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Autonomous Mars Rover Design using SOLIDWORKS and User Interface development via Internet of Things

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***Abstract:** In this paper, an autonomous Mars Rover is designed using the software SOLIDWORKS and a mechanical model is developed with in-depth simulations to analyse the functions of the vehicle. Furthermore, a graphical user interface is also developed based on the principles of Internet of Things using Node-Red to control and monitor the rover remotely. The red planet, i.e.; Mars, has been the centre of attraction for over 2 decades now, with astrophysicists and engineers working in unison to build devices and launch shuttle programs to understand and learn about the planet and gather more intelligence. This paper proposes the detailed development of a 6-wheeled rover that could explore the terrains of Mars, featuring a stereo vision system that could provide live video coverage and a robotic arm that can facilitate investigation of the surface, in an attempt to contribute to and fulfil the human race's mission to Mars. It employs multiple onboard sensors that can acquire necessary data pertaining to the environmental conditions and actuators that enable functionality, with the sensors and actuators integrated onto a control system based on microcontrollers and microprocessors such as Arduino and Raspberry Pi. The rover also has a provision of a payload bay in its rear which enables it to carry loads. The SOLIDWORKS tool from Dassault systèmes is used to design and model the rover and carry out static analysis and motion studies. The GUI developed in the further sections allows overall voice control for the user and makes the task of monitoring the rover a much simpler task by eliminating the complexity that rises due to multiple control platforms.*
***Keywords:** Mars Rover, Graphical User Interface (GUI), Chassis, Mastcam, Actuators, Internet of Things (IoT), Nitinol, Payload*

I. INTRODUCTION

In an age of drastic advancements in the fields of space exploration, the world has been a witness to technology that has never been thought of or seen before. New-age probes and rovers are developed and upgraded on a regular basis, and world-renowned establishments such as NASA itself, have space missions that support the fact, with given examples such as the earliest Pathfinder and its rover Sojourner in 1997. The possibility of a potentially deviating environment for livelihood on a different planet, amongst other similar factors make Mars an evergreen topic of discussion. Millions of dollars are spent annually to gather and analyse intelligence that is received through these missions, and case studies are widely investigated.

The Curiosity rover from 2012 had a set of two mast cameras that could acquire stereo images for investigation at differing wavelengths. Utilizing existing image recognition algorithms with a set of approximately over 100 Mastcams could improve pixel clustering and anomaly detection performance [1]. With 9 bands each on both the Mastcams, the left imager has a wide field of view and low resolution, exactly in contrast to the right imager. Fusing both leads to the forementioned advantages with respect to image quality [2]. For NASA's Mars 2020 rover, the landing site identification began 7 years early and like all other missions, was based on a few objectives that included biosignatures of past microbial life, collecting data to support human missions to the planet in the future, etc. [3]. The collection of soil and rocks is essential and key to the process of understanding the alien environment, and the rover hence requires a 6 degree of freedom robotic arm that can carry out functions like lifting, cutting, assisting the astronaut in manual labour, and more [4]. The Explorer-0100 from the European Rover Challenge (2016) is a fitting example of a fully remote and autonomous rover, with a significant system architecture and a state-of-the-art communication and control system [5].

Internet of Things has been a vital asset when it comes to the rise of Industry 4.0, and the fundamentals of IoT have found importance and differing roles in all fields, be it industrial, domestic, or scientific. Utilising its protocols to maintain a level of security and furthermore, make the communication systems simpler and faster is a common occurrence when it comes to remote devices and vehicles, similar as the Mars rover [6]. Microcontrollers and Wi-Fi modules such as Raspberry Pi and Arduino come in handy when prototypes are built and the vehicular motion is controlled over the internet using GUIs specifically built based on IoT protocols. This increases the integrity and lowers the complexity of the private network [7].

To make the rover completely autonomous, navigation cameras and hazard cameras along with IR sensors, provide guidance in navigation, preventing the rover from crashing into obstacles and help in mapping a path. The IR sensors detect any nearby obstacle and quickly determines the distance till impact, and relays this information to the onboard computer that can work on it and take calculative decisions. A powerful robotic arm controlled by a set of actuators, is composed of a gripper and a guiding camera. The camera provides a close-up visual on the surface, with which the rover can carefully inspect and analyse the soil and rocks, with the gripper being employed to collect those samples. A collection bay is also mounted on the body which could be used to collect samples of varying sizes and masses. The motor drives and the pivot differential make up the mechanical system. This mechanical system is integrated with the node-red system based on IoT and hence grants overall control of each of the functions and features.
In the next section, the overall design and methodologies required to build the model are discussed in detail.

II. DESIGN AND METHODOLOGY

As mentioned in the previous section, this paper consists of majorly two separate categories, the first being an in-depth virtual design of the Mars Rover using SOLIDWORKS to build the mechanical pre-prototype model, and using Node-Red and the fundamentals of IoT to form the graphical user interface for ease of access and control of the rover.

A. *Mechanical Design*

The rover is designed in a way that it can negotiate the rocky terrains of Mars filled with volcanoes, craters, dry lake beds and steep slopes with ease while providing maximum stability to the system. The rover operates in two different conditions, standard and recharge. The standard condition indicates the usual operating state of the rover when the solar panels aren't deployed and the rover carries out doing all the required set of tasks. The recharge condition occurs when the rover needs to replenish its consumed power by fully deploying the solar panels, when it is not in motion. The dimensions of the rover are 7ft. x 8.5ft. x 6ft. (or) 2135mm. x 2593mm. x 1830mm. The weight of the rover is calculated to a 980Kg including all the equipment on board.
The base chassis is in-built into the main body and offers a load carrying capacity of 1000Kg. It is designed in such a way that despite uneven loading of components on board, the mass of the entire setup is evenly distributed across the chassis, accompanied by corner and side pillars.

1) *Material Selection:* The need to consider various parameters such as ultimate strength, density, strength-to-weight ratio, machinability and temperature tolerances narrow down options for suitable materials to graded aluminum or composites. The most suitable material for the chassis would be one that primarily exhibits very high strength-to-weight ratio, since the total mass of the rover should be as minimal as possible while also being able to withstand great pressure and also not too complex to machine. Keeping all this in mind, the material chosen would be an Aluminum-Lithium alloy, Al-Li 2195-T8. The AA 2195-T8 is part of the wrought aluminum-copper family and is a weldalite of aluminum-lithium alloys. It is the most complex grade in the Al 2000 series, with a chemical composition of 92% aluminum, 4% copper, 1% lithium and 3% of other metals such as silver, zirconium, magnesium. The main property of this particular alloy that makes it suitable for the rover is that it is fracture resistant at cryogenic temperatures, meaning it can withstand the extreme conditions of the Mars environment.

Table 1
Characteristic Properties of AA 2195-T8

CHARACTERISTIC PROPERTIES	
Mass density	3000 kg/m^3
Yield strength	3.5 x 10^8 N/m^2
Tensile strength	5.9 x 10^8 N/m^2
Compressive strength	1.9 x 10^8 N/m^2
Elastic modulus	6.9 x 10^{10} N/m^2
Strength-to-weight ratio	High
Machinability	Low to moderate

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2) *Chassis Model:* The dimensions of the chassis are 1535mm. x 925mm. x 35mm. with a weight of 300Kg. The model employs a rectangular channel as base for the chassis as this type can provide maximum factor of safety and also minimal deflection. The corner pillars provide a stronghold for the main body, while the base can withstand both longitudinal and vertical loads.

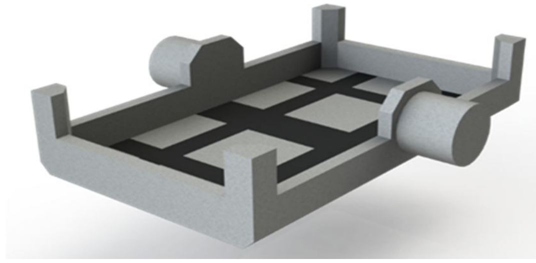

Fig 1. The Chassis Model

3) *Static Analysis:* A static analysis of the chassis was carried out to test out its load carrying capacity. The corner-supporting and wheel system pillars were considered to be fixed geometry. An equal mass distribution of 1000Kg was given across the chassis floor with the side supports withstanding another 100Kg. The test was carried out with a universal gravitational load of value 3.72m/s^2 (since the gravity on Mars surface is 1/3rd that on earth) and under default failure criterion- Max von mises stress. Figure 2 indicates the static loading conditions and distribution of forces.

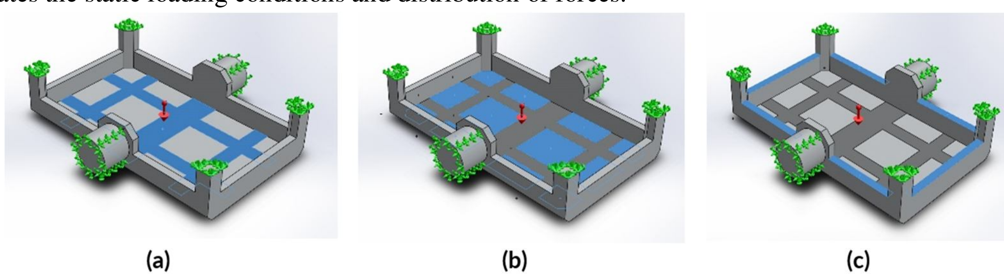

Fig 2. Mass distribution: a. 500kg b. 500kg c. 100kg

Figure 3 displays the solid-standard high-quality meshing and Figure 4 displays the Factor of safety of FOS 3.420 of the chassis model. Figure 5 indicates the total deformation result of the model. The static analysis model shows that the chassis is strong enough to withstand heavy loads and hence the rest of the rover can be safely built on this base.

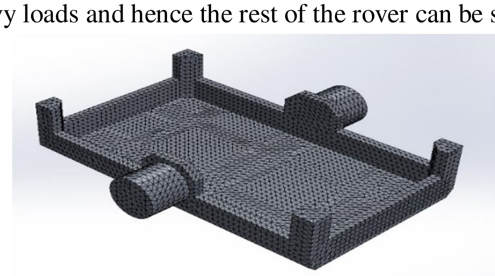

Fig 3. Meshing

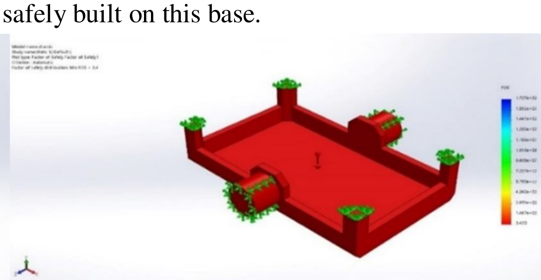

Fig 4. Factor of Safety

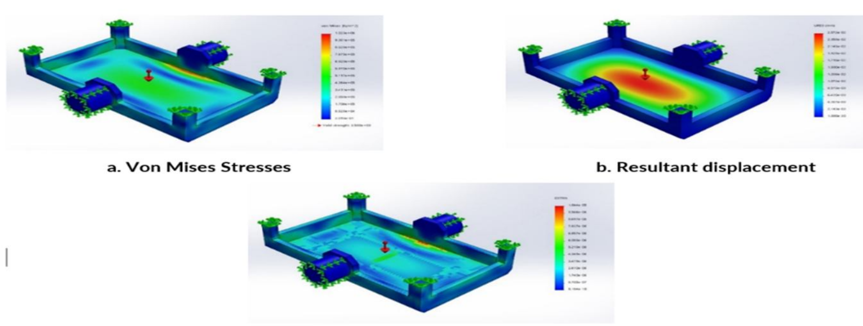

Fig 5. Total Deformation

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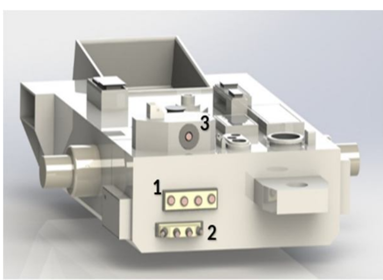
Table 2
Static analysis results and the total deformation

DEFORMATION	MINIMUM VALUE	MAXIMUM VALUE
Von Mises Stress	0.2015 N/m^2	1.023 x 10^6 N/m^2
Resultant displacement	0 mm	2.572 x 10^{-2} mm
Equivalent strain	9.184 x 10^{-10}	1.044 x 10^5

B. The Rover

The main body of the rover acts as a container for all the electronic equipment and computers, safeguarding the instrument cluster from the harsh weather conditions on the Martian surface and aids the effective functioning of the rover on the surface. It is made from high grade aluminum alloy similar to the chassis. Components of the body include all the casings and electrical boxes containing various sensors, a 4-size sample array for collection of Martian specimens and the payload bay. It also has provisions to host the main camera stand (which comprises of the super camera and the master camera) and the live feed camera, which points in the forward directions. On the front of the body, 4 navigation cameras and 4 hazard cameras are mounted and, on the rear, 2 navigation cameras and 6 hazard cameras.

Fig 6. The sample collection array and payload bay



1. NavCams 2. HazCams 3. Live-feed Cam

Fig 7. The Main Body

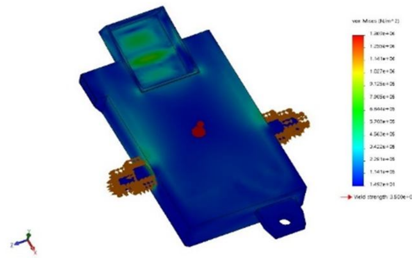


Fig 8. Static analysis of payload bay

The payload bay has a load carrying capacity of 300Kg and of area 1 sq ft. Static analysis was carried out to test the strength of payload bay and it resulted in negative failure test i.e.; the rover can safely carry 300Kg of load in the payload bay. The collection array can hold up to several Kgs of samples and comes with 4 uniquely sized tubes to hold specimen of varying sizes.

The principal mechanism in locomotion of the rover is the Rocker-Bogie suspension system which is comprised of two different mechanisms, the Bogie and the Rocker mechanism. The term Bogie refers to the ability of the wheels to act complimentary to one another while negotiating an incline, such as climbing a hill or overcoming a rock, when the front wheel is raised when riding an incline, the front of the rover is lifted with the middle wheel pressed down against the obstacle, and the rear wheel being pulled along by the front wheel once the incline has been overcome. The Rocker refers to the part where a differential pivot is used in order to limit the incline of the body caused by the bogie mechanism, and subsequently prevent the rover from tipping over. A pivot differential bar connects the starboard and port side rockers to the chassis of the rover. The rockers which are attached to the wheel assemblies, rotate in opposite directions to one another in order to maintain equal wheel contact with the surface.

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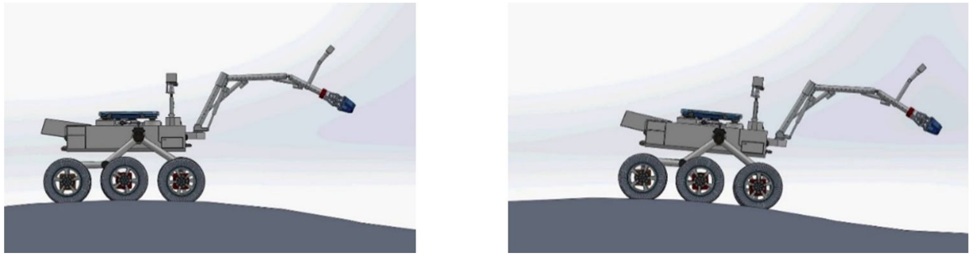

Fig 9. Locomotion of Rover

The rover has six wheels, each driven individually by a motor, with three on either side. There is also a provision of four-wheel steering with the two front and two rear wheels having individual steering which work in complementary to one another. This allows the rover to perform a 360° turn in place, and also make sharp turns. The wheel frame is made from aluminum alloys to withstand impact from rocks and other obstacles and increase durability. The legs for the wheels are made of titanium tubing which is lightweight and very rigid and are designed to withstand great forces that are induced on the wheels by contact with surface.

The wheels are of diameter 608mm or 2 ft. and are driven by motors at a speed of 4 rpm or 0.5 km/hr. The rover traverses at such low speeds in order to prevent itself from lifting off the surface when it negotiates an incline or while climbing a rock. This is due to the fact that the gravitational forces on the Martian surface are much lower when compared to earth and hence even a little increase in speed can cause the rover to lose contact with the surface. The wheels employ the usage of shape memory alloy, Nitinol, over aluminum alloy, as it can temporarily deform upon contact with rigid surfaces but can soon regain the original form rather than having to completely displace the body as the wheels go over the rocks. This replicates the motion of an everyday rubber tire over a stone or a platform. This reduces the wear and tear on the wheel, increasing the durability which helps in traversing longer distances of the surface and reduces the need for a complicated suspension system. It also provides greater stability in driving the rover which is essential in keeping in-tact the internal equipment and maintain calibration of the electrical and computational components which otherwise might lead to errors in measurements, readings and transmission. Nitinol is a nickel-titanium alloy which exhibits two very rare properties- shape memory and pseudo elasticity or super-elasticity. Shape memory is the property of a material undergoing deformation, to be able to return to its original shape when heat is applied. At stable condition, the crystal structure of nitinol is maintained as martensite. When stress is applied, rather than completely deforming by stretching as any traditional material undergoing plastic deformation would, the crystal structure aligns itself in order to absorb the stress. When the stress is released, the tire maintains the shape until a positive temperature difference is applied, upon which, it takes the form of austenite until it naturally cools down to finally return back to the martensite form. The compositions of nickel and titanium present in the alloy could be changed accordingly so as to acquire the temperature boundary at which the transformations from martensite to austenite and vice versa take place. The rover employs EMF braking to counteract the inertial forces caused by gravity.

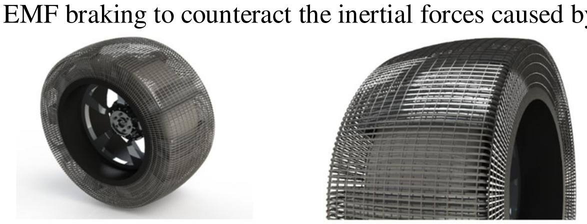

Fig 10. The wire-mesh design of Nitinol wheels

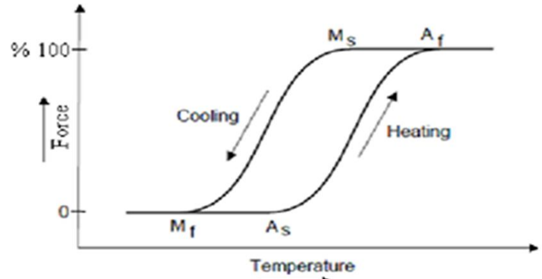

Fig 11. Nitinol hysteresis curve

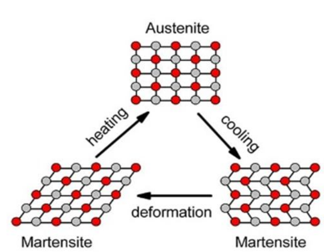

Fig 12. Martensite-Austenite phase change

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The major source of energy to power the rover is solar due to the unavailability of other energy resources. The thin atmosphere of Mars allows for more sunlight on the surface than on earth but however due to the greater distance from sun, the intensity of incident light is lower when compared to earth. Also, the presence of suspended atmospheric dust and lower operating temperatures can alter the solar spectrum and reduce intensity. Considering these factors, the solar panels use an arrangement of multi-junction photovoltaic cells, made of different semiconductor materials which allows for the absorbance of a broader range of wavelengths with a limiting efficiency of 35%. The surface of Mars receives about 6 hours of sunlight per sol and could vary depending on the surface coordinates.

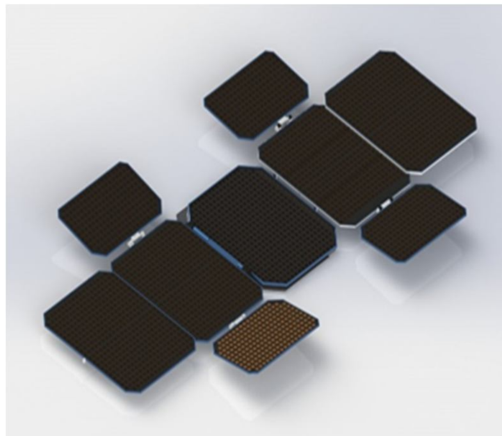

Fig 13. Solar panel configuration

The equators receive 7 to 8 hours of bright sunlight whereas other parts may receive only a faint 4 to 5 hours. The design of the solar arrays includes both horizontal and vertical configurations in consideration of dust settling on the panel surface and the location. A nine-piece solar array, powers two 8 amp-hour rechargeable lithium-ion batteries. When completely illuminated, the 2m^2 solar panel array on average generates about 900 watts of power per sol. The rover requires 150 watts of power per sol to be completely functional and carry out all of its tasks. The energy output of photovoltaic system per hour is calculated using the following equation:

$$E = A \times R \times H \times PR$$

Where E is Energy in Watt-hours, A is Total area of panel which is 2 m^2, R is Solar panel yield which on average is 20%, H is Annual average solar radiation which is 590 W/m^2, PR is performance ratio of standard 0.75 or 0.70 accounting for losses due to temperature, dust, location and battery losses: E = 2 m^2 x 0.20 x 590 W/m^2 x 0.7

E = 165.2 watt-hour

The total energy output available to power the rover is 165.2 watt-hour but to account for varying performance ratio (0.6 to 0.8) due to change in location or settling of dust over time, on average the power output can be considered as 140 watt-hours. The solar array weighs 5 KG and along with the entire power system, would weigh 15KG. Hence, estimating a degradation rate of 0.028% per sol of the PV cells in the panels and a 6 hour per sol battery recharge, the rover could be powered up for more than 4000 sols.

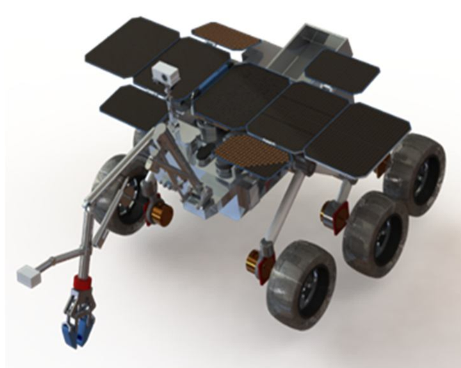

Fig 14. Solar panel deployed

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The most important aspect of the rover, the robotic arm equipped with a guiding and inspection camera, is employed to carefully inspect surface elements like rocks and soil formation. Similar to the legs on the wheel assemblies, the robotic arm uses a combination of three different frames made of titanium tubing. The robotic arm is controlled by a set of actuators, namely the LPHTA (low-power high-torque actuator) which is used to control the extension of the arm and a piezo-electric actuator at the base which controls the linear turning of the arm. These actuators work in sync, controlled by the computers and microcontrollers on board, to extend the arm to the desired length and elevation. The guiding camera provides a closer look at the specimen to be inspected and also relays the visuals back to base. At the end of the arm is a gripper which can pick up rocks and other samples to be stored to conduct further tests. And so, after a thorough and careful inspection is carried out, the rover is able to decide whether the specimen at observation is to be collected or not. The electronic gripper devices a simple screw mechanism in order to open or close. A piezoelectric actuator drives the motor which controls the extension of the gripper allowing it to grab and pick up specimens ranging from 20mm to 120 mm in size.

Fig 15. Robotic arm with the gripper and guiding camera

Built into the rover are three different visual systems- the engineering cameras, the science cameras and the live feed camera. Working together, they provide the visual basis for the autonomous locomotion, inspection and investigation of environment and a live video coverage.

1) *Engineering Cameras:* The engineering cameras consist of the navigation cameras and the hazard avoidance cameras based on the SLAM algorithm (Simultaneous localization and mapping). A receiver provides the GPS coordinates with which the intelligent system determines the shortest path between the current location and the destination. As the rover traverses, with the help of NavCams and HazCams, it creates a 3-dimensional map of the surroundings and localizes itself in the generated map allowing for intelligent and autonomous locomotion. HazCams are located on the lower front and rear end of the rover. They gather visible light from the surroundings in order to capture 3D imagery and hence map the surroundings. These cameras aid in identifying obstacles within a range of 3 meters and using these images, work autonomously to avoid crashing into obstacles. NavCams are located on the front and rear of the rover, these cameras work in tandem with the hazard detection cameras and aid in navigation by forming 3D imagery of the terrain using the visible light gathered by them from the surroundings.

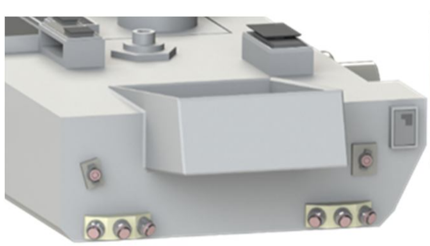

Fig 16. Rear NavCams

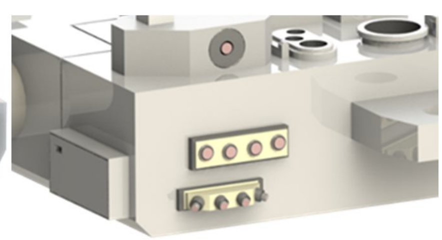

Fig 17. Front NavCams

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Table 3
Technical specs of HazCam

TECHNICAL SPECIFICATIONS	
Image size	1024 x 1024 pixels
Image resolution	2.1 mrad/pixel
Lens	Fish-eye lens
Focal ratio	f/15
Focal length	5.58mm
Field of view	124° x 124°
Diagonal field of view	180°
Depth of field	0.1m to infinity
Spectral range	600-800nm with greyscale at 650 nm
Image compression	1-3 bits/pixel

Table 4
Technical Specs of NavCam

TECHNICAL SPECIFICATIONS	
Image resolution	0.82 mrad/pixel
Focal ratio	Fixed aperture f/12
Focal length	14.67mm
Field of view	45° x 45°
Diagonal field of view	67°
Depth of field	0.5m to infinity
Spectral range	600-800nm with greyscale at 650 nm

The system control of the rover is integrated using microcontrollers like Arduino and Raspberry Pi. The sensors are essential in collecting various important and necessary data about the environment like temperature and pressure. The actuators however control the movement of mechanical joints of the rover such as the extension of the robotic arm and also to drive the rover motors.

2) *Sensors:* Following are the list of sensors that can be incorporated in the design for the actual prototype.

a) *Air Temperature and Humidity Sensor:* Senses and records the ambient temperature and moisture content present in the atmosphere at an interval of 2 seconds. The sensor used for this is DHT12 with improved qualities from the previous gen DHT11.

b) *Pressure Sensor:* Records the atmospheric pressure and accordingly determines the altitude via computational methods. The MPL311A2 sensor is used.

c) *Luminosity Sensor:* Composed of a photo resistor, potentiometer and comparator LM393, the luminosity sensor measures the amount of sunlight and its intensity that is incident on the Martian surface depending on surface coordinates, rotation of the planet and distance from sun.

d) *Radiation and Dust Sensor:* Equipped with gas tubes of helium, argon and neon, it detects beta and gamma rays and measures the radioactive radiation quantity.

e) *Thermal Infrared Sensor:* Consisting of five internal sensors, this device measures the radiative flux emitted by surface of Mars, sky and the surrounding CO2 atmosphere.

f) *Instrument Control Sensor:* This sensor detects the functionality of the electrical and computational equipment and returns Boolean values accordingly to indicate failure/running status of any electronic device on board the rover.

g) *Atmospheric Sensor:* This sensor deduces the carbon monoxide and carbon dioxide content in the atmosphere. MG811 sensor is used to estimate carbon dioxide presence and MQ7 sensor for carbon monoxide.

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h) *Navigation Sensor:* The FC51 uses an infrared sensor to detect obstacle lying within the "safe distance" which is pre-determined by a potentiometer. A gyroscope on board provides data regarding the rover's position, motion and acceleration, which is then processed and computed by the computers. The potentiometer takes information from the computer for factors like inclination and rover speed, using which it mathematically computes the safe distance.

3) *Actuators:* Following are the necessary actuators in the design.

a) *Low Power High Torque Actuators:* These actuators facilitate the movement and control of the robotic arm. LPHT actuators are specifically used since they produce larger displacement for only a small input quantity hence, utilizing the least power possible.

b) *Piezoelectric Actuators:* They are used to drive the motors for the wheels as well as in the control mechanism of the individually enabled steering system. They also control all the fixed rotation mechanics such as opening and closing of the sample tubes, the deployment of solar panels and the extension and turn of cameras.

The rover is equipped with 2 antennas that provide the basic means of a two-way communications between itself and the mission base back on earth. They are the UHF (ultra-high frequency) and high gain antennas. The UHF antenna operates at about 400MHz and relays the data in the form of radio waves to the DSN (Deep-space network) and provides a transmission rate of 1 megabyte per second. To send larger quantities of data such as the live video coverage, images and videos, the rover makes use of the UHF antenna. The high gain antenna also transmits and receives data but operates unidirectionally and hence should be rightly positioned with the antenna being pointed at the specific direction. It provides a transmission rate of 160-800 bits per second to the DSN. The rover makes use of this antenna to transmit readings and values and to receive mission information from base.

C. *Graphical User Interface on Node-Red*

In this sub-section, the GUI for control and monitor of the Mars Rover is designed and discussed. This includes building separate flows in Node-Red that have a login browser page that is necessary for security purposes, and a user interface dashboard that allows the user to access the rover's features after logging in.

In Figure 18, the login form as mentioned is designed to form a webpage in the node-red flow to allow the user to access the dashboard for rover control and monitor interface. The login details are visualized on the dashboard as well as the debug window for the importance of maintaining a login record. Further, the Mastercam feed is included that allows the user to see what is present in the surroundings of the rover, as captured by the camera. The voice control system allows the user to speak out loud commands that are analyzed and read by the rover's electrical design that upon integration with the IoT based systems, carries out the operations instantly.

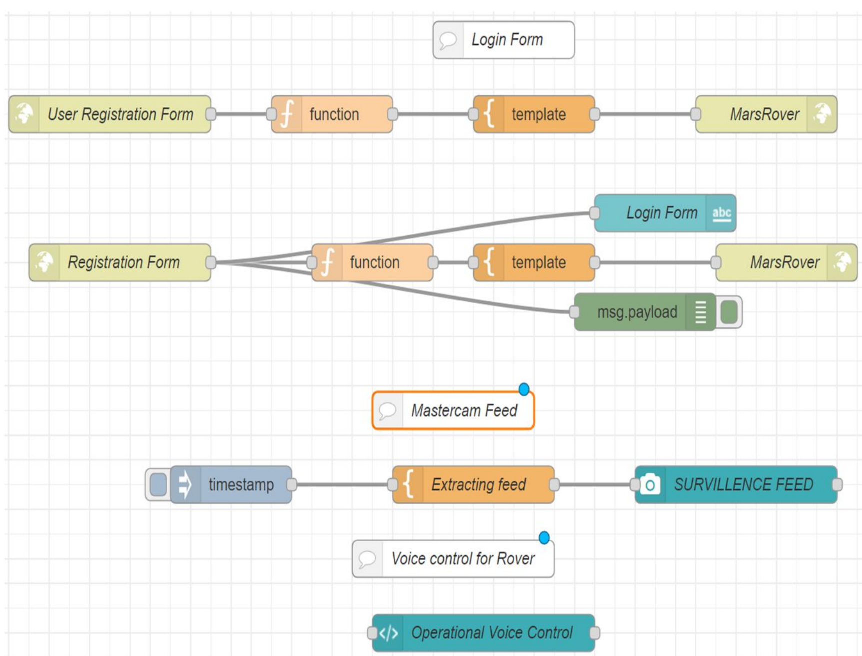

Fig 18. Login Form, Mastercam feed and Voice control

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Figure 19 includes a few features of the rover that are necessary for monitoring purposes. This includes a directional tool that gives the user details regarding its positioning in a 360-degree frame. Next, there is a rover temperature gauge that keeps a track of the current temperature of the rover, and can alert the user if any cases of overheating take place. The current consumption is visualized graphically and the speed check node is included to determine rover speed. Furthermore, there is a damage check and report login section that records any checks or damage related complaints.

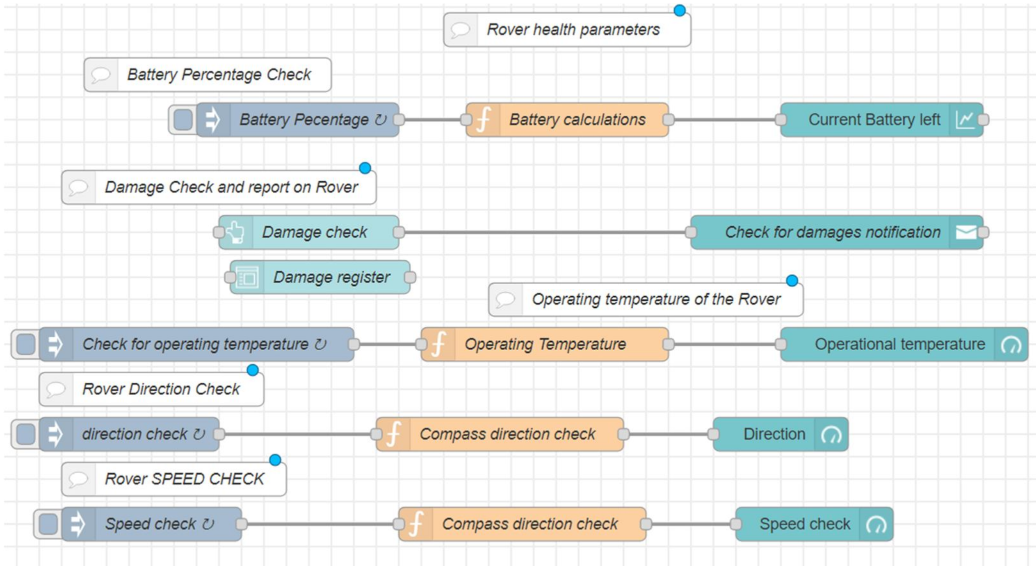

Fig 19. Health, speed, direction, temperature, battery, and damage flow

III. RESULTS AND DISCUSSION

After running simulations of static loading conditions and motion studies, it can be concluded that the rover can withstand more than the actual calculated weight, with the chassis having a FOS of 3.420. The payload bay loading capacity has also been analysed and is tested to carry the required payload. The motion studies produced results of rover speed. With the motor being driven at 4 RPM, the rover can traverse at a maximum speed of 0.5 Km/h (without losing stability), which is much greater than the traditional rovers, due to the usage of Nitinol wheels. The mechanical work done in braking, produces heat energy which is used to revert the austenitic phase back to the martensitic phase of Nitinol, a demonstration of the shape-memory nature of the alloy.

All the results produced are under Martian conditions i.e.; g=3.72 m/s^2. The availability of ample sunlight on the Martian surface helps to power the rover. With minimum to moderate power consumption, the solar panels can produce a power output well over that required for the rover to operate, hence increasing its life-cycle to about over 4000 sols, long enough to carry out crucial and decisive missions. The rover, also equipped with a robotic arm, can collect and inspect rock samples while also providing live video coverage of the surroundings. The sensors and cameras on board integrated on a microprocessor, make the rover fully autonomous, thus enabling it to operate and make imperative decisions all by itself.

With respect to the results in the control and monitor interface, figure 20 visualizes the login webpage that allows the user to fill in his/her respective details before they can access the UI dashboard to monitor the rover. The details are further visualized in the dashboard as well as in the debug monitor to keep a record.

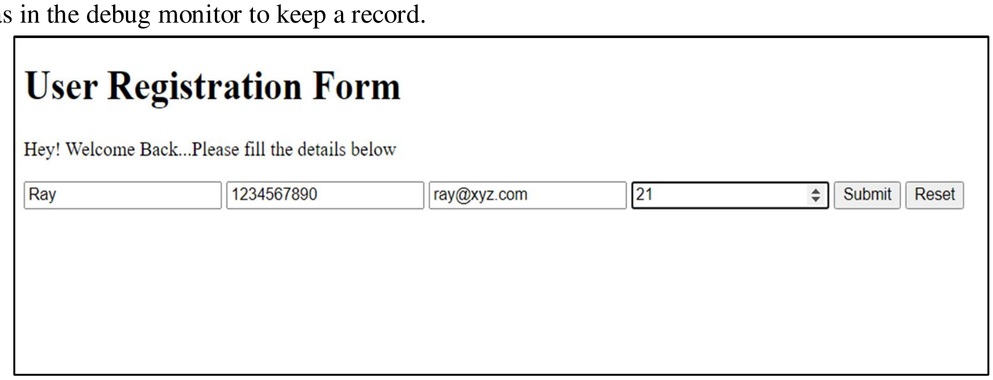

Fig 20. Login form for Users

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This login form opens the user interface dashboard as shown in figure 21. This includes the Mastercam view, which for simulation purposes depicts the webcam view from the laptop the flow is built upon. The nodes implemented portray random values for the experimental purpose. The direction of the bot is visualized by the 360-degree direction node, and the command spoken is analysed and shown in the voice control system. Further, the rover temperature and battery percentage are clearly visualized alongside the current speed of the rover, in a remote system. The damage and complaint forms are available for the user to lodge any complaints with respect to the rover's performance and hence are suitable.

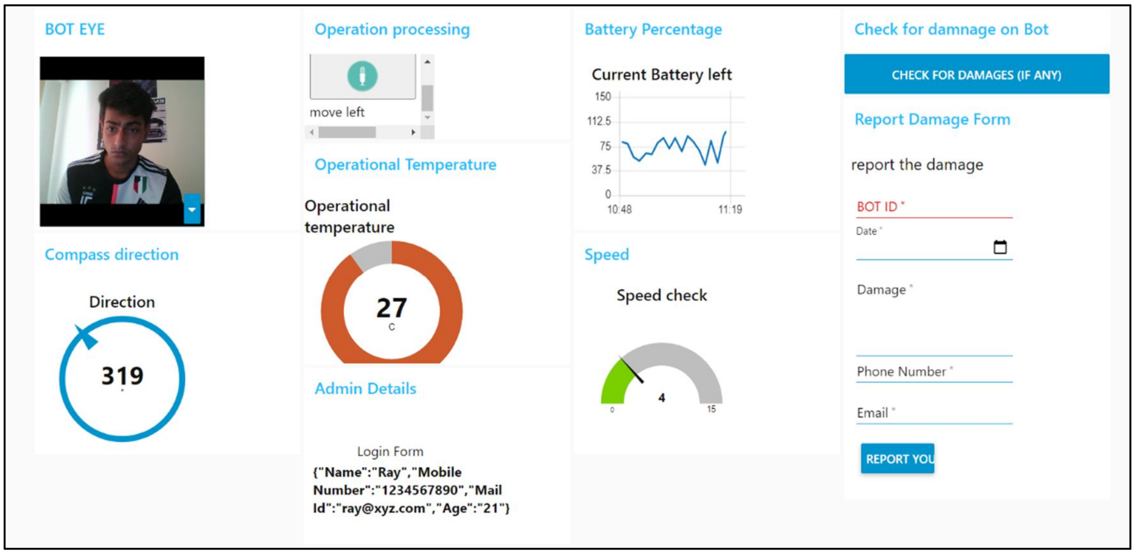

Fig 21. UI Dashboard for control and monitor

IV. CONCLUSION

The fully autonomous Mars rover presented has been designed to fulfil a variety of purposes. Static analysis and motion study were conclusive of the feasibility of the design and thus verify the two principal factors, its load carrying capacity and locomotion. The proposed rover can navigate itself through the terrain of Mars, provide live video coverage of the surroundings, examine the Martian environment, collect essential data and also investigate and collect rock samples. The rover cleared the design review, fitting all the criterion and limits set forth in the vision it was built upon. Although the design has been validated computationally, it is yet to be prototyped and experimented physically and offers a lot to improve as it can accommodate many more features.

Furthermore, the control and monitor user interface of the Mars rover as designed and discussed, benefits the user and makes tasks less complex. Its user-friendly environment is easy to understand, and has potential for further expansion if required. With its set of functions and operations, maintaining the rover's integrity alongside utilizing it in an optimized method is far simpler than having different interfaces for varying functions. Hence, this example clearly shows how the future of control and monitor of remote devices and vehicles depends on IoT, making this field a powerful asset.

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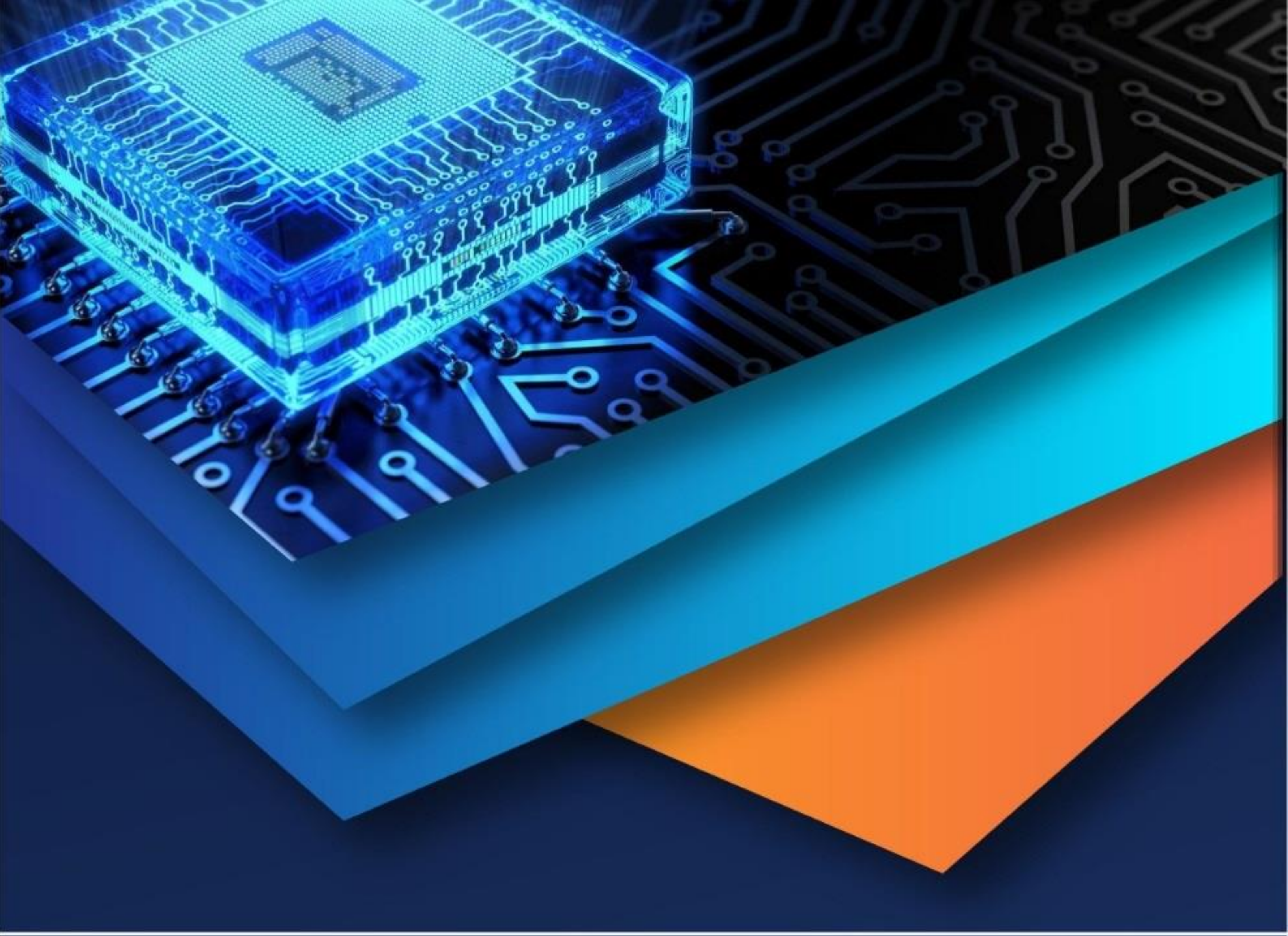

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