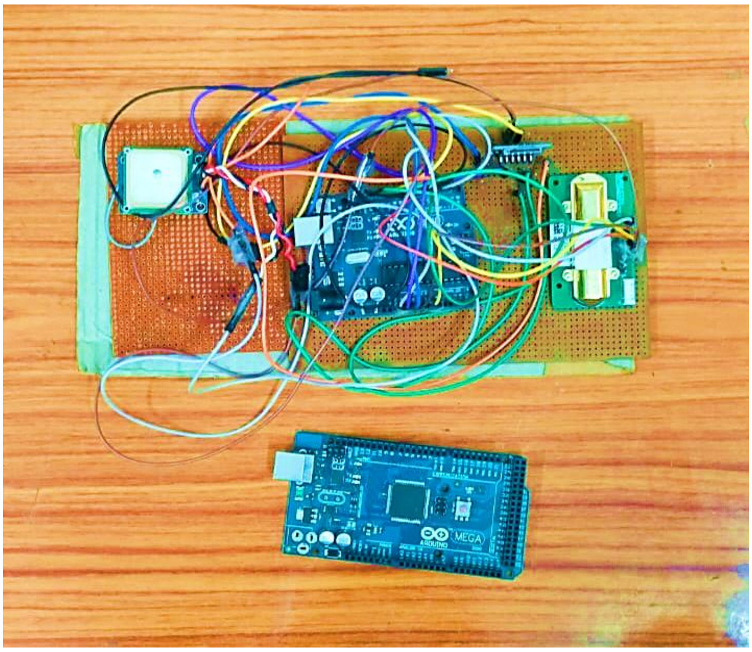
INTEGRATING DEVICES:

Integrating the important devices in the ground segment together is completed in order to enable communication, interaction, and interoperability between those devices. It is a chief step in the project.

DATALOGGER AND SAVING DATA:

The data from the sensors are decoded and it is saved in the datalogger in the .txt or .csv format. There arrives a requirement of a python code for saving the decoded data into the respective format with Arduino. So developed a Python Code to Read Serial Data from Arduino (Appendix 1)

Figure: Byonics Tiny Trak4 Datalogger and Arduino module



GUI DEVELOPMENT:

There data coming from the balloons include latitude, longitude, altitude, temperature, pressure etc. so the latter three quantities are plotted against time and are displayed. The major part of the project is the trajectory predictor working real time. First for a few times interval the data points are fed to the predictor system. With the implementation of the technology of machine learning, the code predicts the landing location of the balloon

DATA COMPARISON:

To discover the closeness and compatibility of the real time trajectory predictor two case studies are worked out.
CASE 1: The required data of a balloon flight from January 2023 is taken for the purpose. The pre-launch flight predictions of the current flight is plotted. Then the actual path of the balloon trajectory is studied with pre predicted path to compare. the error is noted. After that the trajectory prediction with the real time trajectory predictor is carried out and the error of this from the actual path is analysed.

CASE 2:The required data of a balloon flight from march 2023 is collected and the above mentioned comparisons are carried out with the improvised code. Error calculations are done. Later the CASE 1 and CASE 2 are studied together.

6.CONCLUSION AND FUTURE WORKS

6.1 CONCLUSION

The creation of a graphic user interface and prediction of the high altitude balloon experiment on real time is developed is done. Studies on the compatibility of the predictor was checked with two case studies using already existed data from January 2023 and March 2023. From the studies and analysis it is seen that

- it showed much accuracy of the path and the landing site from the pre-prediction path.
- But it predicted almost the landing site of the balloon in the first case 1 study with an error of
- The second analysis case 2 was done using an improved predictor code.
- improvement in the trajectory prediction is observed.

6.2 FUTURE WORKS

In coming days, with the approval of higher authorities, we intend to perform actual flights soon. This will allow us to collect additional data and examine the work more. Planning to do the following;

- Due to the lack of provide time, couldn't work this out on an actual flight. So before head test the predictor on a tethered flight.
- Make it Work in actual launch.
- To self designing an OS to work on the ground segment.

- Currently plotting is shown as a two dimensional map. Later to change the above scenario to a three dimensional plotting.
- Extend the trajectory prediction capabilities in the case of other aerial vehicles UAV, drowns etc.

APPENDIX 1

```
#Develop Python Code to Read Serial Data from Arduino

import serial
import csv

arduino_port = "/dev/cu.usbmodem14201" #serial port of Arduino
baud = 9600 #arduino uno runs at 9600 baud
fileName="analog-data.csv" #name of the CSV file generated


ser = serial.Serial(arduino_port, baud)
print("Connected to Arduino port:" + arduino_port)
file = open(fileName, "a")
print("Created file")


#Create an Arduino Data Logger: Send Serial Data into a CSV File

#display the data to the terminal
getData=ser.readline()
dataString = getData.decode('utf-8')
data=dataString[0:][:-2]
print(data)

readings = data.split(",")
print(readings)

sensor_data.append(readings)
print(sensor_data)

samples = 3 #how many samples to collect
print_labels = False
line = 0 #start at 0 because our header is 0 (not real data)
sensor_data = [] #store data

# collect the samples
while line <= samples:
    getData=ser.readline()
    dataString = getData.decode('utf-8')
    data=dataString[0:][:-2]
    print(data)

    readings = data.split(",")
    print(readings)
```

```
    sensor_data.append(readings)
    print(sensor_data)

    line = line+1


#Add the Arduino Serial Data to a CSV File
#
#Create the CSV
with open(fileName, 'w', encoding='UTF8', newline='') as f:
    writer = csv.writer(f)
    writer.writerows(sensor_data)

print("Data collection complete!")
file.close()
```

APPENDIX 2

```
import tkinter as tk
from matplotlib.backends.backend_tkagg import FigureCanvasTkAgg
import matplotlib.pyplot as plt

# Define the data for the charts
x = [1, 2, 3, 4, 5]
y1 = [1, 4, 9, 16, 25]
y2 = [1, 3, 5, 7, 9]
y3 = [2, 4, 6, 8, 10]

# Create the main tkinter window
root = tk.Tk()
root.geometry("800x500")

# Create the figure and subplots
fig, (ax1, ax2, ax3) = plt.subplots(1, 3, figsize=(8, 4), dpi=100)

# Plot the data on the subplots
ax1.plot(x, y1)
ax1.set_title("Chart 1")
ax2.plot(x, y2)
ax2.set_title("Chart 2")
ax3.plot(x, y3)
ax3.set_title("Chart 3")

# Create a canvas for the figure and add it to the main window
canvas = FigureCanvasTkAgg(fig, master=root)
canvas.draw()
canvas.get_tk_widget().pack(side=tk.TOP, fill=tk.BOTH, expand=1)

# Start the tkinter event loop
root.mainloop()
```

APPENDIX 3

```
import folium

with open('data.txt', 'r') as file:
   coordinates = [line.strip().split(',') for line in file]

mymap = folium.Map(location=[float(coordinates[0][0]), float(coordinates[0][1])],
zoom_start=13)
for coordinate in coordinates:
   latitude, longitude = map(float, coordinate)

   html = f"""
      <div style="white-space: nowrap; font-weight: bold; text-align: center; font-size: 10px;
color: red;">
         Latitude: {latitude}, Longitude: {longitude}
      </div>
   """
   folium.Marker(location=[latitude, longitude], popup=html).add_to(mymap)

locations = [[float(lat), float(lon)] for lat, lon in coordinates]

folium.PolyLine(locations=locations, color='blue').add_to(mymap)

mymap.save("mymap.html")
```

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