Autonomous Planetary Vehicle Development Platform

Bishwajit Pal, Samitha Khaiyum

ABSTRACT--- This paper presents the design, architecture, and constructions of a planetary autonomous exploration vehicle platform, which can be used to develop and test Artificial Intelligence, based software and generate a large dataset for the training of neural networks. Rovers will be at the frontier of planetary exploration, capable of executing tasks without human supervision in a harsh and unpredictable environment, and to do so it requires real-time command execution to keep it away from a risky situation. Due to the limitations imposed by communication latency and small window to communicate through deep space satellites, existing mars rovers are semi-autonomous. To develop AI-based software for the rover, a low-cost alternative of a planetary rover is required to generate data from different types of sensors and actuators for a long duration of time and perform all possible scenarios and actions. Presently this task is done using simulation or replicas of the actual rovers used in planetary missions which are very costly. The proposed rover design is a low-cost alternative, capable of powering, driving varieties of sensors, scale up to new hardware and record data as specified by the user. It can also be used to test the newly developed algorithm before being tested on an actual rover. This platform can be used as a simulation platform for software as the proposed platform is directly in contact with the environmental factors.

Keywords: Autonomous Planetary robotics, Scientific Instruments, rovers, Robotics..

I. INTRODUCTION

Nasa NASA is studying Mars using their Curiosity and Opportunity rover to search for evidence of ancient life, water, habitability and organic carbon [1], [2], [3], [4] as their primary objective. [1] In June 2018, Opportunity switched to hibernation mode because of a dust storm.[5] This resulted into end of the mission as a failure of repeated attempt to wake up the computer remotely. [6]

In last few decades we have seen the evolution of rovers from a stationary Lander to a solar-powered rover with actuated arms and now a car-size rover with a mini nuclear reactor carrying out exploration task in hostile mars environment. It's very evident, if humans want to setup civilizations on another planet, robots will be used to carry out the initial setup tasks. Exploratory robots will be a line of defense and every life support aspect in a harsh planet will depend on the rover's capabilities and the services it can perform. Rovers will be first to explore a planet even before man lands on that planet. Space exploration will be lead by exploration rovers which will do most of the preliminary job of settling a base camp.

Revised Manuscript Received on October 15, 2019

Bishwajit Pal, Department of MCA, Dayananda Sagar College Of Engineering, Bangalore, Karnataka, India.
(Email: bishwajit.pal@gmail.com)
Dr. Samitha Khaiyum, Department of MCA, Dayananda Sagar College Of Engineering, Bangalore, Karnataka, India.
(Email: hod-mcavtu@dayanandasagar.edu)

Stereo cameras are not adequate to detect all types of threat to different types of operations done by the rover; for example, wheels stuck in the sand can be detected by visually inspecting the wheel. Every planet will have a magnetic field; hence accelerometer and compass will be used in rovers to help them with local navigation. Latest mars rovers are now fitted with nuclear generators, making them operational at any point of time are useful. The rover can now navigate throughout the day and night.

II. PROBLEM STATEMENT

NASA uses a Human-robot system [6], [10], [13] to operate its semi-autonomous rovers on mars under an extreme time-constrained deep space communication link. Engineers on earth would do remote planning, command sequencing and visualization of rover activity sequences and related data products on a daily basis and send these commands to rover in mars by daily uplink and downlink cycles. The availability of space satellites in Deep Space Network and a round-trip communication averaging 20 minutes make direct teleoperation of the Mars Exploration Rovers (MER) rovers impossible. As a result, the MER rovers receives scheduled commands every sol [18] and at the end of each sol, the rovers relay back images and log data to an earth station for the planning of next sol. Both the MER is a semi-autonomous vehicle. Required maneuvers of the rover are carried out in a simulator on earth and then equivalent commands are sent to the rover. As the space exploration expands into other planets and their moons, the communication lag is a big challenge in controlling the rover from the earth. The rover is required to have profile/ guidelines for safeguarding itself from risky and threatening situations, which in turn will make them smart. This also brings the task to make rovers smart and carry out simple tasks by itself.

III. PROPOSED SOLUTION

Exploring other planets and their moon for rate/new elements and life-forms are the frontier of space science. The vast distances of the space make real-time remote-controlled operations very difficult and almost impractical. The fundamental aspects of a planetary autonomous vehicle are Mobility, Navigation, motion control, Stereovision, 3-D stereo image range mapping, path planning and obstacles detections like the Grid-based Estimation of Surface Traversability Applied to Local Terrain (GESTALT)[12]. All these aspects need to execute in sync to complete a task autonomously. Because the remote operating of all these aspects is nearly impractical, the need for a smart rover (Fully autonomous) is essential because both the twin mars rover were lost under the same circumstances. In which case the wheels continued spinning, whereas it should have stopped spinning to stop the wheels from digging into the sand. The earth station could not help at the critical moment because the instructions would be sent at the beginning of the day and the rover would execute all the waypoints throughout the day.

The CPU of the rover is radiations hardened and are slowly clocked as compared to the modern processors. This CPU is not suitable for ANN learning and training; however a pre-trained NN network can be executed on these slow processors and will make these rovers AI capable. To develop and trained NN for rover a similar platform will be required to generate the visual and sensor data in sync. Convolution Neural Network (CNN) is used extensively for feature extractions, a crucial capability of rovers, which required a large number of images for training. The proposed rover design facilitated the gathering and collection of images required for the CNN network including data from sensors like the accelerometer.

In this paper, we propose the hardware design and software architecture to assemble and build a low cost alternative of the planetary exploration vehicle to facilitate the development of intelligent software for autonomous planetary vehicles. At present functional planetary exploration vehicle is not available to the masses because they are very costly, complicated to manufacture and not available commercially. The proposed design uses low cost, readily available electronics, SoC and mechanical parts to construct this vehicle. Very few fabricated parts are used to integrate devices together, which can be easily 3D printed. This rover can be used to develop software, control systems and integrate different types of sensors. For e.g. 3d space qualified LiDAR will be available soon and its usage needs to be established for space application. This proposed rover platform can be used to establish its usage and application in space.

IV. DESIGN OBJECTIVES

The objective of the proposed design is to facilitate quick integration of sensors, actuators, embedded development boards and Soc hardware using commonly available interface ports and communication protocols. We will see in the following sections on how the proposed design can accommodate existing variety of hardware/ software and also reserves expansion ports to integrate new hardware and software.

The software used in a Rover requires the sensors and actuators, exposed to real environment, to correctly facilitate its execution. Such software has feedback loops from the onboard sensors. There are various environmental factors which cannot be simulated with precision in a simulator (like sand drift, friction against mixed material, internal friction etc), and test and validate the effectiveness of software. The proposed design is to provide a low cost platform to design and expand software capabilities for rovers, and make use of AI framework.

V. DESIGN AND THEORY & RESULTS

Planetary exploration vehicles use the six-wheel drive, four-wheel steering on a rocker-bogie suspension [Fig. 1, Fig. 2] which provides better stability, maneuverability, and obstacle negotiation. The autonomous system in Spirit and Opportunity could achieve an average velocity of 35 m/hour in rocky terrain and maintaining estimated position knowledge. These capabilities are justified due to observations of 7% rock abundance [20] at the site where the NASA Viking-1 Landed.

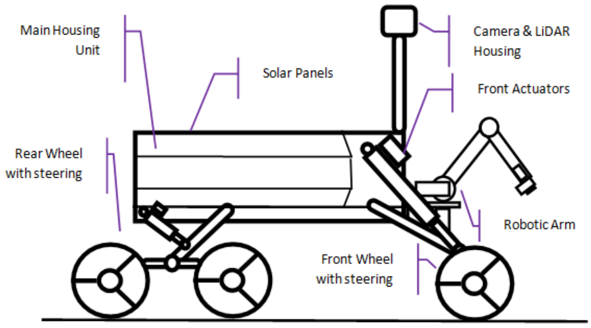

Fig. 1. Rover assembly Side view.

The body [Fig.. 3] of this rover is constructed using polycarbonate sheets and Aluminum which will give moderate protection towards the external environment. A holding area is required to mount electronics and should have enough space for further development and expansion. Figure 1 shows the side view and the top view of the proposed rover.

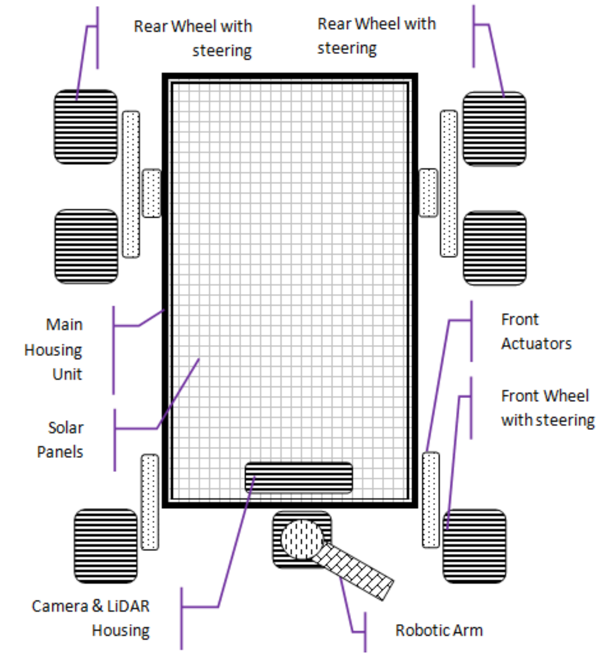

Fig. 2. Rover assembly Top view.

For normal operation, the rover is designed to maintain 30 centimeters of ground clearance on a flat surface. Due to actuated wheel shafts, it can vary its ground clearance by additional 15 centimeters. The base of the rover is build using a 6mm polycarbonate sheet and 3mm 1-inch cross-section aluminum L section beam. Polycarbonate sheets are the best choice to build the rover body because these materials are light and are very strong. Cutting and even heat molding them is easy. Aluminum L bars will add extra strength to the outer shell.

The design of the rover is divided into 5 sections:

- Perception using sensors
- Mobility and telemetry.
- Electronics, Communication and Computation Systems
- Power Generation and management.
- Software

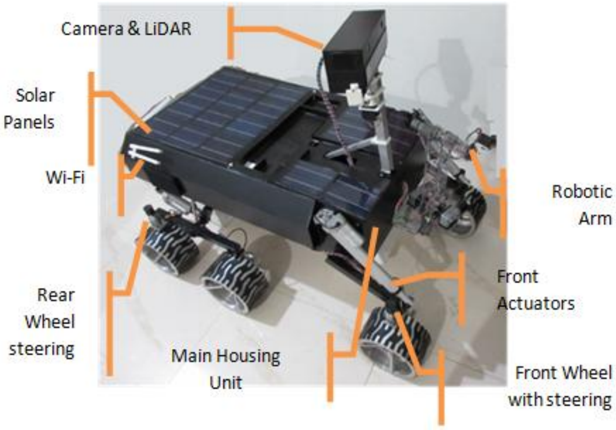

Fig. 3. Parts of Rover.

a. Perception using sensors

The most widely used vision system used in rover is a stereo camera system mounted on a pan-tilt assembly. Solid Sate LiDAR will be soon used for autonomous navigation. In this proposed design, the vision system [Fig.. 6] consists of a set of a stereo camera which can be used for depth perception and an additional low-cost 3D depth camera can be used for the 3D point cloud generation. Optionally solid-state LiDAR can also be mounted to obtain long-range measurements. Combined these three types of vision sensors will make a variety of sensor data. The combination of Stereo and Depth camera can be used to extract 3D information of the terrain and build an advanced object recognition system The Mars Pathfinder rover, Sojourner, used autonomous stereo triangulation [29]. The proposed vision system uses standard Stereo camera like Intel® RealSense™, Bumblebee series, Stereolabs® ZED™, ASUS® XtionPro™ Live, Ensenso® , as an alternative to stereo cameras used on an MER rover. In another similar design, we used two independent USB camera Like the Logitech C310 HD cameras with USB 2.0 interface aligned and mounted next to each other. These cameras can generate images above HD resolution. Many of the mentioned stereo cameras also come with an additional 3D Depth camera. A depth camera can be used to generate 3D point cloud-like the Microsoft Kinect and Intel realsense 3d Depth camera.

Traditional LiDAR systems are electromechanical and rely on moving parts that have to be precise and accurate. The moving parts put a restriction on the size of the system and compactness would increase the difficulties in precise manufacturing, hence the overall cost is high. The Solid State LiDAR uses optical emitters to send out bursts of photons in specific patterns and phases to create directional emission and focus. No physical adjustment to the optical emitters needs to be made to achieve this, making it resilient to vibrations and compact in size. LeddarVu 8 or 16 segment solid-state LiDAR sensor ranges are readily available online. This is a low-cost alternative used in this rover development platform. There are also Micro-Electro-Mechanical System (MEMS) based LiDAR, which uses micro-mirrors to directionally control emission and focus. This vision system closely resemble stereo vision software [18], [29], robotic systems like Mars rover research [11], [16], [24], [25], [26], Pioneer [21], Unmanned Ground Vehicles [15], Urbie [17], and PerceptOR [23] .

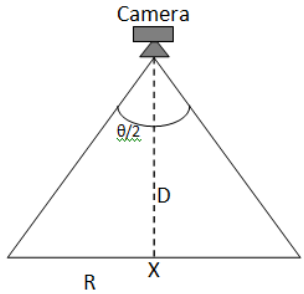

Fig. 4. Magnitude of a pixel for Horizontal Field of view.

Horizontal length per pixel = 2D [Tan (HFOV/2)]/R (1)

The horizontal and vertical FOV of a camera greatly influences the manoeuvrability of a rover to navigate on a terrain and path panning. A rover making sharp turns requires a wide angle camera and a cruising rover will require a narrow FOV camera. The following (1), (2) must be considered to match the volumetric resolution required by the rover to safely navigate. For a given camera with resolution R, Horizontal FOV and vertical FOV, every pixel represents a 2D area of space in 3D. A point at X (Fig. 4) and Y (Fig. 5) which is a pixel from a 3d Depth camera; at a distance D from the centre of the camera will have a horizontal magnitude as in (1) and Vertical magnitude as in (2).

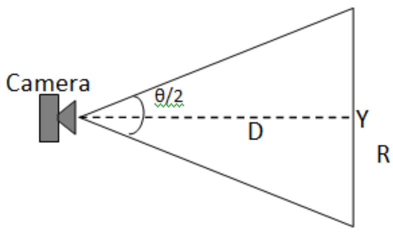

Fig. 5. Magnitude of a pixel for Vertical Field of view.

Horizontal length per pixel = 2D [Tan (HFOV/2)]/R (2)

Define In this proposed vision system [Fig. 6], the components require a DC power source and high-speed communication bus to send all the images to the main computer. The Vision component is mounted on a pan-tilt assembly [Fig. 7] and has a 4 channel USB hub mounted inside the housing for camera connections. The total bandwidth required [eq. 3] for the all camera running at the same time needs to be less than the maximum bandwidth of the bus (USB, Ethernet, RJ45 etc.). The maximum bandwidth is governed by the USB Host Controller and not by the number of USB Port. A Motherboard can have many ports or hubs which connect internally to a single Host Controller and so the bandwidth will effectively be shared among them. To increase the bandwidth, we recommend installing a Multi-Host PCIe expansion card which has dedicated Host Controller. This is same for Ethernet or any other kind of interface available on modern computers. (3) estimates the cumulative bandwidth required by n number of sensors having a resolution (X, Y) running at a frame rate F per second and each pixel takes P amount of bits.

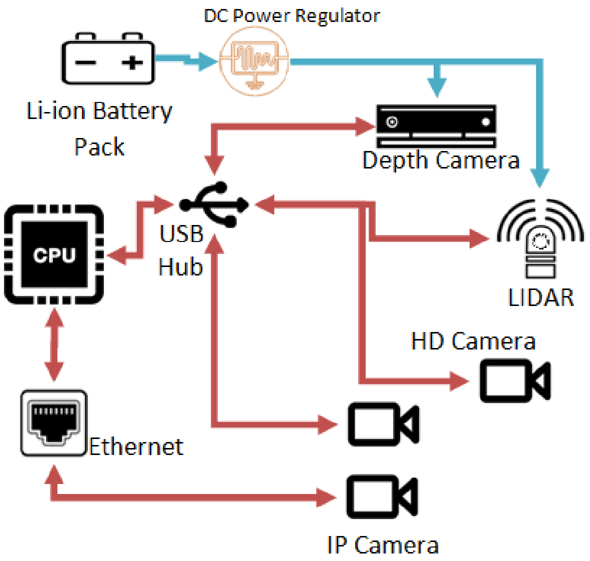

Fig. 6. Block Diagram of vision System of Rover.

Some camera may need an external power supply, which can be fulfilled by a DC to DC buck converter. These are compact and can be fitted inside the camera mounting unit. More than one may be required if sensors need different voltages to operate. There can me many stereo cameras for navigation [14]. Front and rear stereo camera pairs used for local terrain hazard detection and avoidance during autonomous navigation and global path planning.

$$Bandwidt\ required = \sum_{i=1}^{n}(X_n * Y_n * F_n * P_n) \quad (3)$$

b.Mobility and telemetry

The design of the mobility system consists of articulated arms, DC motor drive units and sensors. This rover uses 6 aluminium wheels on rocker bogie configurations [Fig. 4] which minimize the overall vehicle tilt caused by driving over the uneven surface, as mentioned in [13]. All six wheels are fitted with absolute encoder 10 RPM DC PMDC motor, can be driven at translational speeds (forward and backwards) up to 4.1 meters per minute. Four corner wheels are steerable facilitating double-Ackermann steering, which enables execution of driving arcs with curvature radii as tight as 1.5 meters and turns-in-place rotation about its central vertical axis. Linear actuators are fitted on the shafts.

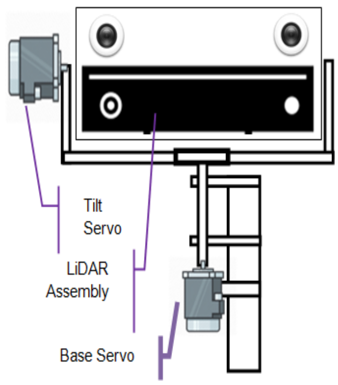

Fig. 7. Pan Tilt Assembly for mounting vision system.

Sensing and control of mobility includes wheel absolute encoders, potentiometers for articulated suspension kinematic state, 3 axis accelerometer, gyroscope and digital compass for absolute heading determination. This rover maintains an estimate of their local position and orientation updated at 30 Hz while driving. Sensors used like the MPU6050 can achieve a sample rate of 200Hz on an I2C Bus. The rover software can perform safety checks to ensure vehicle safety during basic mobility by adhering to reactive safety checks, predictive safety checks, and physical limits. Physical limits are allowed the duration of motion command execution, which enables the software to stop or pause execution in the event which takes longer to execute than expected. Reactive protection will stop the execution based on unexpected triggers send by its onboard sensors such as low-battery power. Predictive safety is generated from the vision system predicting risky terrains or excessive vehicle tilt. A complete list of mobility faults is listed in [10].

The design of a custom wheel with hub motor requires to addressing 2 design considerations. Firstly the torque required moving the entire vehicle (even in case of partial failure) and secondly a dc motor drive unit which is easy to interface or there should be multiple ways to interface the motor. To address the Interfaces of the hub motor, this proposed design recommends use of motors integrated with encoders and power regulator build into same unit. Such devices have less wiring and proximity of the controller to the motor shaft adds benefit in abstracting the functionality between physical implementation and software API. There are 360 degree servo motors available which are ideal for this proposed design. A 6 wheel configuration can suffer maximum of 2 failed wheels and still maintain movements. To maintain such capability trade off can be between the radius of the wheel and the total power required by the wheel motor. This will sometime require cutting an aluminum pipe [Fig. 8] into equal pieces and building shafts and hub unit to house the drive shaft of the motor. The motor and wheel can be difficult to build as a single unit. Hence custom fitment will be required.

Fig. 8. Custom wheel block for Rover.

To address the torque requirements, the final torque output of the wheel depends on the diameter of the wheel. The net driveable power calculation can be estimated by considering forces acting on the wheel. For starting the vehicle from 0 to x meter/sec speed requires to overcome the static friction in non-slipping condition and once the body is in motion the kinetic friction is to account for to estimate the torque requirement of the motor. Static friction is usually higher than kinetic friction hence we should take the static friction coefficient into account in order to estimate the required torque of the drive motor.

The following equation must be considered while designing the wheel. The total mass of the rover is equally applied on each of the 6 wheels then the frictional force Ff for static friction μ and weight N can be expressed by (4).

$F_{fr} = mg\,\mu/6$

Where, Ff = frictional force (N, lb), μ is static (μs) or kinetic (μk) frictional coefficient, N is normal force between the surfaces in Newton. From Fig. 9 the torque required at the motor shaft and at the wheel rim is given by T Drive Shaft which is Fd r and T friction as Fr R. Torque at Drive Shaft should be higher than Total friction in order to move the rover. Whenever Torque at Drive Shaft is greater than Total friction Wheel Slip will occur.

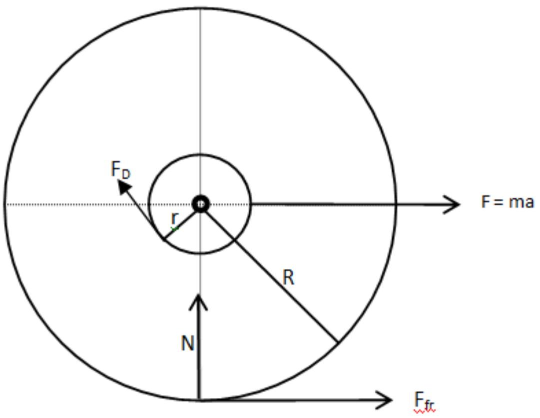

Fig. 9. Forces Acting on Wheels Force.

$F_d\, r = F_{fr}\, R$ (5)

And the maximum acceleration, without sipping the wheel is given by (6):

$A_{max} = F_{fr} / m$ (6)

In this proposed rover the wheel is mounted with a hub motor fitted with an absolute encoder achieving max speed of 10 rpm. The wheels are 8 inches in diameter which can clock speed up to 246 meters per hour. For the wheel hub motor, we have used RMCS-220x from Rhino Motor [Fig. 10]. The hub motor should consist of an absolute encoder encased in a dustproof casing. The motor used in the prototype vehicle had an encoder DC Servo motor whose absolute optical encoder (32bit) has a resolution of 0.2deg and a high power electronic servo drive on an Industrial grade high torque dc motor @ 18000 RPM Geared down to 10rpm @ 120kgcm of torque using metal gears encased in industrial grade aluminum. The driver of theses motor can be communicated using multiple protocols like UART, I2C and direct signals like PPM and analog signals directly for absolute speed and absolute position control. The controller provides high correction torque through a closed PI control loop. A high rpm motor with higher gear reduction will give higher positional control.

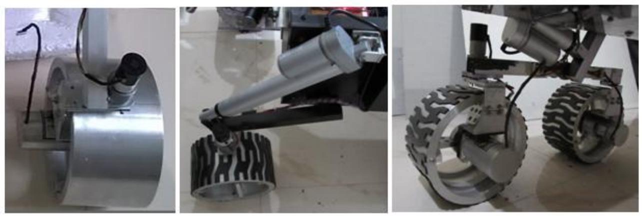

Fig. 10. Front and rear wheel Actuator.

Position and Speed of an RMCS-220x can be controlled through UART I2C, PPM or an analog potentiometer. DC Drive motor takes high current during start-up, high load, climbing terrain or irregular load conditions. Hence the power supply to the DC drive motor should match the maximum stall current of the drive motor.

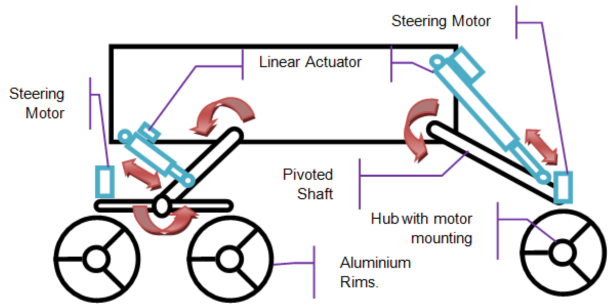

Fig. 11. Directions of actuation.

Actuated arms [fig11], [12] are used to mount the wheels which give the rover maneuverability on uneven surfaces. The front wheel has a longer actuator compared to the rear one. The front actuators can carry up to 500 Newton of force at 20mm/sec of speed, whereas the rear actuators can take up to 900 Newton of force at 10mm/sec of speed. These actuators are made from aluminum alloy. The main advantages of this setup are to recover from risky situations where the rover needs to shift its weight from its effected wheels to other wheels which are at firmer ground.

This rover has steering capability [Fig. 13] at the front and rear motors. With 180-degree steering capability, the rover is highly mobile and manoeuvrable. Various types of steering angles can be made to move the rover. Each of these steering assemblies is independent. The steering motor is a 10RPM 12V DC producing 60Kgcm of torque with quad encoder in a full metal construction.

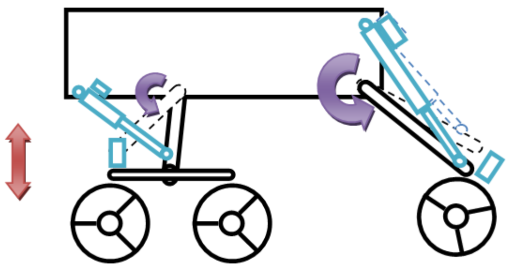

Fig. 12. Maximum Actuation suspension

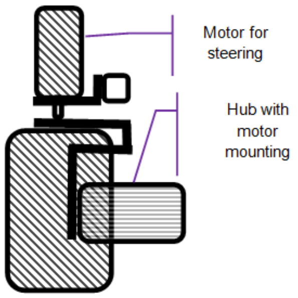

Fig. 13. Steering and hub assembly

C.Electronics, Communication and Control Systems

The proposed planetary rover development platform can be used to execute algorithms which are complex single-threaded and training of neural network. The later requiring parallel computing support to save time and achieve better performance than single CPU. The rover is designed to support a large set of software which are used for NN development and support varieties of sensors and devices whose API / drivers are available either in windows, Mac or Linux OS. To fulfil such requirement, the main computer has to be a x86 based CPU with GPU capable of hosting windows and Linux operating system. This combination of CPU-GPU design is preferred because CPUs have large caches and branch-prediction logic for decision-based code, complex algorithms, flow control and disposition of data whereas GPUs are a massively parallel array of processors with small cache and high memory bandwidth but limited branching performance operating on large amounts of data simultaneously using computational kernels, architected to maximize arithmetic performance. The GFLOPS/Watt unit for GPU is very less than that of CPU.

The CPU of a space-qualified rover is radiation-hardened, like the Computer in both Spirit and Opportunity houses, a radiation-hardened 32-bit Rad 6000 microprocessor with 128 megabytes of RAM, 256 megabytes of flash memory and smaller amounts of other non-volatile memory. The other similar example is the RAD750 PowerPC microprocessor built into the rover's redundant flight system, the rover is equipped with two computers, but only one is active at a time. Both are built around a radiation-hardened BAE RAD750 microchip operating at up to 200 megahertz. Each computer is equipped with 2 gigabytes of flash memory, 256 megabytes of random access memory and 256 kilobytes of erasable programmable read-only memory. These processors are very costly and cost thousands of dollars and the resulting computers can cost anywhere from $200,000 to a half-million dollars.

The proposed rover houses an Intel i5 quad-core computer [Fig. 14] mounted towards the front end, coupled with a high speed of 240 GB solid-state drive. The SSD can read at 530 MB/s and write speed at 440 MB/s, which will support AI and machine learning development, resistant to vibrations and consumes less power than conventional hard drive. It also hosts a dedicated USB 3.0 controller to match with the bandwidth requirements of the vision system.

This proposed rover houses a Graphic card from Nvidia consisting of 192 CUDA Core units operating at a 954 MHz with 2,048 MB DDR3 @ 900 MHz, connected using a 64-bit memory interface. The overall power draw is rated at 19 W maximum delivering 366.3 GFLOPS @ FP32 (float) performance or 122.1 GFLOPS @ FP64 (double) of computation power is available. Most of the python based neural network frameworks (Tensorflow, Keras etc.) is capable of using CUDA GPU cards to accelerate its learning phase.

For the end users a 10 inch LED touch Screen from SainSmart capacitive HD display [Fig. 19] features is mounted at the rear of the rover. This screen works with HDMI, VGA, and AV (CVBS) input.

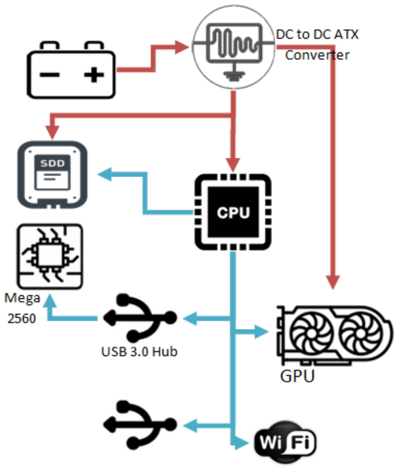

Fig. 14. Main CPU and block diagram

The proposed design for the computational unit recommends, the motherboard chosen should have to support the latest processors and further more from the same processor family and memory module. From connectivity prospective, the motherboard should have as many different types of interfaces as possible like the USB 3.0/2.0, serial port header, parallel port header, PS/2 keyboard/mouse port, D-Sub port, DVI-D or VGA/HDMI port and RJ-45 port for upward scalability and interfacing variety of devices.

For controlling the electro-mechanical units [Fig. 15], Atmel 2560 the microcontroller has been used to interface the power electronics with the computer. Atmel 2560 has a dedicated USB interface to the computer and uses virtual ports for the interface. This is easily scalable and compatible with all major operating system. 2 Unit of Atmel 2560 is used to control electronic and drive system in the rover. One of the microcontrollers is used to control all the wheel actuators and steering, whereas the second one is used for interfacing mechanical arm. The Atmel® AVR® architecture is more code efficient while achieving

International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249 – 8958, Volume-9 Issue-1, October 2019

throughputs up to ten times faster than conventional CISC microcontrollers.

The DC power supply to the computer is complicated as it required different regulated voltage supplies. A typical computer motherboard will have 24 pin ATX power supply. To feed this power supply a DC to DC ATX converter is used to power the computer and solid-state drive. A 400 Watts DC to DC-ATX Power Supply from HDPLEX is used to power to the main computer. To maintain a good DC supply without spikes or noise, the converter unit should have dedicated ripple noise suppressing circuit, high current inductance, preferably WIMA Audio Grade Capacitors, high grade MOSFET, dedicated Control Chip, and copper based high-quality PCB. The control chip should be able to protect the computer from Overvoltage, Overload, over current, short Circuits and operate between wide voltages Input. Wide voltage operability is required as the lithium-ion battery packs has a non linear discharge voltage cycle.

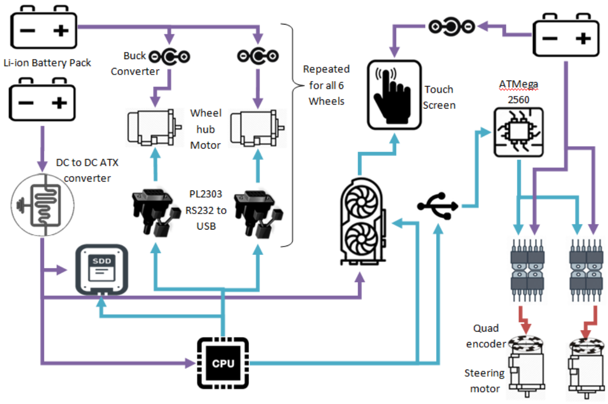

Fig. 15. Rover Electronics, power and control flow Diagram

To design a flexible communication between Microcontrollers and the main CPU, PL2303 USB to RS232 converter is used to interface [Fig. 17] the wheel hub motor to the computer. Every wheel hub motor should have its own independent PL2303 interface. The PL-2303 provides RS232-like full-duplex asynchronous serial connection to any USB host and can simulate the traditional COM port on most operating systems allowing the existing applications based on COM port to easily migrate and be made available on USB. This interface is compatible with any hub motor having RS232/RS422/RS485 interface.

This rover allows end user or other devices to connect via Ethernet router for communication using IP protocol. The Ethernet offers many IP Based devices to communicate with the main CPU. The router requires to supports Wi-Fi Protocols like 802.11b/g/n, 802.3/3u for connectivity to a wide set of equipment commercially available. Using 4 antennas, this router is capable of achieving speed up-to 300Mbps.

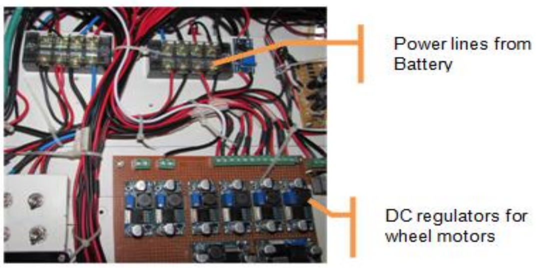

Fig. 16. Wheels Power Regulators Diagram

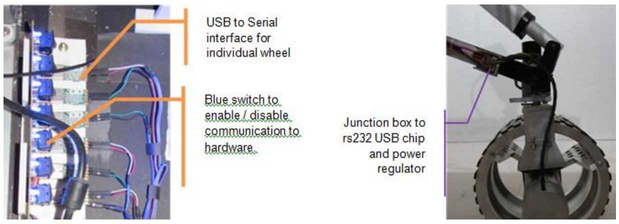

Fig. 17. USB Hub Interface to Wheel motors

There are 4 scenarios [Fig. 18] where a user can connect to the rover. Starting with attaching a Monitor to the GPU card directly, the user can mirror the display to a separate monitor. Secondly, a user can connect to the router using an RJ45 network cable and directly network into the operating system of the rover. Thirdly, a user can connect using Wi-Fi from a distance (up to 300 meters) to the rover. This mode can be used while testing the rover in movement. And fourthly by connecting the router to internet via WLAN and then using remote desktop software tools to connect to the rover. The total power consumption of the router is 5 watts.

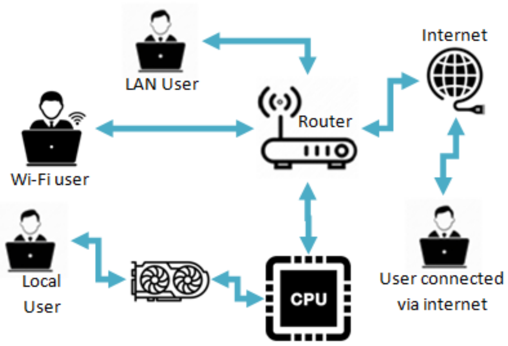

Fig. 18. Rover Communication Diagram

d.Power Generation and management

The power module of the proposed rover is designed to handle power fluctuations and provide multiple regulated power supply. Separated battery packs are required because the fluctuation caused due to the

sudden need of power by hub motor or robotic arm can result in CPU Shutdown. Separated battery packs will also facilitate partial switching off of devices, while diagnostic routines.

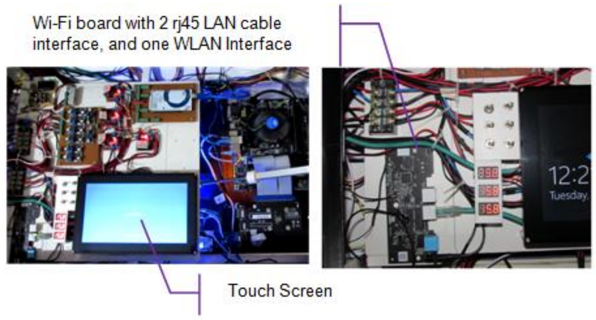

Fig. 19. Display unit Diagram

This rover houses 3 independent Li-ion battery packs [Fig. 20]. One of the 3 packs [Fig. 21] is having 4S10P configuration. 18650 Li-ion cells are used for these packs which are rated at 3.6 volts @ 2.6 amps. These cells can be safely pushed to 2 amps. The 4S10P configuration cell can deliver 3.6*2.6*40 = 374 Watts. The other two Li-ion are 4S5P configuration and can deliver 187 watts each. The overall combined power output of the battery pack is around 748 watts. Appropriate cell configuration has to be chosen because of the voltage difference between fully charged and discharged battery increases as the cell increases. Some components may shut down when a minimum voltage is encountered. This can result in uneven battery usage. Hence independent calls pack must be used in a rover. Voltage regulator and dc to dc converters also can be used to normalize voltages for different devices.

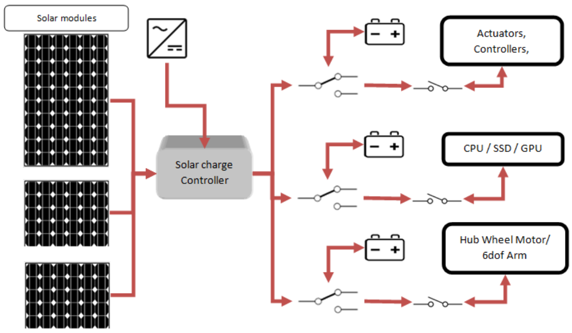

Fig. 20. Rover Solar and Battery Power Diagram.

The solar panels (optional) are rated at 12-volt nominal usage. The voltage will not be consistent and the Li-ion battery pack will require 17 volt DC. A step-up DC to DC booster is used to achieve the desired voltage to charge the battery.

This proposed design uses the following equations to estimate the power needed by the rover equipment, and estimate the battery pack required for a rover. The voltage drop, while battery discharge as Vmax and Vmin , for a given battery type. There are 2 types of devices used in rover, power converters and Power consumers. Power converters convert voltage to higher or lower voltage at the cost of some energy. Power consuming equipment will consume power between ranges. The Power lost while conversion is directly proportional to the sum of efficiency lag of all converters.

$$P_{cnv} = \sum_{i=1}^{n} Vmax_i * Imax_i \left(1 - \frac{D_{eff}}{100}\right)$$

Where, Power lost by the converter running at V volt and I ampere is Pcnv and Deff is the conversion efficiency in percentage. The total Power Used by devices is also related to the sum of max load required by each device, is denoted by eq. 8.

$$P_{devices} = \sum_{i=1}^{n} (Vmax_i * Imax_i) \quad (8)$$

Using (7) and (8) , the total Power needed by the entire system is given by the (9) .

$$P_{total} = \sum_{i=1}^{n} Vmax_i * Imax_i \left(1 - \frac{D_{eff}}{100}\right) + \sum_{j=1}^{n} (Vmax_j * Imax_j) \quad (9)$$

In order to discharge the battery safely, the maximum power needed by all devices must meet the Nominal rated power of a battery pack. To estimate the battery needed (10) can be used. The C discharge rating can greatly reduce the total battery required by the system at the cost of runtime, as shown in (10).

$$P_{total} = V_{nominal} * A_{rated} * C_{discharge} \quad (10)$$

The The Li-ion battery pack used in this rover is rated at 16 volts and the hub motors are rated at 12 volts. The battery voltage drops as it is discharged, which can cause motion errors in the wheel hub motors. This requires a step-down regulator to control the maximum current and voltage supplied to the hub motor under different stress and load condition. This is achieved using an LM2596 monolithic step-down switching regulator, capable of driving a 3 ampere load. LM2596 converter is a switch-mode power supply; its efficiency is significantly higher in comparison with three-terminal linear regulators, especially with higher input voltages.

All 3 battery packs are interfaced with a 16.8V 40A lithium battery protection boards with auto Recovery. These BMS are programmed to Charge at Nominal voltage of 3.6V, 3.7V lithium battery. Charging a 4 battery in series at 16.8V to 18.1V. Each battery pack is having a continuous upper limit discharge current of 20 Ampere. A standard double rail 16 volt SMPS is used to charge the battery from the 110/230 volt AC grid power outlet. The voltages of each battery are indicated at the left side of the touch screen.

Sometimes the Dc to ATX converter may not fall within the Li-ion battery discharge rate. In Such case a Dc to Dc converter will be required to deliver the suited voltage to the ATX converter. The 400 watts dc to ATX converter mentioned before is pre-fitted with a DC 10-60V 30A 1500W to 12-90V Non-isolated Boost Converter Step up Power module. This module can power up to 1500 watts of total DC load, hence it can be fitted to many types of ATX converters. L293D H bridge drivers are used for stepper motor / motor and speed controller.

E Robotic Arm

This proposed rover design consist of a 6DOF mechanical arm [Fig. 22], [Fig. 23] fitted at the front. The robotic arm is designed to facilitate quick communication with each of the motors at each joint. The Base Motor delivers a torque of 6 Kgcm and fitted with a quad encoder which has 15120 Counts per revolution @ 10 RPM. The shoulder motor is a twin worm gear motors, operates at 24V with a speed of 7RPM @ 140 kg-cm of the massive torque, facilitating locking in the absence of power.

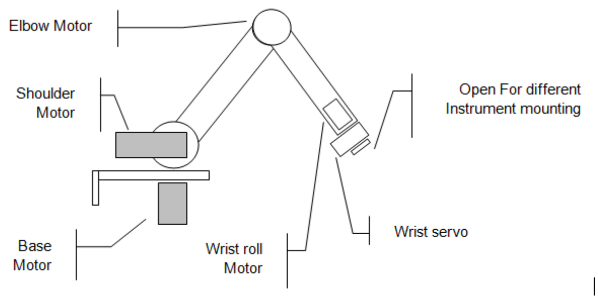

Fig. 21. 6 DOF Robotic Arm

The elbow motor is a 10RPM 12V DC geared motors delivering a torque of 60Kgcm. The motor comes with metal gearbox and off-centred shaft operating at 18000 RPM

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DOI: 10.35940/ijeat.A2979.109119

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consuming 7.5 amps of current at its peak load. An Integrated Quad encoder for precise position and speed control delivering 2164320 Counts per Revolution resulting in very precise movements. These motors are controlled using H bridge bidirectional drivers [Fig. 19], taking PWM signals from microcontrollers which are in turn connected to the main CPU. Each of these motors can be operated independently. Each of the arms is also fitted with limiter switches which stop the arm from moving beyond its maximum limit angles. This is essential because during development of accidental movements of the arm beyond the limit

Fig. 22. 6 DOF Robotic Arm

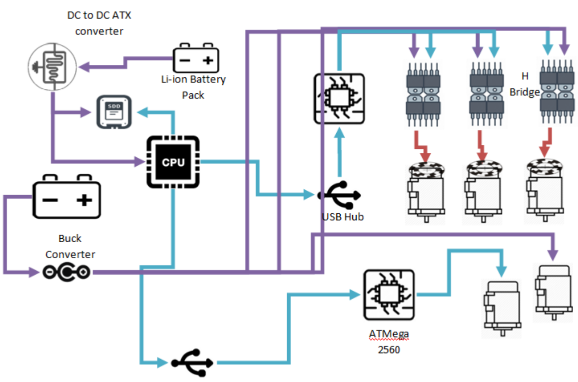

Fig. 23. Robotic Arm Control block diagram

This rover platform can accommodate new sensors using open ports for future expansion [Fig. 25]. There are 3 ways to add new devices to the rover. Firstly, attaching the new device to the existing microcontroller's communication ports (USART / I2C/ ICSP / SPI). Secondly by plugging directly into the USB (2.0 or 3.0) port and the third way is to use RJ45 cable (network cable).

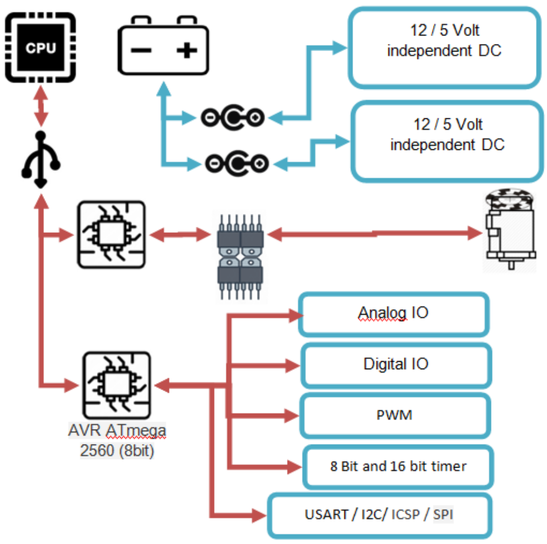

Fig. 24. Robotic Open for future expansion

D Software for Rover

The proposed software architecture for this rover is flexible to add new features. Any new feature can be added as a new program independently executing without interrupting other programs. This is achieved using bus architecture. This rover platform will support software addressing different aspects like control and management of the computing resources, devices, command processing, sequence execution, data collection/ compression , telemetry, time management, power/control switching, Celestial body position estimation (Earth, sun, Mars, etc.) and solar array control and communication.

The following types of software can also be developed in this rover platform rover (but not limited to the following):

- AI and Neural network based development frameworks running on Linux and Windows can be used here with GPU support.
- Microcontroller, Sensors and 3d sensors integration.
- Reverse kinematics for robotic arm and Software for real time motor control.
- Grid matrix of path planning, terrain mapping, 3d point cloud mesh.
- Drive and control system for mobility and traversal.
- Logging & Monitoring.
- Inter process communication.

The software required for different aspects of an autonomous rover can be built into the independent applications, communicating with each other using Inter-Process Communication channels [27].These group of software can be architected similar to bus type [Fig. 26] and on publish/subscribe message-passing model.

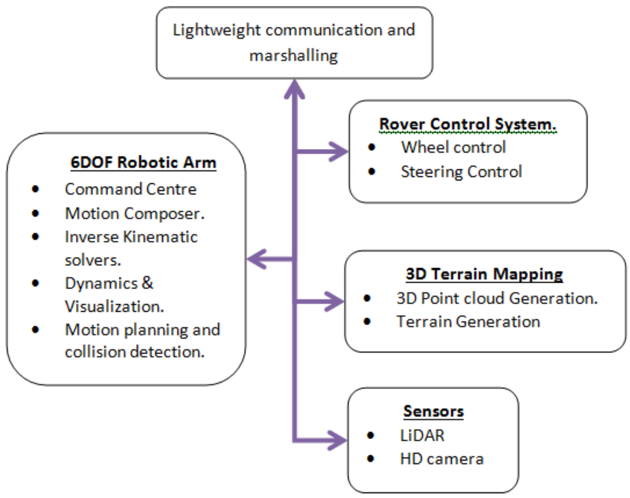

Fig. 25. Software architecture layers

This rover's robotic arm can carry out manipulative activities. The software for robotic arm consists of a 3D viewport, a command interface and a simulation of the robotic arm and algorithms for reverse kinematics. Fig. 27 is an example of a robotic arm simulator with the necessary calculation for kinematics.

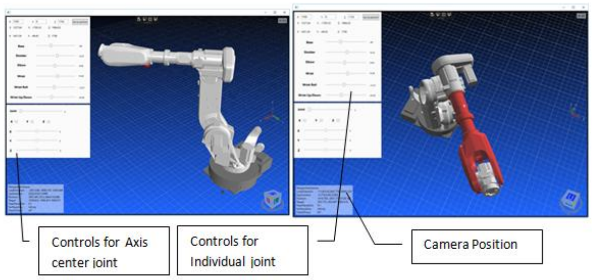

Fig. 26. Robotic arm simulation

This rover's onboard LiDAR / 3D Depth camera can be used for the development of terrain mapping [Fig. 28] algorithms, generate 3D point cloud or 3D mesh, Grid Matrix for traversal [Fig. 29], Outliers or edge detections and Object Detection.

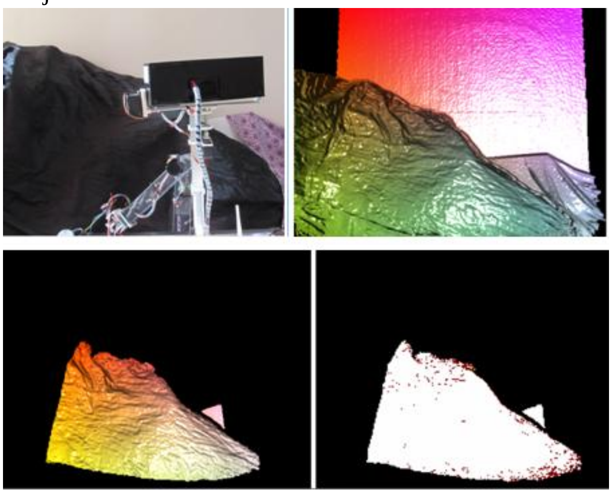

Fig. 27. 3D terrain Generation using kinect fusion

The software of a rover has to be resilient to a fault, hence the modular design of the software component is preferred and for easy maintenance. This architecture requires mapping of rover's capability into software applications and to execute task individual software applications need to communicate with each other over an IPC channel at the least latency.

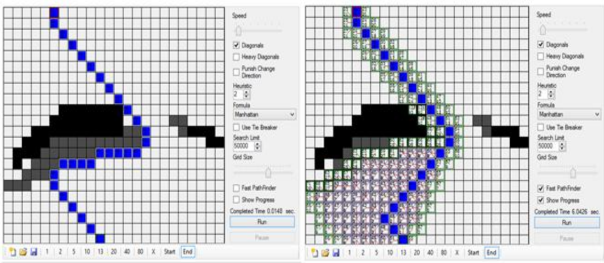

Fig. 28. Path Planning Models.

F Results

The proposed rover platform closely resembles the functioning of an actual planetary rover, but with very less cost of construction and also provide necessary hardware to develop software which can be used to test and develop AI capabilities and other utilitarian software required for the explanatory vehicles. Testing directly on a space qualified rover will be time consuming and costly as these space qualified rovers are few in numbers and are very costly to build.

Commercially available industrial grade vision sensors (Solid state LiDAR, Laser Ranging etc.) can be tested and verified on this platform. These Solid state Sensors will find applications in space in future. Different types for motor drives can be fitted, interfaced with the open ports and tested for its effectiveness and performance.

NASA's twin rovers were lost due to similar reasons, where the rovers got their wheel stuck into the sand. A smart rover would have recovered from it as soon as it found its wheel in sinking position, rather than waiting for the earth station to figure out. In this rover, such a situation is handled by shifting the weight from the sinking wheel by actuators and counterbalancing the weight on other wheels.

The CPU of a space-qualified rover can costs anywhere from $200,000 to a half-million dollars, whereas the CPU used in this rover are industrial grade and costs below one thousand dollars. This rover's CPU is an Intel i5 processor which can run both 32 bit and 64-bit instructions at 3.4 GHz which is 14 times faster than the RAD750. This enables the user to execute a number of programs and do testing faster and save time cost and energy. The algorithms can also be tested on Window or Linux operating system. Once the tested program shows good result it then can be taken to the actual rover to execute.

Solid-state LiDAR is on the rise and will find its application in planetary rovers very soon. As lasers are already used in space, having a LiDAR will not be very difficult. For navigation, a LiDAR will be generating point cloud which will be used by the rover to autonomously navigate itself on the hostile planet surface. In this project, we have used a laser-assisted Depth camera to generate a 3D point cloud. Using software in sensor fusion technology we have been able to generate terrains in 3D and have used path planning algorithms to navigate the rover on a safe path.

Software for the robotic arm has also been developed where the user can perform all the possible iterations of the robotic arm movements. Robotic arm movements are risky as it can be handling instrumentations. These movements can be recorded, modified and replayed whenever required. A whole collection of movements can be stored and orchestrated, whenever required.

We have also found that the locomotion of the rover is much better when the electronic driver and absolute encoder are mounted into one unit. This rover also leverages the power of CUDA framework and hence supports heterogeneous computing. The provided hardware can support tensor flow, all versions of python. The overall power of the rover has been reduced to 400 watts.

G Conclusion

Smart rovers are a potential contender for future planetary exploration as remotely operating the rovers from the earth is not a practical solution. This rover can prove to be a helpful platform to design and test smart rovers. The overhead to send humans on other planets is very high compared to rovers. A smart rover is practical and economical and can be used to explore setting up and maintain new base camps on other planets before humans arrive.

Retrieval Number: A2979109119/2019©BEIESP
DOI: 10.35940/ijeat.A2979.109119

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This rover can execute software running on 32 /64-bit version of radiation-hardened computer and simulate movements of Robotic arm and formulate kinematic measurements. The 3D depth camera in the vision system with additional HD cameras and options to add more HD cameras makes the system capable to mapping terrains, mesh, point cloud, path planning and also test varieties of vision sensors. With the addition of a CUDA capable hardware, AI/ML development frameworks can leverage better performance. This rover is a feasible and low-cost platform to develop and test AI/ML-based software for smart rovers.

REFERENCES

1. NASA declares Mars rover Opportunity dead after 15 years on the red planet". The Daily Telegraph. February 13, 2019.
2. A. Mishkin, J.C. Morrison, T.T. Nguyen, H.W. Stone, et al., “Experiences with operations and autonomy of the Mars Pathfinder microrover,” Proc. IEEE Aerospace Conference, Aspen, CO, March 1998.
3. A. Rankin, C. Bergh, S. Goldberg and L. Matthies, “Passive perception system for day/night autonomous off-road navigation,” SPIE UGV Symposium, Orlando, FL, April 2005.
4. A.H. Mishkin, D. Limonadi, S.L. Laubach, D.S. Bass, “Working the Martian night shift: The MER surface operations process,” IEEE Robotics and Automation Magazine, in press.
5. B. Harrington and C. Voorhees, “The challenges of designing the rocker-bogie suspension for the Mars exploration rover,” Proc. 37th Aerospace Mechanisms Symp., Galveston, Texas, USA, May 2004.
6. C. Leger, A. Trebi-Ollennu, J. Wright, et al, “Mars Exploration Rover surface operations: Driving Spirit at Gusev Crater,” Proc. IEEE Intl. Conference on Systems, Man, and Cybernetics, Waikoloa, HI, October 2005, pp. 1815-1822
7. D.A. Forsyth and J. Ponce, Computer Vision: A modern approach, Prentice Hall, 2003.
8. Grotzinger, John P. (January 24, 2014). "Introduction to Special Issue - Habitability, Taphonomy, and the Search for Organic Carbon on Mars". Science. 343 (6169): 386–387. Bibcode:2014Sci...343..386G. doi:10.1126/science.1249944. PMID 24458635. Retrieved January 24, 2014.
9. Grotzinger, J.P. et al. (January 24, 2014). "A Habitable Fluvio-Lacustrine Environment at Yellowknife Bay, Gale Crater, Mars". Science. 343 (6169): 1242777. Bibcode:2014Sci...343A.386G. CiteSeerX 10.1.1.455.3973. doi:10.1126/science.1242777. PMID 24324272. Retrieved January 24, 2014.
10. J. Biesiadecki, E. Baumgartner, R. Bonitz, et al, “Mars Exploration Rover surface operations: Driving Opportunity at Meridiani Planum,” Proc. IEEE Intl. Conference on Systems, Man, and Cybernetics, Waikoloa, HI, October 2005, pp. 1823-1830.
11. J. Biesiadecki, M. Maimone, and J. Morrison, “The Athena SDM rover: A testbed for Mars rover mobility,” Proc. Intl. Symp. on Artificial Intelligence, Robotics and Automation in Space, Montreal, Canada, Paper No. AM026, June 2001.
12. J.J. Biesiadecki and M.W. Maimone, “The Mars Exploration Rover surface mobility flight software: Driving ambition,” Proc. IEEE Aerospace Conf., Big Sky, MT, 2006.
13. J.J. Biesiadecki, C. Leger and M.W. Maimone, “Tradeoffs between directed and autonomous driving on the Mars Exploration Rovers,” Proc. 12th Intl. Symp. on Robotics Research, San Francisco, CA, Oct. 2005.
14. J.N. Maki, J.F. Bell III, K.E. Herkenhoff, S.W. Squyres, et al, “The Mars Exploration Rover engineering cameras,” Journal of Geophysical Research, Vol. 108, No. E12, 2003, pp. 12-1–12-24.
15. L. Matthies, A. Kelly, T. Litwin and G. Tharp, “Obstacle detection for unmanned ground vehicles: A progress report,” Proc. 7th Intl. Symp. on Robotics Research, Springer-Verlag, 1996.
16. L. Matthies, E. Gat, R. Harrison, B. Wilcox, R. Volpe, and T. Litwin, “Mars microrover navigation: Performance evaluation and enhancement,” Autonomous Robots, Vol. 2, No. 4, Kluwer Academic Publishers, Dordrecht, Netherlands, 1995, pp. 291-312.
17. L. Matthies, Y. Xiong, R. Hogg, D. Zhu, et al, “A portable, autonomous urban reconnaissance robot,” Proc. Intelligent Autonomous Systems, Venice, Italy, July 2000.
18. L.H. Matthies, “Stereo vision for planetary rovers: Stochastic modeling to near real-time implementation,” International Journal of Computer Vision, Vol. 8, No. 1, July 1992, pp.71-91.
19. Lightweight Communications and Marshalling for Low-Latency Interprocess Communication.Published in: 2010 IEEE/RSJ International Conference on Intelligent Robots and Systems. Date of Conference: 18-22 Oct. 2010, Date Added to IEEE Xplore: 03 December 2010. INSPEC Accession Number: 11689465 DOI: 10.1109/IROS.2010.5649358 Publisher: IEEE Conference Location: Taipei, Taiwan
20. M. Golombek and D. Rapp. “Size-frequency distributions of rocks on Mars and Earth analog sites: Implications for future landed missions,” Journal of Geophysical Research – Planets, Vol. 102, No. E2, 25 Feb. 1997, pp. 4117-4129.
21. M. Maimone, L. Matthies, J. Osborn, E. Rollins, J. Teza and S. Thayer, “A photo-realistic 3- D mapping system for extreme nuclear environments: Chernobyl,” Proc. Intl. Conf. on Intelligent Robots and Systems, Victoria B.C., Canada, 1998, pp. 1521-1527.
22. Mars Exploration Rover - Opportunity mission updates, mars.nasa.gov
23. P. Bellutta, R. Manduchi, L. Matthies, K. Owens and A. Rankin, “Terrain perception for Demo III,” Proc. Intelligent Vehicles Symposium, Dearborn, MI, Oct. 2000.
24. P.S. Schenker, T. Huntsberger, P. Pirjanian, E. Baumgartner, et al, “Robotic automation for space: Planetary surface exploration, terrain-adaptive mobility, and multi-robot cooperative tasks,” Proc. SPIE Intelligent Robots and Computer Vision XX: Algorithms, Techniques, and Active Vision Conference, Vol. #4572, October 2001.
25. R. Volpe, “Navigation results from desert field tests of the Rocky 7 Mars rover prototype,” International Journal of Robotics Research, Special Issue on Field and Service Robots, Vol. 18, No. 7, July 1999.
26. S. Singh, K. Schwehr, R. Simmons, et al, “Recent progress in local and global traversability for planetary rovers,” Proc. IEEE Intl. Conf. on Robotics and Automation, 2000.
27. Various (January 24, 2014). "Special Collection - Curiosity - Exploring Martian Habitability". Science. Retrieved January 24, 2014.
28. Various (January 24, 2014). "Special Issue - Table of Contents - Exploring Martian Habitability". Science. 343 (6169): 345–452. Retrieved 24 January 2014.
29. Y. Xiong and L.H. Matthies, “Error analysis of a real-time stereo system,” Proc. IEEE Conf. on Computer Vision and Pattern Recognition, IEEE Computer Society, San Juan, PuertoRico, 1997, pp. 1087-1093.

AUTHORS PROFILE

Bishwajit Pal, MCA from Anna university, Chennai is working as research scholar in Dayanada Sagaar college of engineering, Bangalore. He is currently researching in autonomous vehicle and pursuing PhD from VTU, Belagavi.

Dr. Samitha Khaiyum PhD Currently working as Associate Professor and HOD in department of MCA in Dayananda Sagar college of engineering, Bangalore. Holder of Master of Computer Applications, followed by a M. Phil degree in Computer Science.