2017 20th International Conference of Computer and Information Technology (ICCIT), 22-24 December, 2017

Explorer-0100: An Autonomous Next Generation Mars Rover

Md Mainul Hasan Polash[1], Sanjida Nasreen Tumpa[2], Sadman Sakib Saumik, Mahmuda Binte Rashid Samia, Muhtasim Fuad Rafid, Saborni Shernaj Binte Elahi, Priyanka Kundu Moumi, Shubhashis Roy Dipta, Toki Tahmid Inan, Sahrima Jannat Oishwee, S M Anisur Rahman, Md Mahboob Karim, A B M Humayun Kabir
Department of Computer Science and Engineering
Military Institute of Science and Technology (MIST)
Dhaka-1216, Bangladesh
Email: [1]mainulhasanpolash@gmail.com,[2]tumpa.sanjida@gmail.com

***Abstract*—In the field of planetary exploration, rovers play a vital role. This paper highlights about the design and development of advanced Mars rover "Explorer-0100". The rover successfully participated in European Rover Challenge - 2016. The rover can be operated remotely and autonomously in the rough terrain of Mars. It has an operation range of 1 km radius and can perform various tasks assigned to it. This paper discusses the system architecture, power distribution system, communication system, rover control system and components of the rover briefly. Moreover, we have tried to enlist the capability to complete the tasks which have been assigned to it by providing test data set. Finally, we have discussed our progress to use this rover in different aspects of our society. During an earthquake or any other sorts of natural calamity, a smaller version of it can assist human in the rescue operation.**

***Index Terms*—Autonomous, ERC, Human Assistant, Mars Rover, Robotics, Rocker-bogie Suspension System**

I. Introduction

Conquering the space has always been a great fantasy of human. To meet this earnest wish many scientific researches have been done to know the mystery in space. After a series of failure and success scientists have conquered moon and now Mars has got the highest attention to be explored. In 4 December 1996, NASA launched a spacecraft, Mars Pathfinder consisting of a Lander and the Sojourner rover to the planet Mars. This 11.5 kg six-wheeled mobile rover explored the surface of Mars and collected revolutionary amount of data. After this mission people have understood the viability of mobile rover to explore and traverse the surface of various planets, specially the Mars [1], [2].

Before having footsteps on Mars it is wise to explore the environment of the Mars as much as possible by a Mars rover as substitute of human. So, scientists have been working on developing and testing the Mars rover, capable of exploring a planet with less cost and minimum effort. In fact, Mars society, NASA and some other organizations have been arranging different Mars rover challenges like URC[1], ERC[2], UKRC[3] etc. for last few years to inspire students to come out with their innovative ideas and technical approaches for designing and constructing rovers. European Rover Challenge is the largest space and robotic event in Europe. It is a prestigious event where young engineers from all over the world compete over tasks those are done by the actual rover on Mars [3]. Taking this competition in view we have featured our rover "Explorer-0100" so that it can perform the assigned tasks of this competition effectively. This autonomous mobile rover is the result of some integrated hardware component modules and associated supporting software which were completely developed by our team.

Considering the global requirements of space exploration, the team tried to design and develop a Mars rover to help mankind to know its next world to live in. Our rover is also featured in a way where we can reduce the analytical barrier between human and robots. We hope to build a human assistant rover to help astronauts as well as mankind in various aspect of life.

To present the paper effectively we have organized it as follows: the following section covers the related works, section III highlights the design architecture and the rover mechanics, section IV discusses about rover electronics, section V describes the communication system of the rover. The next section comprises of the software and associated hardware for controlling task and features. In the later section, the brief descriptions of the assigned tasks have been given. Section VIII holds the experiments and comparison while section IX concludes the paper with our future plan.

II. Related Works

The journey of exploring Mars started from the year of 1971 with the hand of Mars 2 and Mars 3 with the failure of

[1]University Rover Challenge
[2]European Rover Challenge
[3]United Kingdom Rover Challenge

978-1-5386-1150-0/17/$31.00 ©2017 IEEE

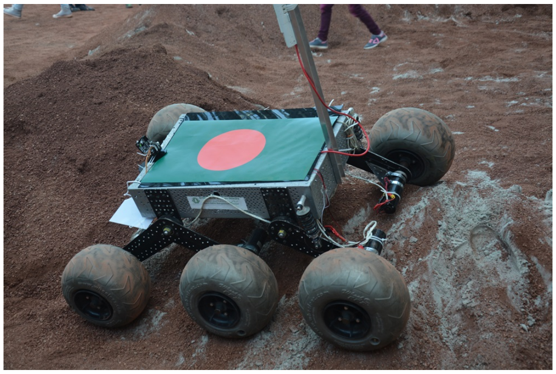

Fig. 1. Explorer-0100: Mars Rover

communication system just after landing. But this could not stop researchers to conquer the Mars in the long run. Marnier series and Vikings spacecraft are such example to observe the environment of Mars. Observation on these spacecrafts and their failure analysis were described by Snyder et al. in 1992 [4]. As previously stated, Sojourner rover carried by Mars Pathfinder landed successfully on 4th July, 1997 [1]. Later Spirit (MER-A) and Opportunity (MER-B) landed successfully on January 2004 on the Mars [5]. The detail designs of mechanical hardware, test and performance of the mobility assembly of these rovers have been reported by Lindemann et. al. [6]. Another rover Curiosity by NASA landed on August 6, 2012 and is still operational till date [7].

Wilcox et. al. discussed about two modes of controlling the Mars rover along with some technical concerns which was launched in 1990 [8]. Meanwhile, Bares et. al. discussed about the issues and approaches for an active planetary exploration on Mars and described their research programs on six legged autonomous rover Ambler in 1989 [9]. In 1997, Ohm et. al. gave a brief description of a small rover prototype, Rocky 7 including the aspects of whole system design for mobility, sampling and autonomous navigation, software infrastructure, sensor suite, on-board science instrument, and outdoor rover testing on Mojave Desert in California [2]. Volpe et. al. gave an overview of a new manipulation system developed for sampling and equipment placement from small autonomous mobile robots [10]. Tarokh et. al. described a method for kinematic modeling of the Rocky 7 Mars rover to secure full six degree of freedom motions along with movements in all three directions, pitch, roll and yaw rotations. Maurette's work on autonomous navigation of a rover is a helpful one for the traversal of a rover on Mars surface [11]. The Russian rover Marsokhod had been designed for Mars exploration with stereovision for autonomous motion ability [12]. An analog rover named Magma White was created by ABM SE for space exploration missions [13]. A team from IUT described their approach on building a simplified semi-autonomous Mars Rover and success in meeting the challenge of ERC in 2015 [14]. A team named "Mongol Barota" from MIST was participated in URC in 2014 and 2015 and secured 12^{th} position and 9^{th} position respectively. They also discussed about their rovers Mark and Maya [15], [16].

We have also studied some works of different researchers on rover which are being used during disaster, military, assistance purpose and so on. Vargas and Mizuuchi described about the current progress of a networked robotic system for deploying in disaster area on 3D geometry acquisition in 2017 [17]. Therefore, we aimed to make a human assistant rover to improve the work of team "Mongol Barota" highly which can be useful for planetary science purpose as well as other different aspects of life at the same time.

III. System Architecture and Rover Mechanics

The design architecture of "Explorer-0100" can be divided into two major parts such as rover body and rover arm.

A. Structure of Rover Body:

"Explorer-0100" is a six wheeled rover with a very light aluminum body. The frame is designed to mount several boxes without cover which is made with plastic to accommodate the electrical box, batteries, rover hand and other components. Several steel cross patterns are used to lessen the possibility of shape exaggeration and also for evenly balanced pressure. These crosses are bounded together as one whole pattern. The dimension of the full rover is 49"x37"x18" and the dimension of the main body is 26"x17"x5". Under the consideration of rough terrain, we designed a rocker-bogie suspension system [18] that has been used to drive smoothly over bumpy ground and there is one rocker-bogie assembly on each side of the rover at the very origin of rover design. For going over an obstacle, front wheels are forced against the obstacle by the rear wheels. One end of a rocker is shaped with a drive wheel and the other end is rotated to a bogie. We have used a simple three-gear differential. Two gears are connected to the two rockers and the third (middle) gear is connected to the body.

Having no springs on the rocker-bogie mechanism, all six wheels can be kept on the ground with approximately same pressure on each wheel which is a good thing while driving on sand specially. When the rover rotates in right direction, the right wheels go backward and left wheels go forward. To balance this pressure a steel crisscross pattern is used.

For giving support of the mounting of legs on the rover and proper alignment of wheels, shafts are also used. In order to increase the performance in various tasks, a brake system is implemented by ourselves to keep control on motion. We have used balloon wheels (with PVC tube) which are designed for full expansion at relatively low pressure and widely used in hauling heavy equipment over hot sand or beach. In this rover, we used RPM gear motors to control it. While crossing, if the rover faces any obstacles, it uses the rotational degree to cross with support of rear wheel. To ensure proper and positive outputs, we maintained our rover architecture in this way so that it can overcome any kind of challenging situation.

B. Rover Arm:

The design of the rover arm includes six degree of freedom and the hand can be divided into four parts- the base, which

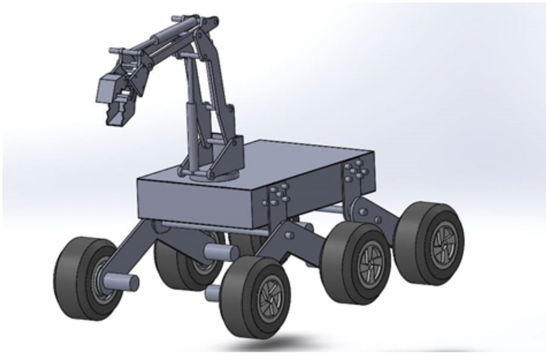

Fig. 2. Design of Rover Body with Arm

can rotate 360^o and is of two layer, shoulder joint, elbow joint and wrist joint. The palm of the hand is of two types, one is a graspable grip with fingers which able to rotate 360^o and other one is a digger. We have used two gear motors. One is for the digger with 400 rpm and the other is for the base (50 kg torque). Rest of the movements is controlled by the actuators. Our aluminum structure gives the hand more stability. We have used three actuators:

1) Arm Actuator (stroke 6",load capacity 110lb, static capacity 500lb, speed max load 0.5 in/sec)
2) Elbow Actuator (stroke 12",load capacity 110lb, static capacity 500lb, speed max load 0.5 in/sec)
3) Wrist Actuator (stroke 4",load capacity 110lb, static capacity 500lb, speed max load 0.5 in/sec)

The weight of the hand of this rover is maximum 7.5 kg (with digger grip) while as per competition requirement, total weight of the rover is less than 50 kg. Figure 2 shows the complete design of our rover drawn in Solidworks and Figure 3 illustrates the full rover along with all connections.

Fig. 3. Explorer-0100 with all Connections

IV. Rover Electronics

The electrical and electronics system of “Explorer-0100” is a standalone system. A Lithium polymer battery of 7 cells having an output voltage of 25.9v and a 12v Lead (pb) acid battery generates the main power. The main power is distributed in 2 types of motor driver and a power bridge. The first motor driver needs 24v and 25amp which controls the motors for rover movement by taking 24v each and second one needs 12v and 10amp for controlling 12v actuators and gear motors. We have used 4 Arduino of 5v to interface different sensors.

We have used our self-made power bridge for distributing power to the all necessary components of the rover. The main input power of the power bridge is coming from a 12v Lead (pb) acid battery. It has 3 different voltage outputs of 3.3v, 5v and 12v. 7805 ICs in series is used for 3.3 volts, 7805 ICs in parallel is used for 5v and 7812 ICs is directly used for 12v output of the power bridge. For a stable output of power bridge, we have incorporated a capacitor of 10μF. The power bridge distributes the power to the Raspberry Pi, Router, Switch, Access Point, Arduino, Camera (used for streaming), DC voltage converter and several industrial motor drivers. A DC voltage converter is used for the IP camera (main) which is powered by 44v.

The control system is divided into two parts to control the movement of the rover and the hand. We have used 3 Raspberry Pi in our system. Each of them gets power of 5v through a micro USB port from the power bridge. One Raspberry Pi controls the main rover, the second one controls the hand as well as is used for backup. The last one is used for controlling the RPLIDAR of 5v. The rover wheels are turned on by the power supply from a 25.9v, 7 cells Lithium polymer battery, which are connected through a 25amp dual motor driver, capable of providing the wheel multiple speeds corresponding to an input signal supplied by the control system of the rover. The power supply of rover wheel can be switched on and off remotely by another controller which controls the supply of the 25.9v Lithium polymer battery. We have used three industrial motor drivers for movement control. We have used five self-made motor drivers for controlling the five different parts of rover arm. Here we have used 12v actuators and 12v gear motor. Figure 4 shows the power flow of our system.

Besides, any occurrence of disconnection from the control station shuts down the power supplies of the wheels and hand within one second, which ensures safety. We have used a heat sink and few cooling fans in the rover so that the circuit will not be over heated. There is an emergency switch to shut down the main power supply of the rover in case of any emergency.

V. Rover Communication

For communicating from remote areas, we have used Ubiquiti Networks antenna and access points. We have used one 2.4GHz Omni-Directional antenna, each with one access point, on both side of the rover and control station. We mounted one 8 port switch on the rover side to integrate all connection. The wireless access point is of 2402-2462MHz, with IEEE 802.11 b/g/n protocol. The system is capable to communicate with a 5 miles range. We tried to follow the FCC[4] standards and regulation while maintaining the communication of the rover.

[4]Federal Communications Commission

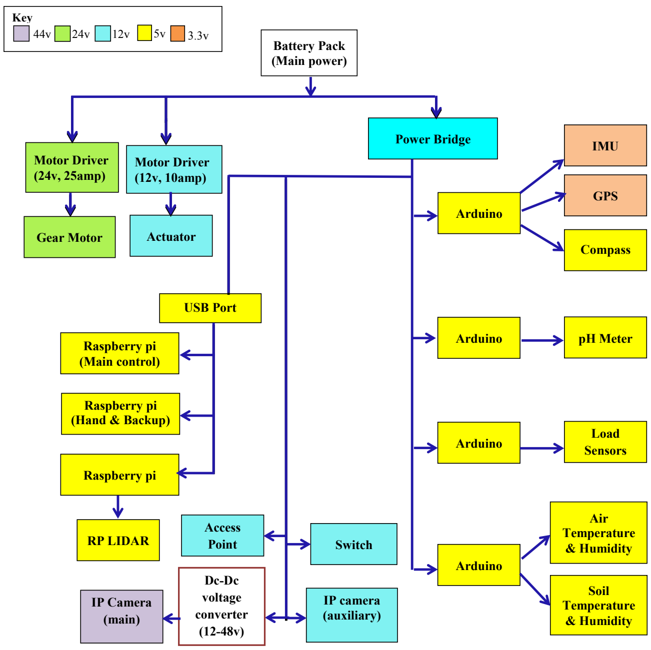

Fig. 4. The Power flow of our system

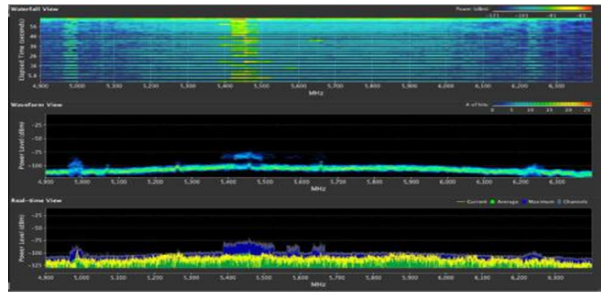

Fig. 5. RF spectrum analysis when equipment (both on rover and ground station) is on

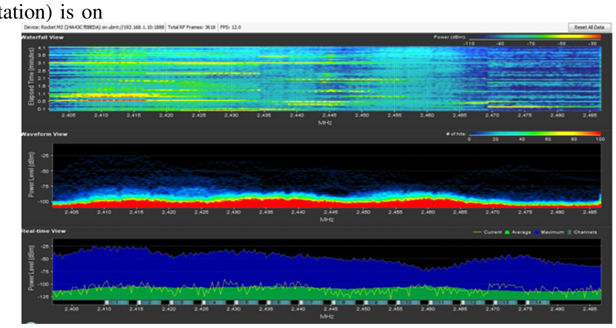

Fig. 6. RF antenna radiation pattern for rover

We have used Rocket M2 which is a Ubiquiti Networks airMAX BaseStation. This can support a speed of 150+ Mbps real TCP/IP throughput. It is ideal for deployment in Point-to-Point (PIP) bridging or Point-to-MultiPoint (PtMP) airMAX applications. We used UDP[5] protocol and own developed software to maintain proper connection and control the rover smoothly. Figure 5 shows the RF spectrum analysis when all the equipment (both on rover and ground station) is on while Figure 6 illustrates the RF antenna radiation pattern for rover.

We have mounted three cameras on the rover for live streaming. The main camera is AXIX M5014 PTZ dome network camera, attached on the antenna of the rover. This high resolution ip camera has Pan-Tilt-Zoom capability. The other two cameras are ELP-IP 1881mini IP cameras of high resolution. One of them is used to observe the hand movement and another one is attached at a side of the rover body.

VI. Rover Software and Associated Hardware

We have used a set of self developed software to ensure proper control and interaction with the rover. The software have user friendly interface for sending commands and receiving necessary data. The images of our software have been uploaded in our site [19], [20]. We had to control the rover movement, hand movement, sense and analyze different kinds of data collected from the environment (i.e. temperature, humidity, soil moisture etc.), determine the current position of the rover and the required direction to move to reach the destination by these software.

The sensors are connected through Arduino Uno which transmit or receive data from sensors, also transmit that data to the software via network using Ethernet shield. As the rover may go away from the control station, wired connection is not a feasible solution. In this case, our way of communication limits to wireless networking. For this reason, necessary hardware and software have been used to transfer the data via the network. The software has also been written in python which is suggested for Raspberry Pi.

A. Rover Motion Control System

The motion control system controls the movement of the rover through Raspberry Pi and Arduino. A Python program works as a server of the Raspberry Pi, and the control station runs another Python program as a client. Client-server communication is done by UDP protocol. The rover has four basic control signals: UP, DOWN, LEFT and RIGHT. Signals also exist for POWER and GEAR. The control system can designate up to four gears, each has an increasing speed twice as the previous one. The Raspberry Pi receives the signal from the control station and forwards it to the Arduino, as Raspberry Pi cannot supply PWM[6] signals. The Arduino works like a D/A converter and converts the digital signal of the Raspberry Pi to analogue, then sends it to the motor driver. Each level of signal voltage designates the direction and motion speed of the rover - 2.5v for a steady state, 5V for a full speed forward, and 0V for a full speed backward motion according to our program. Three dual are attached to six motors, giving full control of the rover to the control station.

B. Rover Arm Control System

The hand control system has one Raspberry Pi and five motor drivers, controlled by digital signals. A server Python

[5]User Datagram Protocol

[6]Pulse Width Modulation

program runs in the Raspberry Pi, and a client Python program on the control station using UDP protocol. Five basic components namely: 'Base', 'Shoulder', 'Arm', 'Wrist' and 'Claw' can be controlled from the control station. The Raspberry Pi GPIO[7] pins give output corresponding to the signal and then the power supplies have been determined to the actuators and motors accordingly. Multiple hand components can be controlled simultaneously. This system also has a 1 second disconnection safety protocol.

C. Load Measurement Software

Weight of the collected soil is measured using the load cell. The software developed for the weight sensor shows the data to the user. The weight sensor needs to be used with a container that holds the collected soil and connected to an Arduino Uno to pass the data to the server via Ethernet shield.

D. Software for Measuring Moisture, Temperature and Basicity of soil

The soil collected with the hand of rover is tested for humidity, temperature and pH with soil moisture, soil temperature and pH meter sensors. All these are integrated together and combined output is then transmitted to a single interface on the server side of the software.

E. Navigation Software

GPS sensor receives the location of the rover from satellite and transmits it to the software. The compass sensor gives us the angle of the rover with North. The data from these two sensors are used to serve 2 purposes: first, to know if the rover has reached its destination and second, to which direction the rover should go to reach its destination. The two sensors are integrated together with an Arduino Uno to get our desired data which will then send to the server software.

A RPLIDAR device is one of the main devices in our navigation system. It was used for 2D mapping and assistance in navigation task. From the GPS system we can get the coordinates of the current position of rover. We used RPLIDAR for mapping surroundings and identify obstacles in our path. It can provide us up to 2000 samples per second. The range of the laser used in the RPLIDAR device is 6m with 3600 scanning. Mainly, it uses laser to detect the obstacles of the surrounding and for mapping in our side we have used a JAVA software.

F. Software to Determine Air Temperature and Humidity

Temperature and humidity of the environment are measured with temperature and humidity sensor and transmitted through the network to the software.

G. Angular Velocity Detection System

IMU[8] is a sensor that measures in degrees per second or revolutions per second the angular velocity. It was used to measure the balancing of the rover at a particular time. As there was possibility of traversing through uneven surface, there was a possibility of the rover loosing its balance. So, to ensure the balance of the rover we need to know the constant orientation of the rover. IMU provides the data of the rover along the 3 axes and this data is used to plot as an object using Processing language to make it easier to visualize.

[7]General Purpose Input/Output

[8]Inertial Measurement Unit

VII. Description of the Tasks

As the rover, "Explorer-0100" was designed and built to participate in ERC-2016, the team had to follow the general instructions and rules of the competition [3]. The team was given four different kinds of tasks.

In Science task, the rover had to collect three different samples of a rock or stone, a surface soil and a piece of deeper soil from different locations defined by the organizer. All the samples were to be delivered in different containers with specific weight.

Maintenance task was a challenge to test the ability of the team and rover in operating an electric rack with switches and other device mounted on. Using the subsystem embedded in the rover, the team had to plug in switches to correct position, set up different parameters and took the feedback from the device. The rover had to rotate different nob to set different control parameters also. All the things were arranged in separated places so the mobility performance of the rover was also a concern.

Assistance task was design as analogous to a helping hand for the astronauts. The rover had to pick up an object from a particular position and then put it in a particular orientation. Then the rover had to return back to its starting position to make a delivery report. Besides, the steady state position of the rover hand was to be demonstrated for at least 10 seconds. The team had to take an image of the object at the final location and deliver it to judges.

In Navigation task, the team had to navigate the rover without any visual data i.e. any video streaming or any live sensor data. The team used a smart navigation technique using RPLIDAR [21] to complete this task.

Apart from mandatory part, there were some opportunities to have bonus points. We were successful to gain some of the bonus points also. Besides, the team had to give a presentation on the technical parts of the rover and the techniques that were used to solve different problems.

A. Additional Features:

The team tried to meet the mentioned challenges as much as possible. Because of our onboard embedded system, the data from the soil temperature and humidity sensor, air temperature and humidity sensor, pH sensor can be observed from the base station. Our rover is able to traverse through extremely rough terrain and dig or grab objects by its robotic claw. The data obtained from sensors help to visualize the environment and take decisions. Other instruments, IMU sensor, compass and GPS help to locate the rover and also provide the orientation and position of the rover. It can be operated from a base station that is 1 km away from the rover.

"Explorer-0100" has some unique features that enable opportunities to use this rover in difficult situations. During natural calamity, the misery of our country people know no bound and it becomes very difficult to reach those affected areas for rescuing operation. Aids can be sent to the risky and dangerous affected areas by our rover. The rover can go places which are difficult and almost impossible for human and other vehicles. Besides, in recent days terrorist risks are at an alarming rate. In 2017 a total of 924 attacks that caused 5,456 fatalities has been reported [22] and more is being included daily with the total. As video or live streaming is not required to navigate the rover, this autonomous remote controlled rover can also be used during terrorist attack to rescue and diffuse bomb. Therefore, our rover can contribute in our society in different aspects.

VIII. Experiments and Comparison

The rover was extensively tested to ensure its functionality. The tests were divided as per competition requirements and was tested thoroughly according to it.

A. Manoeuvrability Testing:

The manoeuvrability of the rover was tested on different terrains so that it could tolerate rough terrain of the Mars environment. As most of the Mars terrains contain sand, the rover was mostly tested on sand. All tests were done remotely with wireless camera guidance only. Table I shows the result.

TABLE I
MANOEUVRABILITY TEST RESULTS

Serial	Terrain	Result	Average Speed
Run 1	Rough with no sand	Success	12.4km/h
Run 2	Sand terrain	Success	10.1km/h
Run 3	Extremely rough terrain (Stairs)	Success	1.2km/h

B. Hand Testing:

The rover hand was designed completely according to this competition requirements and as a result needed a new set of tests. The new design consists of both digging and grabbing capabilities and thus increased the rover's functionality. Table II shows the result of the testing.

TABLE II
HAND TEST RESULT

Serial	Test	Result
Test 1	Digging 200gm soil	Success
Test 2	Grabbing screwdriver and storing on rack	Success
Test 3	360^o rotation of the base	Success
Test 4	Opening and closing door	Success
Test 5	Rotating certain control nobs	Success

C. Weight Measurement Test:

The rover has a weight testing box which remotely sends the weight of an object put into it. Table III shows the result.

TABLE III
WEIGHT MEASUREMENT TEST RESULT

Serial	Given Weight	Reading	Error
Test 1	50gm	49.4	1.2%
Test 2	100gm	100.2	0.2%
Test 3	200gm	198.8	0.6%

D. Comparison with Other Rovers:

The significant improvements of the Explorer-0010 compared to the rovers Mark and Maya. Table IV shows the comparison among these rovers.

TABLE IV
COMPARISON BETWEEN EXPLORER-0010 (MONGOL BAROTA-2016), MAYA (MONGOL BAROTA-2015) AND MARK (MONGOL BAROTA-2014)

Improved Areas	Explorer-0010	Maya	Mark
Hand	Completely redesigned for both digging and grabbing with 360^o rotation	360^o rotation added to the base	Fixed base hand with no rotation, separate claws for digging and rotation
Speed control	4 gears	3 gears	No gears
Hand control	Multiple hand components can be controlled simultaneously	Only one hand component can be moved at a time	Only one hand component can be moved at a time
LIDAR	Used for mapping surroundings	Not present	Not present
IMU	To help balance the rover	Not present	Not present

IX. Future Plan and Conclusion

We worked to reduce the barrier between the human and robot to provide assistance in planetary science as well as other regular work. Till now we are capable of making human controlled rover. But to meet our aim, we will focus on making a fully autonomous rover by integrating artificial intelligence. Thus our rover will be able to complete all given tasks like traversing, carrying payloads, switching on off a particular machine on a remote area or isolated planet without any human help or with human control depending on situation. For now, the rover can carry highest 1 kg load. We will work on improving our rover body to increase its capacity of carrying a huge load to serve different purpose. Finally we want to meet the challenge of carrying at least one human being on the rover. We are highly inspired by the Human Exploration Rover Challenge of NASA for this. This feature may help in rescue mission during adverse situation or providing aids during calamities or disaster. The rover has certain utilities in favor of assisting humans in different horizons. With more research, observation and logistic implementation the possibility of enhancement of the rover is still on the table.

Acknowledgement

The authors are very much thankful to all team members of Team "Mongol Barota" for their contribution. The authors are extremely grateful to the Authority of Military Institute of Science and Technology (MIST), Dhaka, Bangladesh, Department of Computer Science and Engineering (CSE) of MIST for laboratory and logistics support along with their warm cooperation throughout the system development. We would like to express our thankfulness to Islami Bank Bangladesh Ltd., Trust Bank Limited, BBS Cables and Lafarge Surma Cement Ltd. for their finalcial support. We would like to express immense gratitude to Brigadier General K M Salzar Hossain, Brigadier General Md Shohail Hossain Khan, Group Captain Md. Afzal Hossain, Md. Kishwar Shafin, Iffatur Ridwan, Tanvir Ahmed Fuad and Md Ismail Hossain Raju for their constructive recommendation, professional guidance and whole-hearted cooperation.

References

[1] "Mars exploration past missions nasa." https://www.nasa.gov/mission_pages/mars/missions/index-past.html. [Online; accessed 09-Sep-2017].

[2] S. Hayati, R. Volpe, P. Backes, J. Balaram, *et al.*, "The rocky 7 rover: A mars sciencecraft prototype," in *Proceedings 1997 IEEE International Conference on Robotics and Automation*, vol. 3, pp. 2458–2464, IEEE, 1997.

[3] E. R. Challenge, "European rover challenge 2016." http://roverchallenge.eu/en/, 2017. [Online; accessed 10-Sep-2017].

[4] C. W. Snyder and V. I. Moroz, "Spacecraft exploration of mars," *Mars*, pp. 71–119, 1992.

[5] "Spirit and opportunity mars exploration program." https://mars.nasa.gov/programmissions/missions/present/2003/. [Online; accessed 09-Sep-2017].

[6] R. A. Lindemann and C. J. Voorhees, "Mars exploration rover mobility assembly design, test and performance," in *Systems, Man and Cybernetics, 2005 IEEE International Conference on*, vol. 1, pp. 450–455, IEEE, 2005.

[7] "Two years ago, curiosity rover lands on mars." https://www.nasa.gov/content/two-years-ago-curiosity-rover-lands-on-mars-captures-image-of-mount-sharp. [Online; accessed 09-Sep-2017].

[8] B. H. Wilcox and D. B. Gennery, "A mars rover for the 1990's," in *Autonomous robot vehicles*, pp. 444–449, Springer, 1990.

[9] J. Bares, M. Hebert, T. Kanade, E. Krotkov, T. Mitchell, R. Simmons, and W. Whittaker, "Ambler: An autonomous rover for planetary exploration," *Computer*, vol. 22, no. 6, pp. 18–26, 1989.

[10] R. Volpe, T. Ohm, R. Petras, R. Welch, J. Balaram, and R. Ivlev, "A prototype manipulation system for mars rover science operations," in *Intelligent Robots and Systems, 1997. IROS'97., Proceedings of the 1997 IEEE/RSJ International Conference on*, vol. 3, pp. 1486–1492, IEEE, 1997.

[11] M. Maurette, "Mars rover autonomous navigation," *Autonomous Robots*, vol. 14, no. 2, pp. 199–208, 2003.

[12] M. Lamboley, C. Proy, L. Rastel, T. N. Trong, A. Zashchirinski, and S. Buslaiev, "Marsokhod: Autonomous navigation tests on a mars like terrain," *Autonomous Robots*, vol. 2, no. 4, pp. 345–351, 1995.

[13] S. Meszyński and M. Józefowicz, "Analog mars rover service as a robotic hardware and team building platform," in *Aerospace Robotics II*, pp. 145–161, Springer, 2015.

[14] N. Sakib, Z. Ahmed, A. Farayez, and M. H. Kabir, "An approach to build simplified semi-autonomous mars rover," in *Region 10 Conference (TENCON), 2016 IEEE*, pp. 3502–3505, IEEE, 2016.

[15] M. K. Shafin, K. L. Kabir, I. Ridwan, T. A. Fuad, S. Bardhan, M. I. H. Raju, A. Tahira, I. Afrin, S. Mondal, S. N. Tumpa, *et al.*, "Mongol barota: A next generation rover," in *Proceedings of 2014 8th International Conference on Software, Knowledge, Information Management and Applications (SKIMA)*, pp. 1–8, IEEE, 2014.

[16] T. A. Fuad, I. Ridwan, M. I. H. Raju, A. Mohiuddin, S. S. Saumik, M. M. H. Polash, *et al.*, "Maya: A fully functional rover designed for the mars surface," in *Proceedings of 2015 18th International Conference on Computer and Information Technology (ICCIT)*, pp. 423–428, IEEE, 2015.

[17] A. E. M. Vargas, K. Mizuuchi, D. Endo, E. Rohmer, K. Nagatani, and K. Yoshida, "Development of a networked robotic system for disaster mitigation,-navigation system based on 3d geometry acquisition," in *Intelligent Robots and Systems, 2006 IEEE/RSJ International Conference on*, pp. 4821–4826, IEEE, 2006.

[18] Wikipedia, "Rocker-bogie Wikipedia, the free encyclopedia." http://en.wikipedia.org/w/index.php?title=Rocker-bogie&oldid=799636568, 2017. [Online; accessed 10-Sep-2017].

[19] "Software images of explorer-0100." https://sites.google.com/view/exp-docx/home. [Online; accessed 15-Sep-2017].

[20] "Software images of explorer-0100." https://sites.google.com/view/explorer-0100/pdf-documents. [Online; accessed 15-Sep-2017].

[21] "Rplidar a2 360 laser scanner." http://www.robotshop.com/en/rplidar-a2-360-laser-scanner.html. [Online; accessed 10-Sep-2017].

[22] "2017 eu terrorism report: 142 failed, foiled and completed attacks." https://storymaps.esri.com/stories/terrorist-attacks/?year=2017. [Online; accessed 08-Sep-2017].