MARS SOCIETY SOUTH ASIA

INTERNATIONAL PLANETARY AERIAL SYSTEMS CHALLENGE

GARUDA

DRISHTI

A Revolutionary Concept

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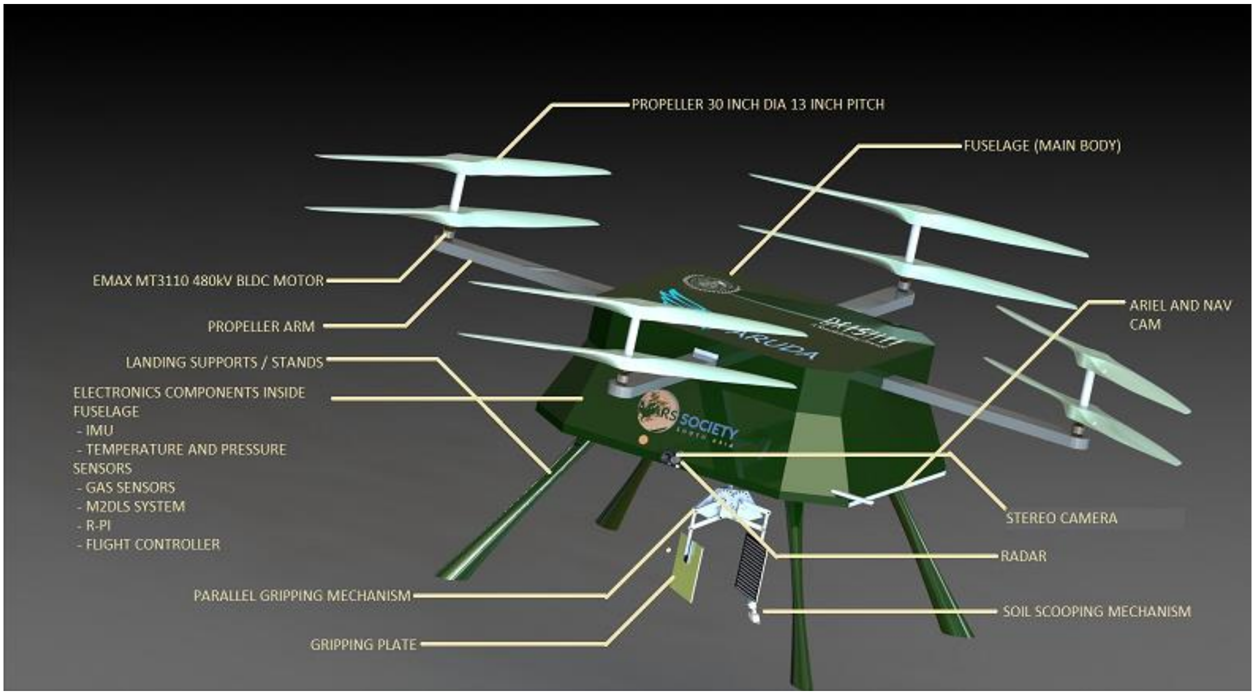
ISOMETRIC IMAGE OF UAV



Introduction

Mars exploration is one of the most popular areas of research. In our project the Mars UAV, which is a technology demonstration to test powered, controlled flight and performed tasks on another world. The design of this UAV with the possibility to use for transfer payloads, process images and collect soil sample will give higher mission productivity. Future space exploration requires close study of extra-terrestrial bodies such as Mars.

Report Description

The following EDR focuses on giving a brief outline of the different technologies implemented to design the mars UAV. This project will present preliminary studies for the conceptual design of the Mars UAV. Furthermore, it will summaries the steps required for the UAV sub-system architecture and systems engineering. The report also gives a brief description of the design process and in addition to that various reasons are mentioned to implement a particular idea owing to different constraints. It aims to be a guide for future research work

Contents

1.Types of UAV Designs:

- Fixed-wing aircraft
- Tilt wing
- Quadcopter
- Tricopter
- Bicopter
- Hexacopter

1.1 Fixed-wing:

After analyzing the Martian atmosphere and its properties, we decided "Not to use Wing included aircrafts" because the atmospheric density on Mars is too low that is around 0.02 kg/m3 which is 64 times lesser than here on Earth because of this reason the lift generated by wings or the moments generated by control surfaces will be very low or if we want a desired lifts and moments the control surfaces will be very large which is structurally inefficient.

Fl =Cl*ρV2A/2 (where 'ρ' is atmospheric density)

And when comes to hovering which is a crucial part of the UAV the wing included aircraft's performance is behind the copters.

So, after analyzing these points we decided to disclude "Fixed-wing & Tilt-wing" aircraft which have the same disadvantages over there on martian conditions.

Now the remaining are copters: Bicopter, Tricopter, Quadcopter, Hexacopter.

1.2 Bicopter:

Bicopters are unstable in the Longitudinal direction i.e in the direction of the fuselage, we can solve this by opting for a swashplate mechanism as the control of rotors but it would complex the system, and also the blade diameter will increase to achieve the same thrust as in other copters which have the problem of exceeding blade tip velocities greater than local Mach No. on Mars. Finally, Bicopter UAVs task performance is also quite lower than that of Quadcopters and Hexacopters so we discluded the Bicopter.

1.3 Tricopter:

Tricopters aren't much popular in the field of UAVs but it doesn't mean we shouldn't use them and we found out that their control system is difficult and have large chances of failure. We shouldn't take any chances of failure in this kind of project so we discluded it.

Finally, we are with the two efficient UAVs "Quadcopters" & "Hexacopters" now we need to decide which is the best possible UAV for Martian exploration.

1.4 Quadcopter:

Quadcopters are mostly used UAVs, they have better "*Controllability, Power Efficiency, Maneuverability, Ease of Payload packaging*" than the Hexacopters, due to their symmetricity quadcopters has a very good combination of Stability & Maneuverability than Hexacopters which are much stable and less maneuverable. But at this point, we did consider both of these and thought to evaluate them after the power requirements are made clear.

1.5 Hexacopter:

These 6 rotor aircrafts are bulkier and heavier but a bit more stable than Quadcopters in *"heavy winds"*. Winds on earth are strong and can be significant in affecting the flights. But on Mars, due to its very low atmospheric density, they won't impact significant momentum on the aircraft so we shouldn't choose on this point which makes little or no difference in the stability. Now when we consider the power consumption Hexacopters definitely take more power and can lift heavier payloads than Quadcopters but, the payload isn't much higher and the total external payload will be 105-115 gm (15cm×15cm×15cm box of 100gm & soil sample weighing 5gm). So the only factor remaining is the *power which is the most crucial thing of any extraterrestrial bots or vehicles* so the lesser the power usage the better vehicle.

Based on all these factors, we have decided to consider "Quadcopter" as the final design.

2. Types of Propulsion:

At some point, we did consider using a different propulsion system than using propellers and, in the process, we thought of "Electric propulsion" which has a high-power density but due to its early stages of development in the tech field and its high-power requirement to maintain large Voltages for ionization of propellent (Xe) we excluded it and came to propellers.

We chose to use stacked propellers than that of single prop-driven propulsion for our UAV because of its capability to generate more thrust than a single propeller and because of its ability to compactify the flow even more and, stacked propeller design is finalized.

$$Tt = 1.6667(Tu)$$

(Tt = Tu + Tl = total thrust, Tu & Tl are Thrust from upper and lower blades)

After estimating the total weight of the UAV, we did calculations on the diameter of the propeller required to produced desired thrust and came to the result of choosing 2 bladed 30" * 13 (30-inch diameter 13 pitch) propeller for our design. We opted for 2 bladed props because if we increase the number of blades in each propeller its angular velocity will be decreased which shouldn't happen because in this scenario to generate the required thrust the props should be driven at heavy RPMs and also the stresses at the center of the propeller will be very high due to high centrifugal forces generated by high speeds of the propeller. So, increasing no of blades will even increase this stress. So, we finalized a 2 bladed propeller to be used in the design.

3. Mechanisms:

After selecting the type of UAV, we started to work on the mechanical subsystem required to accomplish the tasks. i.e., "*Payload Picking", "Soil Sample collection".*

'*We started working on the selection of mechanisms for gripping and soil collection'.*

3.1 For Gripping Task - Use of Magnetic Strip:

At the initial stage, we thought we would consider attaching the magnetic strips to the payload and to the part of the fuselage where the payload is loaded. We rejected this idea because the Martian dust is comprised mainly of iron particles. These iron particles get attracted to the magnets, readily forming a layer around them which hinders the attachment of payload to the fuselage.

3.2 Electromagnet:

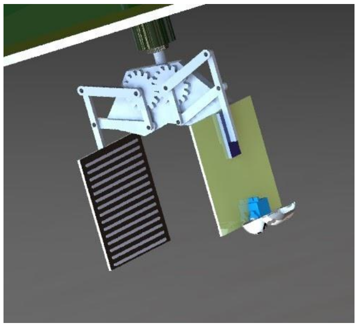
The problem in the above mechanism came with an alternative solution of using an electromagnet. The iron in the sand composition is now not readily attracted to the magnet, so we thought to attach this mechanism to our UAV. But the disadvantage of this mechanism is that it would consume more amount of power, which can affect flight time and efficiency, and also Martian dust is very fine and sticky to any surface, so again the mechanism is compromised because of the same reason.

3.3 Hook Mechanism:

The magnetic approach to lift payload had many impracticalities, so we shifted to find a more practical and more convenient mode of lifting like the hook. In this type, we need to attach a hook on the fuselage, which will connect with a prebuild construction on the payload shell. There is a disadvantage in this idea that we needed to construct an exterior structure on the payload or place the load on the preconstructed body. This approach restricts our possibility to lift variable payload, i.e., payload, without any preconstructed structure.

3.4 Parallel Gripper:

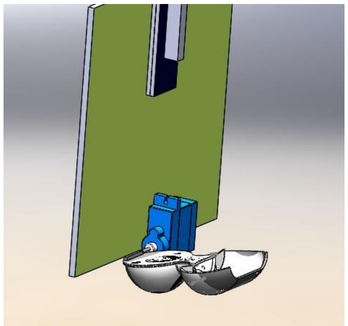
At last, we came to the most commonly used approach "*The gripper*". Herewith the construction of a parallel gripper, we were able to grab the payload with the help of just one motor. Thus, reducing the power consumption. Moreover, to increase the grip, we attached a rubber material at the surface of both plates to get a firm grip.



Gripping Mechanism

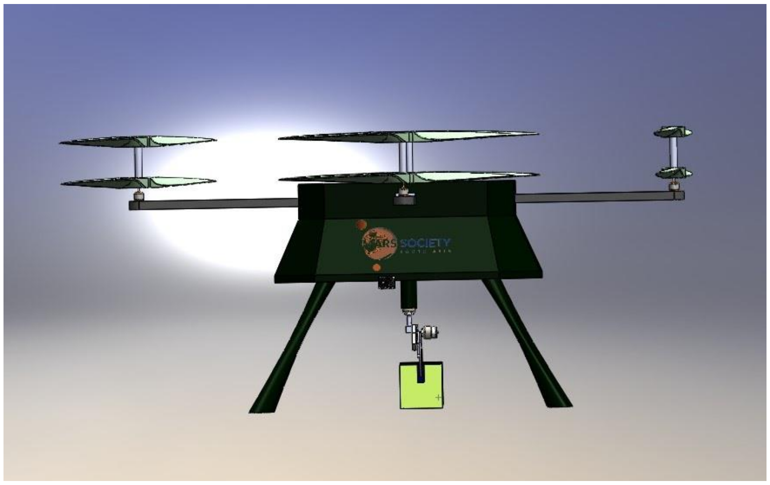
3.5 For Soil Collection-Scooping Mechanism:

For collection of the soil sample, we opted for a scooping mechanism because rest all the mechanism uses more power which is unnecessary for small(5gm) soil sample collection. In the mechanism, the scoop will rotate around the storage section and scopes through the soil, and stores the sample in the storage pot with the help of a servo motor. The plus point of this mechanism is that it consumes significantly less power and lighter than other mechanisms. Also, the scoop will act as a cover so that the atmospheric dust cannot enter the



Scooping Mechanism

soil sample to degrade it. The whole subsystem (Gripping + Scooping) is kept outside of the fuselage. If we keep it halfway through the fuselage, then Martian soil can enter the body of the UAV and can damage the onboard electronics, which can be a burden for the smooth flight. The main advantage is all the subsystems will be independent of each other's tasks.



Orthographic Side View

4.Design parameters:

4.1 Propeller design:

4.1.1 Basic idea:

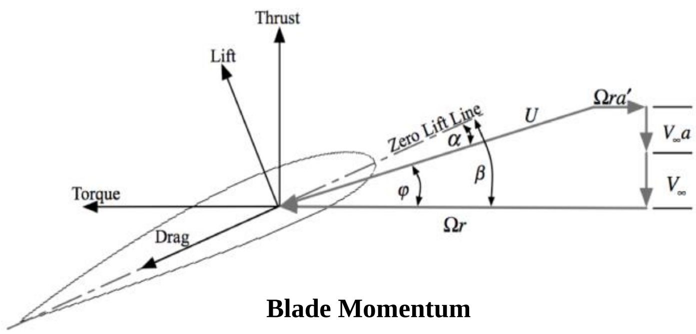
Since maximum power is needed to hover, it was decided to minimize the energy required to hover while still maintaining good forward flight performance. Weight and packaging considerations on the UAV indicate the size and thus constraining the rotor diameter to be as small as possible. Producing the required lift with a minimum rotor disc area necessitates a high tip speed, which becomes a relatively high tip Mach number condition in the Martian atmosphere. To keep the power required low, solidity must be minimized, and thus the blade loading must be increased. Added to these considerations is the unusual requirement of sizing the rotor so that blade Reynolds number can be maximized. The Martian atmosphere's low density makes the flight Reynolds number range one or two orders of magnitude below that encountered for helicopters on Earth.

The rotor design process began with an estimate of the maximum performance expected of airfoils in such a low Reynolds number environment. Very little is known about airfoil behavior below Reynolds numbers of 100,000, and even less about behavior at such Reynolds numbers and high subsonic Mach numbers. It was recognized that while relying on the airfoil sections to work to their extremes, the combination of these two difficult conditions would require conservative initial estimates.

4.1.2 Momentum analysis:

In the generalized momentum theory, several assumptions make it less reliable to extract flow parameters. For this purpose, Blade Element theory was proposed. The blade element theory uses the geometrical profile of the cross-section of the rotor to compute aerodynamic forces acting on the rotor. This results in a higher number of equations to solve for the Forces and Moments. The rotor twist distribution is also taken into consideration in the blade momentum theory.

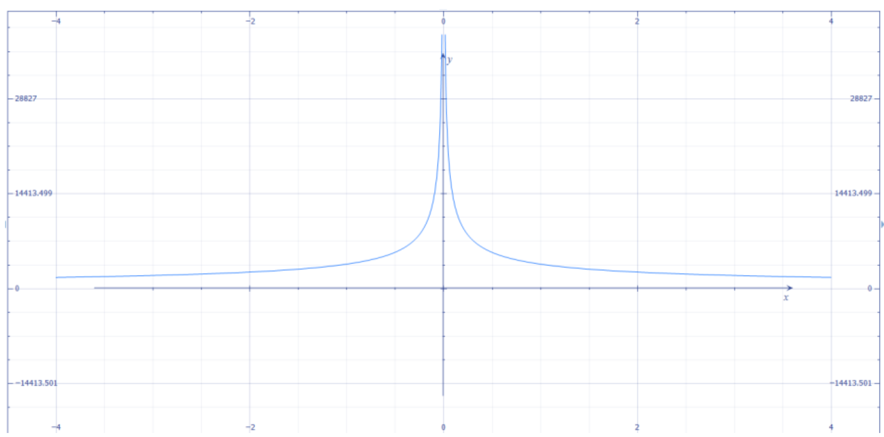
When dealing with the low Reynolds number flow, the boundary layer is assumed to be fully laminar up to the point at which it separates from the rotor surface. The subsequent turbulent flows are not observed until the end of separation; this is mainly because the separation point is delayed further towards the trailing edge when low Reynolds number and a low angle of attack is considered.



Blade Momentum

After selecting the rotor configuration and number of blades, the next step was to develop the planform. Since the Reynolds number at inboard stations would be very low regardless of the planform. The tip section might be suffering from tip loss effects. It was decided to carry the most lift and generate the highest Reynolds number and lift coefficient.

At first, *"Blade element theory"* was considered to design the propeller by considering the variation in aspect ratio, take in the angle of attack. Still, due to less available experimental data and errors and complexity in fixing the relation between terms, the blade was selected by using conventional methods. Using a coaxial propeller gives more thrust as the stream is more converged and gets momentum, and as there is less thrust generated by one rotor it is opted to use coaxial blades.



Diameter vs RPM

The lower blade gives 40% of the whole thrust while the upper blade gives 60% due to change in lift coefficients and Reynolds number. By optimizing tip velocity and angular speed, it is taken as a 30-inch propeller with a 13-inch pitch, which works at 0.8 Mach at 4800 rpm.

The distance between two coaxial propellers will be 0.05 times its diameter.

0.05d = 0.05*30 =1.5inches

4.2 Motor-Basic idea: *The output of the powerplant is used to run a DC electric motor.*

The advantages of DC motors over rotating field motors are, current increases linearly with load torque, thus higher efficiency may be expected over the operating range, and speed can be easily controlled by varying the supply voltage V.

The disadvantages are that they have a limited lifetime; there may be unreliable contact, especially at low voltages, there may be electric interference, and there may be additional noise.

4.2.1 Brushless Dc motor:

Solutions to the problem of driving a motor from a direct voltage supply without brushes are:

- combination of induction motor and constant frequency inverter
- combination of synchronous motor and constant frequency inverter
- a built-in electronic commutator in place of the conventional mechanical commutator

With constant inverter output frequency, the motor speed is almost constant, but the starting torque is small compared with the classical DC motor. In the higher power range, the combination of the inverter with the induction motor is generally satisfactory.

The angular velocity of the brushless DC motor can be adjusted by changing the supply voltage V. If only a constant direct voltage supply is available, reduction of speed can be achieved utilizing a series resistor which achieves voltage reduction at the motor by a voltage divider, a transistor or a DC chopper with its attendant low heat losses.

4.2.2 Selection of motor:

The motor is selected by considering the required kV. As rpm is 4800 and power output is 12 volt and considering torque generated due to drag and inertia and considering weight 480 kV motor is used for propelling coaxial blades, which is graded as lipo 4-6s which gives a max thrust of 1.620 kg. 480kV Brushless DC Motor for Multirotor equips the high-quality bearings to ensure the efficient and vibration-free operation and silicone steel for high-performance operation with low temperature. We are using EMAX:MT3110-480KV BLDC Motor for our system.

EMAX:MT3110-480KV

5.Material Selection:

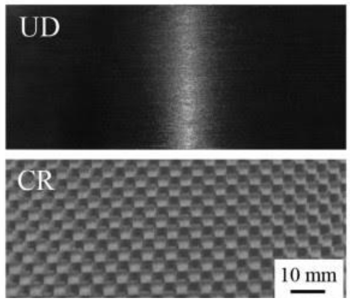
After deciding the power source and heating system, material selection for different parts of the UAV is made.

5.1 Carbon fiber reinforced plastics (CFRP):

In material selection for UAV, the most important factor is temperature because the temperature is low at Mars. At a low temperature, our material can fail, so for this reason, we go for carbon fiber reinforced plastics. This material has a low specific weight and high specific strength. For material, the most crucial property is fatigue failure, and 90% of failures occur due to fatigue failure, and CFRP has suitable fatigue property at low temperature (-196°C).

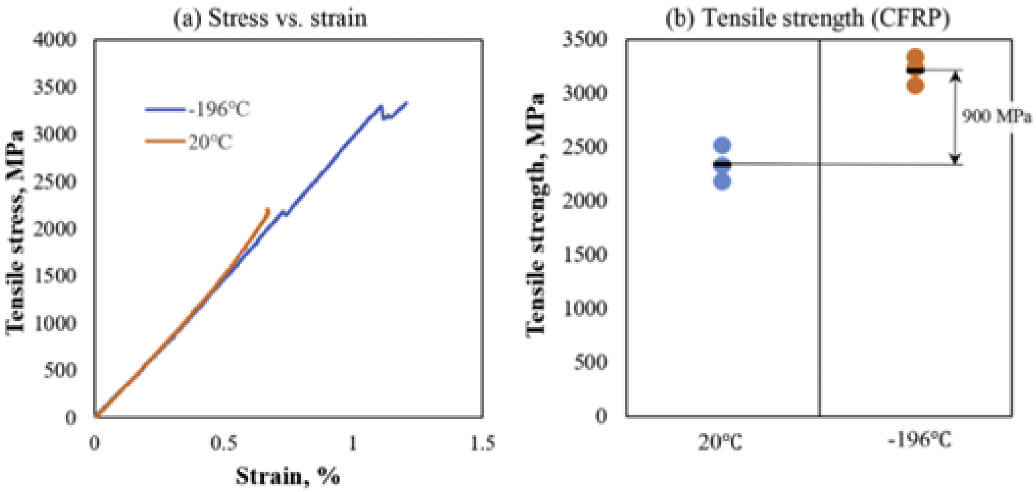
Two types of CFRPs have been manufactured using 3D printers today:

- Unidirectional (UD)
- Cross poly (CR)



Unidirectional (UD) & Cross Poly (CR)

The bending strength of the UD-CFRP was approximately twice that of the CR CFRP. The higher bending strength of the UD-CFRP is directly attributed to the more significant proportion of carbon fiber oriented along the loading direction (60% for UD-CFRP vs. 30% for CR-CFRP). The low temperature (-196 °C) tensile and fatigue strengths of the UD CFRP were more than 1.5 times greater than those at 20 °C.



(a) Representative stress–strain curves and (b) the ultimate tensile strengths of the UD-CFRP at 20 and −196 °C.

Based on the above points, we decided to select UD-CFRP for UAV Frame rods, Fuselage, and the propeller, because of high RPMs, centrifugal stresses will be very high in the propeller in order to overcome them a material of high tensile strength and appreciable bending strengths are required which are satisfied by this material.

6. Power Source & Insulation system:

6.1 Power Source:

Considering the mission time of 10 mins per flight of the UAV on Mars, the power system is designed to be lightweight and have high energy storage capacity possible within the mentioned time. The system consists of two Power sources: Primary source (Li-Po Battery) and Secondary source (Supercapacitors).

6.1.1 Primary Source (Mechanical Systems): Li-Po (Lithium-Polymer) Battery

Due to a shorter mission time, varying temperature ranges, and payload mass constraints, lithium-polymer, is preferred over other batteries as they are one of the compact and lightweight sources of power.

We will be using the ORANGE 8000mAh 4 cell lithium polymer battery pack, it can minimize resistance, sustain high current loads and these batteries also have good temperature control after high-rate discharge.

Li-Po Battery

Specifications:
1) **Output Voltage:** 14.8V
2) **Rate:** Charge - 5C   Discharge - 40C

6.1.2 Secondary Source (Electronics System): Supercapacitors

The Supercapacitor, also known as ultracapacitor or double-layer capacitor, differs from a regular capacitor. A Supercapacitor stores charge 1000 times higher than an electrolytic capacitor. The Supercapacitor undergoes frequent charge and discharge cycles at high current in a short duration. We will be using 10 "XT3585-3R0567-R" Supercapacitors which have an operating voltage of 3V each.

Supercapacitor

6.2 Insulation System:

The environment on Mars is well known for its low temperature. A typical Martian day temperature is from –90 at night to –20 at daytime. This places a strict constraint on various components of the UAV. As with previous Mars missions, a warm central core is required for the battery and other major electronics. Beyond this essential temperature-controlled inner, most vehicles can sustain operation at these typical Mars temperatures.

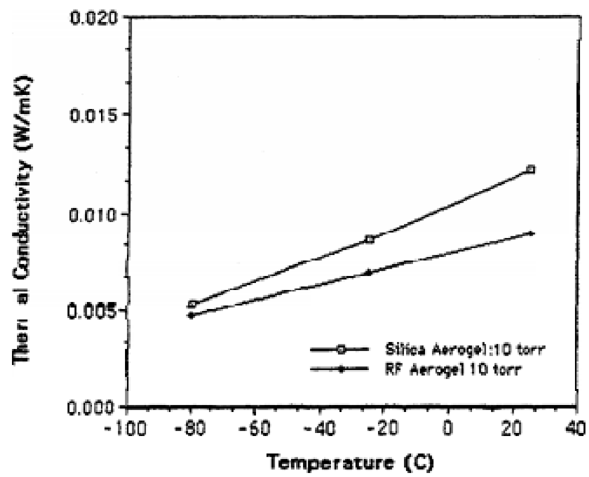
6.2.1 Insulation material:

1) Foam insulations are advantageous for many applications. They are inexpensive, easy to handle and machine, and provide moderate insulative properties in environments with atmospheres. The disadvantage is that they tend to be bulky and lose their integrity at very low densities. They can be utilized in structures with minimal difficulty. The primary mode of heat transfer is conduction.

2) Fibrous insulations have advantages over foam insulation in that they can be obtained in lower densities. Still, they cannot support mechanical loads, so additional structures must be built around them. The modes of heat transfer of fibrous insulation are conduction, convection, and radiation.

There is a small effect on density of the material, but there is also an effect of pressure on the thermal conductivity of the fibrous insulation.

3) The Third type of material that is being used for insulation for Mars missions is aerogel. It has the advantage that it is very lightweight and has low conductivity. The use of aerogel for thermal control on Mars considers the thermal transport limitations for the transition between the continuum and free molecular regime. The effective thermal conductance of an aerogel insulation system consists of two components, the solid conductance-radiative component, and the convective component. Gas conductance depends on the mobility inside the voids of a material. It is governed by the relative dimensions and connectivity of the open volume and the gas mean free path. Solid aerogel has pore dimensions of 6 to 11 nanometers. This means that the effective gas conduction within the aerogel is a fraction of value in the continuum regime and is dominated by the conductive-radiative component of the silica aerogel structure.



Aerogel

Because of the high void fraction and low-density aerogels' resulting in low mechanical properties, a lightweight supporting structure has to be designed and integrated into the thermal control. This basic integrated structure and thermal insulation design became the basis for the Sojourner Rover, the payload for the Pathfinder mission.

Hot CO2 gas is used to trap the heat with the inner avionics to make sure components remain at a specific suitable temperature during cold nights. The battery heat is also used effectively by using this CO2 inside the fuselage.

7. Communication System

We will be using the **Mini-Micro Datalink system** for our UAV's communication. It uses SDR (Software-defined Radio communication) technology that implements any necessary cryptography, forward error correction coding & source coding of voice, video, or data in software.

Mini-Micro Datalink Module

7.1 Advantages

- Lightweight, Small in size
- Embedded Encryption
- High Data rate and Full duplex
- Beyond Line-of-sight capabilities
- Low Power Consumption

7.2 System Parameters:

Frequency Band	S-Band: 2-4 GHz C Band: 4-8 GHz
Data Rate	Up to 16 Mbps
Transmission Power	250mW - 1W

This system has two terminals, i.e., Platform Data Terminal (placed on UAV) & Ground Data Terminal (placed at Base station).

Platform Data Terminal

Range	10km
Weight	450g
Power Supply	9-36 V

Ground Data Terminal

Mechanical Dimension	61*52*20 mm
Weight	60 g
Power Consumption	10 - 12W

Dust Storms are pretty common on Mars. Dust particles can cause attenuation of radio waves through the scattering and absorption by particles. However, it is expected that Martian dust storms will have relatively small attenuation effects on radio wave propagation because of the small dust particle sizes. At worst, Martian dust storms could have a 3-dB attenuation at Ka-band.

8. Electronic Subsystems:

8.1 Sensors and Components:

The following tables lists all the sensors and components which will be used onboard the UAV along with their power requirements.

Component	Name	Quantity	Function	Current	Voltage	Power
IMU	BMI 270	1	Acceleration, attitude, relative X and Y positions	685uA	3.6V	2.466mW
Temperature sensor	HTU 31 series	1	Measure Humidity and Temperature	0.78mA	5.5V	4.29mW
Pressure sensor	Protonic Microtechnik sensor	1	Measuring the pressure difference	750uA	5.5V	4.125mW

Stereo Camera	Arducam 2MP Global shutter Stereo camera	4	360° vision and obstacle avoidance	<25uA	3.3V	380mW
Aerial Imaging Cam	Lt-C3200B Board Level Camera	1	Ortho-photography	600mA	5V	3W
Nav Cam	PX4FLOW Optical flow Sensor	1	Measuring the velocity	115mA	5V	575mW
Gas sensor (CO, NO2, H2, NH3)	MiCS - 6814 MOS Sensor	1	Detect CO, NO2, H2, NH3	32mA	2.4V	76mW
Gas Sensor (Ozone, O3)	MQ 131	1	Detect O3(Ozone)	180mA	5V	900mW
Gas Sensor(O2)	Gravity: I2C oxygen sensor SEN0322	1	Detect O2	200mA	5.5V	1.1W
Gas Sensor (CO2)	MG 811	1	Detect CO2	200mA	6V	1200mW
Spectrometer	APXS	1	Soil collection aid	300mA	~5V	1.5W
Communication system	COMMTACT M2DLS	1	Communication	~2A	~5V	10W
R-pi	Raspberry Pi 4 Model B	1	Microprocessor	3.0A	5.1V	15W
RADAR	AWR1642	1	To map the environment - total 360 degree (in obstacle detection)	1.3A	2V	2.6W
Altitude sensor	TF-miniLidar	1	Measure altitude (Z-position)	120mA	5V	0.6W
Controller	i.MX RT1176	1	Microcontroller	1.2A	2.5V	3W

8.2 UAV Cameras:

The following provides the list of cameras along with their specifications used in the UAV. We have used a total of six cameras to gather the necessary information about the surrounding terrain for seamless automatic or manual traversal. The Stereo Camera is used for obstacle avoidance, the Nav-Cam is utilized for Localization, and the Aerial Imaging Cam is used for the Reconnaissance Mission.

Specification	**Aerial Imaging Cam** (Lt-C3200B Board Level Camera)	**Nav-Cam** (PX4flow v1.3.1)	**Stereo Camera** (Arducam 2MP Stereo Camera, with dual OV2311 Monochrome Global Shutter)
Fixed Aperture	f/3	f/16	f/2.9
Fixed Focal Length	~20 mm	~2mm	2.8 mm
Hyperfocal distance	~4.5 m	~0.01 m	0.06m
Diagonal FOV	48.9°	106°	101°(D),83°(H)
Angle of view	40° x 28°	86° x 62°	77°x 66°
Depth of field	2.3 m - ∞	0.005 m - ∞	0.03 m - ∞
Operating Temperature	0-50 °C	∞	-40 -105 °C
Wavelength Range	550-850 nm		
Power consumed	3W	575mW	380mW

8.2.1 Requirements:

Aerial Imaging Cam: The UAV will take multiple images from an optimum altitude that will cover an area of 300m². These images after ortho-rectification can be used for studying the terrain and topography of the Martian surface.

Stereo Cam: The primary task of the Stereo Cams is used to provide 360° vision to the UAV and further help in mapping surrounding environment and obstacle detection.

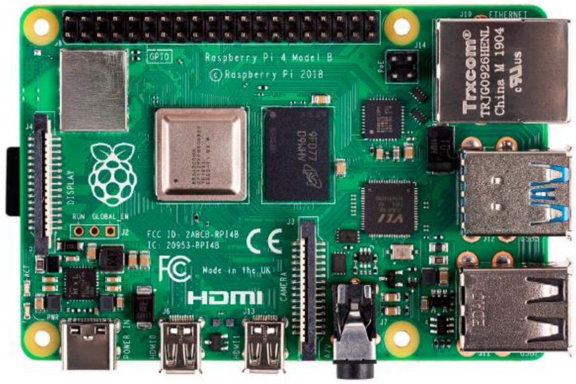
Nav-Cam: The Nav-Cam (Px4 Flow) is used to measure the velocity of the UAV by optical flow method. Further integrating velocity, relative x and y position can be calculated.

- **Optical flow method:** Lucas Kanade method is differential based technique for computation of optical flow, here we are dealing with high speed so we are using pyramid-LK algorithm, which start tracking from lowest detail of the image pyramid and gradually tracks to finer details.

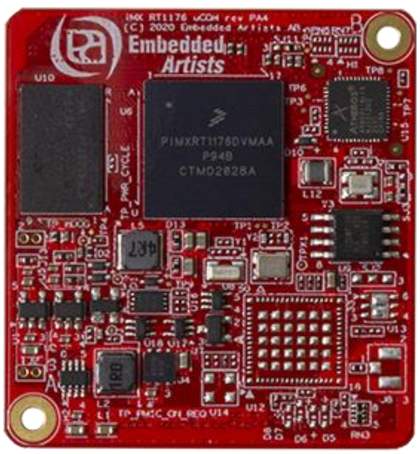
9. Processor & Microcontroller

9.1 Processor: Raspberry Pi 4 Model B

To process the data transmitted by sensors and cameras and run the algorithms mentioned below, a high-speed processor is required, so we have selected “**Raspberry Pi 4”** as our processor. Its key features include high-performance quad-core Cortex-A72 (ARM v8) 64-bit SoC clocking at 1.5GHz, 4GB of LPDDR4 RAM. It offers ground-breaking increases in processor speed, multimedia performance, memory, and connectivity compared to the prior generation. In addition, it is compatible with all the sensors used in this project, so we have chosen it for this project.



Raspberry Pi 4 Model B



i.MX RT1176

9.2 Microcontroller: i.MX RT1176

To achieve a stable flight, we need a high-end microcontroller which can dedicated to process Flight control algorithms (mentioned in section 12) and to control BLDC motors RPM accordingly, so we have selected **“i.MX RT1176”** of i.MXRT family features NXP’s advanced implementation of a high-performance Arm Cortex®-M7 core operating at speeds up to 800 MHz and a power-efficient Cortex®-M4 core up to 400 MHz. The i.MX RT1176 controller has 2 MB on-chip RAM in total, including a 768 KB RAM, which can be flexibly configured as TCM or general-purpose on-chip RAM. In addition, it has a fast real-time response with latency as low as 12 ns and can withstand temperature ranges between -40 °C and 125 °C.

10. Localisation:

The UAV operates in an unknown and dynamic environment, and it simultaneously needs to build a Map of its environment and localize itself within a 5km radius. To perform Simultaneous Localization and Mapping (SLAM), we have used IMU, Optical flow camera (Nav-Cam), TF Mini Lidar, Radar and Stereo Cameras.

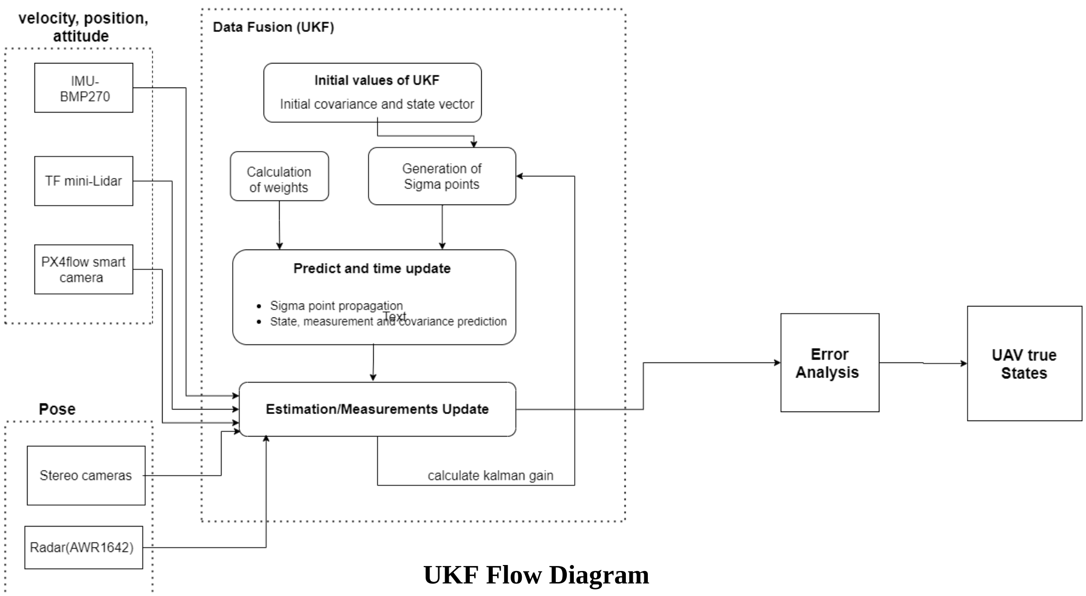
10.1 Sensor Fusion:

From the sensor data, we can estimate the actual states (coordinates(x,y,z) and attitude (roll, pitch, yaw)) of UAV by implementing a sensor fusion algorithm using the Unscented Kalman filter.

10.2 Unscented Kalman filter:

Kalman filters are used to estimate the states of the system. Among various Kalman filtering methods, we have used Unscented Kalman Filter (UKF) over Kalman Filter and Extended Kalman Filter (EKF) measurements because UKF can handle non-linearities more accurately.

UKF is based on selecting a deterministically calculated set of weighted samples, called the sigma points. UKF creates some sigma points, maps them through the non-linear transition function, and then tries to reconstruct what the original distribution would look like in the new space. The UKF follows Prediction and Update steps in a recursive manner. (sigma points are calculated using mean and square-root decomposition of the error covariance of the state vector). As mentioned in the below**,** data from IMU, TF mini-Lidar, Optical flow Camera, Stereo Camera, and the Radar are fused in UKF, to obtain true states of the Quadcopter.



UKF Flow Diagram

The fusion algorithm takes radar point clouds and RGB images as input and generates accurate object proposals for a two-stage object detection framework. Outputs of each sensor are processed independently first and are merged at a later stage for more processing.

10.3 Grid Mapping:

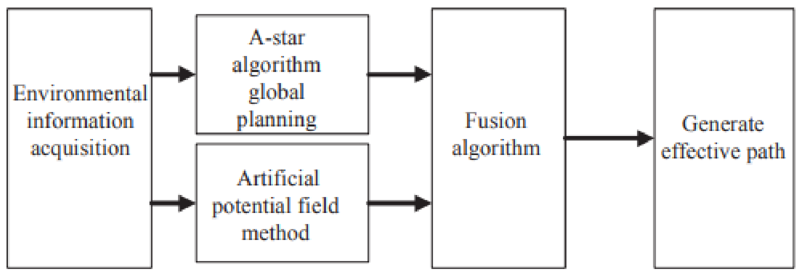
To enhance the accuracy of the maps, the environmental information received from multiple sensors must be merged. So, we are making generating different grid maps **(**the environment is divided into a fixed size discrete grid. Each grid cell is assigned a binary value that indicates if that location is occupied by an obstacle or not.) from all the analytical sensors were fused into one map using fusion algorithms. *Adaptive fuzzy logic algorithm* **(**AFL) fusion algorithm will generate final global grid map using performance measures quantify (These performance measures use the binary decisions about the cell's condition in the grid maps evaluating the difference between two grid maps)

11. Obstacle avoidance and path planning:

The purpose of 3D path planning of UAV is to find an optimal and collision-free path in the 3D workspace while taking into account the kinematic constraints.

Here we are trying to mix two known motion planning methods, the A-star and the Artificial-Potential Field method.

On the one hand, it tries to reduce the overall path cost by using A-star. On the other hand, it reduces the time complexity by adapting real-time reactive power from the Artificial-Potential method of Motion Planning.

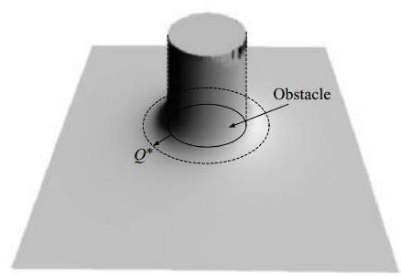


Structure Diagram of Artificial Potential Field and A* fusion algorithms

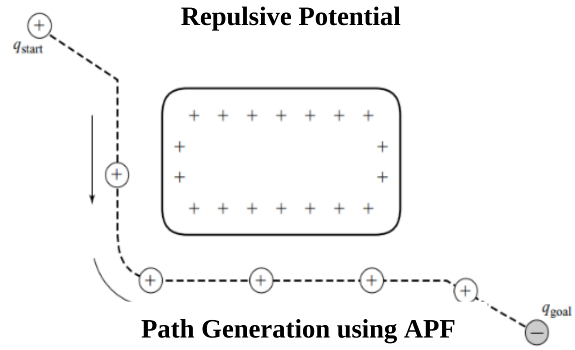
11.1 Artificial Potential Field (APF) Method: (Sampling-based algorithm)

11.1.1 Potential Functions

The potential function approach directs a robot as if it were a particle moving in a gradient vector field. Gradients can be viewed as forces acting on a positively charged particle robot attracted to the negatively charged goal at lower potential. Obstacles also have a positive charge which forms a repulsive force directing the robot away from obstacles. Combining repulsive and attractive forces directs the robot from the start location to the goal location while avoiding obstacles.



Repulsive Potential

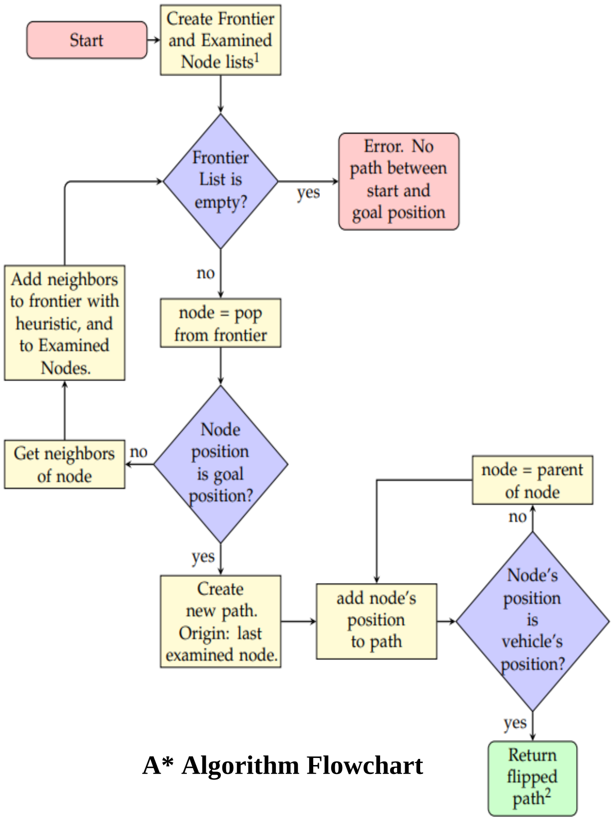


Path Generation using APF

11.1.4 Gradient descent method:

We are using this method to get to the bottom /minimum of the potential. Hessian matrix is used to identify the behaviour of critical points as a minimum, maximum, or saddle points.

'The local minima problem of the Gradient Descent method is solved using the A Algorithm.'*



A* Algorithm Flowchart

11.2 A* (Star) Path Planning Algorithm: (Node-based algorithm)

A* uses a best-first search and creates a path with the least cost from a given start sector to the desired one. As A* crosses the map, it follows a track of the lowest known heuristic cost, keeping an arranged priority queue of consecutive track sectors along the path.

11.3 Path Planning using APF and A* Fusion Algorithm

It first uses the A-star algorithm for planning to obtain the initial path and then sequentially uses each inflection point of the initial path as a sub-target point and uses the improved Artificial Potential Field method of local path planning to obtain the absolute path.

12. Flight Control System:

As there are High winds in Mars, we should need a Flight Control System that can tackle the wind and stabilize itself. Among various control system, we have selected Model Predictive Control (MPC) System to our UAV system.

12.1 Model Predictive Control (MPC):

MPC is an advanced method of process control used to control a process while satisfying a set of constraints. It is a robust optimization feedback control. Model predictive control solves an optimal control problem over a receding horizon, subject to system constraints, to determine the next control action. This optimization is repeated at each new time step, and the control law is updated. Thus, the core of MPC is optimization. As MPC re-optimizes at every single step, MPC requires a powerful, fast processor with ample memory.

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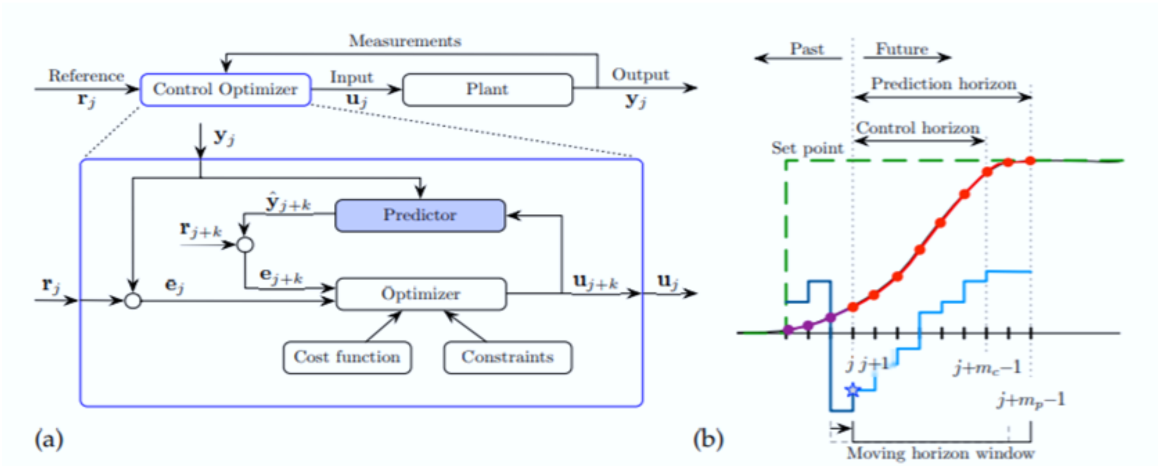
12.2 Non-linear MPC (NMPC):

Since our system has non-linear constraints and non-linear cost functions, hence we have to use nonlinear MPC. It uses the most accurate representation of the plant and predictions made by the NMPC for the plant are more accurate. Optimization of this NMPC is the Non-Convex Optimization Problem. So, it has to be linearized at each optimization by taking tangents to the curve and using all those linearly converted equations.

NMPC optimizes and selects the best of all different possible smooth control actions and estimates all the future steps for our system from the present state to further states (up to certain states). Then it implements the next control action. The horizon window moves one step forward, it optimizes and chooses the best control action and implements it, and so on. Thus, we can minimize the error occurring at each step by continuing re-optimization. So, it can modify our control signal behaviour whenever our system starts to deviate or change dynamics.

Optimizer of NMPC divides into constraints and cost Function. Constraints are the limitations of dynamic parameters (like velocity, angular momentum, etc.). In addition, an NMPC method has been incorporated into the controller. Thus, at each event sample time, the infinite horizon quadratic optimization problem is minimized while guaranteeing the closed-loop stability of the system.

Compared to the centralized NMPC, the decentralized NMPC control scheme applies a controller to each subsystem, and each controller then solves its online optimization problem locally.



a) MPC Control loop b) Receding Horizon of MPC

13. UAV capabilities:

13.1 Communication Range:

As mentioned in earlier subsections, our UAV can communicate up to a range of 10kms using the Mini-Micro Datalink system module. When it goes beyond the given range (5km) due to crash or primary power failure, we can easily trace the UAV.

13.2 Time of flight:

- Battery capacity = 8000mAh
- Total Battery Capacity = 2*8000mAh = 16000mAh

We will be using only 70% of our LiPo batteries so that they remain in good state of health

Now we have Battery capacity = (no of motors) *(avg. current req. by motor) * (Time of flight)

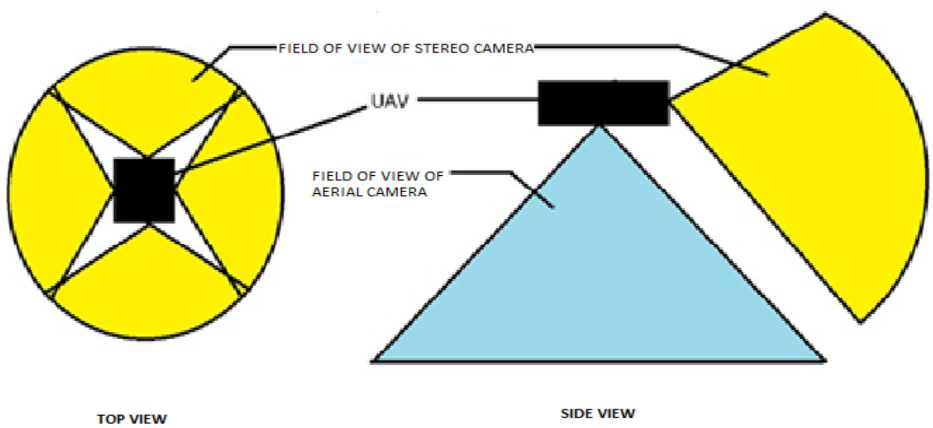
$$0.7 * 16000 = 4 * 13.3 * 1000 * T \text{ (in hrs)}$$
$$T = 0.2105 \text{ hr}$$
i.e., Time of flight = 0.2105 * 60 = **12.63 minutes**

Our UAV is capable of a minimum of 10 minutes time of flight. All Electronics systems & sensors should be able to function continuously for 10 minutes for the smooth operation of UAV.
Total Power = 41.1W (Refer Table 8.1)
Total Energy Required = Total Power * Time of operation
= 41.1W * 600s
= 24,660 J

To power these electronics, we will be using 10 "XT3585-3R0567-R" Supercapacitors (3V each) in a suitable series-parallel combination.

13.3 360degree Vision Capability:

Our UAV has 4 Stereo cameras placed such that it gives us a total 360 degrees view of the surrounding. The picture below shows us the placement of different cameras.



Top and Side Field of View of Stereo(yellow) and Aerial(blue) Imaging Cameras

13.4 Soil Selection Aid:

Digital Soil mapping is the prediction of soil classes or properties from point data using a statistical algorithm. The digital soil map is a raster composed of 2-dimensional cells (pixels) organized into a grid in which each pixel has a specific geographic location and contains soil data.

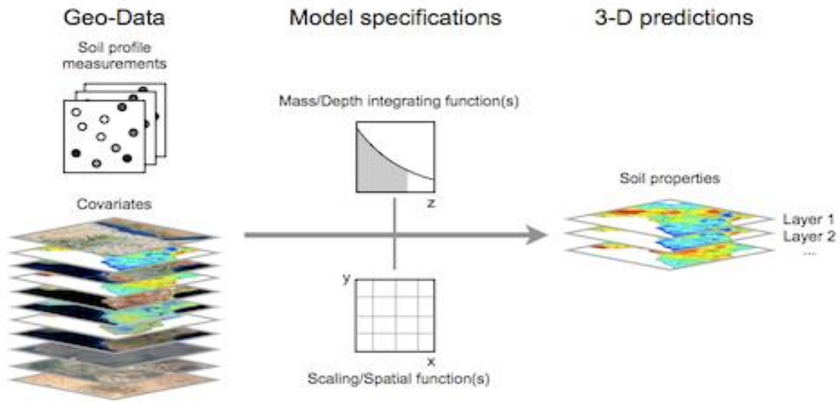
13.4.1 Requirement of Soil Mapping

For Mars colonization, many questions are unanswered. To find the answers to some of those questions, soil mapping is essential.

- It gives us terrain & soil types in different regions.
- It tells us the number of nutrients in soil like Calcium, Magnesium, phosphates & Nitrates.
- It will help us in finding suitable places for human settlement in the future.

13.4.2 Procedure

- Images taken by different onboard cameras will give us data about location & different soil parameters like moisture, roughness, texture & temperature.
- The APXS (Alpha Particle X-Ray Spectrometer) determines the elemental chemistry of rocks & soil (Regolith).



Digital Soil Mapping Workflow

With the help of data collected by the above processes, we will decide where soil samples of 5g will be taken & carry to the base station for testing.

14. Tasks:

14.1 Reconnaissance Mission:

Aim: To capture a digital orthophoto using photogrammetric methods of a piece of land on Mars, measuring at least 300 square meters.

Camera system used: Lt-C3200B Board Level Camera

Digital Orthophotography:

A digital orthophoto quadra (DOQ) or any orthoimage is a computer-generated image of an aerial photograph in which displacements (distortions) caused by terrain relief and camera tilts have been removed. It combines the image characteristics of a photograph with the geometric qualities of a map.

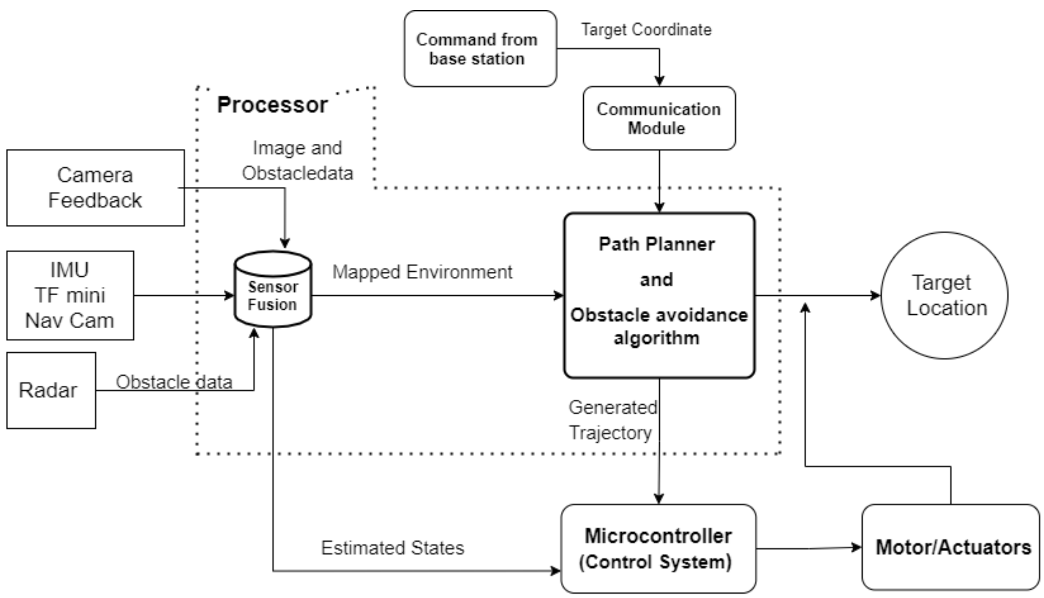
An orthophoto is an accurate representation of any terrain. Orthophotos have the benefits of great detail, timely coverage combined with the benefits of a map, including uniform scale and precise geometry.

After reaching a certain altitude, the camera system will take multiple aerial photographs, which will then be sent to the base station; after ortho-rectification, the final orthophoto graphs will be produced.

14.2 Logistics Mission

Aim: The UAV must be capable of picking up and delivering a package weighing 100gms from the base station to another delivery station. The package has to be in the form of a cube of at least 15x15x15cm. UAV has to pick up/drop the package using its abilities, without human interference. Teams may put any external features on the package to help it attach to the UAV.

After picking up, the base station (reference) package, using localization and path planning techniques mentioned above, the UAV will be able to deliver the package from the base station to any other delivery station. The stabilized flight is achieved using the NMPC Control System. Information of states and relative location will be sent via communication module to the base station continuously.



Process Flow to reach from Base station to Another Delivery Station

14.3 Atmospheric Analysis Mission:

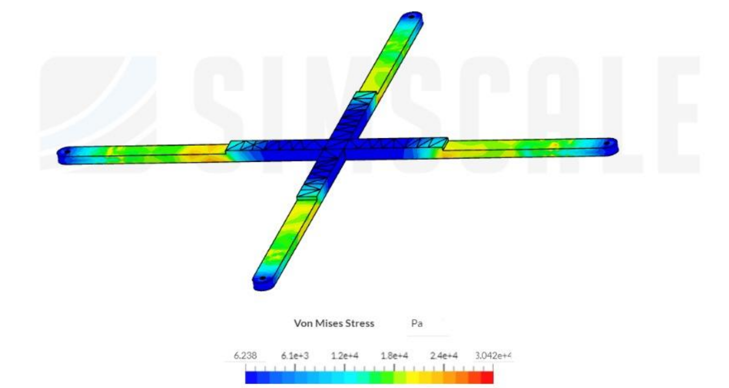
Aim: To collect data of relative abundance of different gases present in Martian Atmosphere, Relative Humidity & Temperature at a given coordinate.

The UAV has a combination of 4 gas estimation sensors, i.e., MiCS-6814, MQ 131, Gravity: I2C & MG 811, that are interfaced with processors & will give us the concentration of different gases like O2, CO2, O3, NO2, CO, H2, NH3, etc. in the Martian Atmosphere.

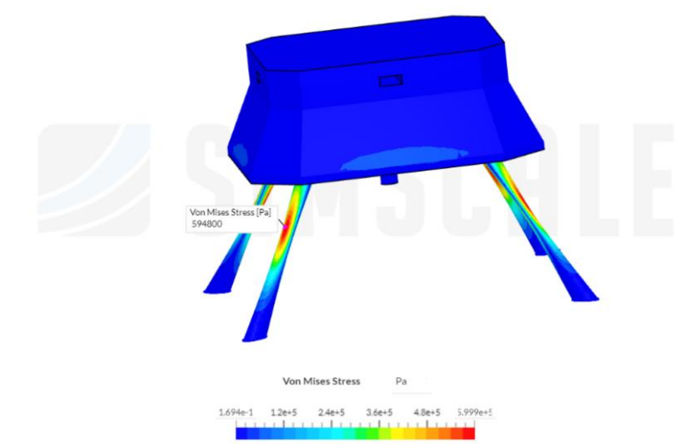
Apart from this, UAV has HTU 31 Sensor that measures surroundings temperature & humidity at a given coordinate with high accuracy.

15. Analysis and Result

We did some simulation and analysis on our model whether it will sustain the conditions or not, the results are satisfyingly good all the stresses are in the limit of the material therefore the design can be successfully implemented on mars as an astronaut assisting UAV



Stress analysis on UAV arms



Stress analysis on landing support

16. UAV System Mass:

Components	Quantity	Mass of Single component (in grams)	Total Mass (in grams)
BLDC motor	4	80	320
Propeller	8	35	280
Primary PS	2	900	1800
Secondary PS	10	110	1100
Johnson Motor	1	300	300
Servo for scooping	1	60	60
Mech Subsystems	1	700	700
Frame	1	400	400
Payload	1	110	110
APXS	1	100	100
connecting wires	1	150	150
ESC	4	20	80
Stereo Camera	4	30	120
NAV CAM	1	25	25
Aerial Imaging Cam	1	30	30
Radar	1	250	250
IMU	1	25	25
Co2 sensor	1	20	20
TF-mini lidar	1	5	5
Temperature sensor	1	20	20
pressure sensor	1	20	20
O2 estimator	1	40	40
Shafts	4	12.5	50
Processor	1	60	60
Communication system	1	60	60
Gas sensors	2	10	20
Controller	1	5	5

Total Mass of UAV = 6.15 Kg

Appendix

- Evaluation of grid-map sensor fusion mapping algorithms by Ramin Nabati, Hairong Qi University of Tennessee Knoxville.
- Sensor data fusion using Unscented Kalman Filter for accurate localization of mobile robots ((PDF) Sensor data fusion using Unscented Kalman Filter for accurate localization of mobile robots (researchgate.net))
- https://commtact-systems.com/products/micro-data-link-system/
- https://soilmapper.org/soil-introduction.htmlhttps://mars.nasa.gov/msl/spacecraft/instruments/apxs/
- https://core.ac.uk/download/pdf/61806036.pdf
- https://www.thomasnet.com/articles/instruments-controls/How-Gas-Detectors-Work/
- Raspberry Pi 4 Model Bi.MX RT1176
- https://in.mathworks.com/videos/series/understanding-model-predictive-control.html
- NMPC for Collision Avoidance And Control of UAVs with Dynamic Obstacles
- Path Planning Using Artificial Potential Field Method And A-star Fusion Algorithm
- Overview of Path Planning
- A Real-Time 3D Path Planning Solution for Collision-Free Navigation of Multirotor Aerial Robots in Dynamic Environments
- https://smartech.gatech.edu/bitstream/handle/1853/59094/iple_lacerda_michel_park_dongjin_2017_gtmarsuav.pdf
- https://vtol.org/files/dmfile/2000SDC_1stPlaceGraduateProposal_UMD_MARC.pdf
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