Intelligent machines and software

TESTING ALL-TERRAIN ROBOTS ON SAND, GRASS, AND CONCRETE

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Abstract

For this project, I built three different robots and ran them on 1.5 meter courses of sand, grass, and concrete. I used the same programming, and I recorded my data in seconds. My hypothesis was that the Gripp3r, one of the robot designs with tractor wheels with an added rubber wheel, would overall be the best. My hypothesis was not supported. The Ev3Storm has 4 rubber wheels and the times were better than the Track3r (tractor) and the Gripp3r on sand. Track3r was the best on grass. All the robots had similar times on concrete. I had difficulty running the robots on the sand and grass courses because sand and dirt clogged the motors, and I had to constantly clean the robot out. The conclusion is that the rubber wheel Ev3Storm prototype is the most effective robot on sandy surfaces like Mars. For future studies, I will try this experiment with Ev3Storm prototypes that lift the brick further off the ground, add inclines to the course, and use sensors (color, infrared) to work around obstacles.

Problem

With space exploration being a prominent factor in our future, vehicles or "rovers" are needed to explore new planets and send information back to Earth. Mars is known as the Red Planet, because it has an arid, iron-rich, sandy environment. To explore this planet, many models of explorer vehicles must be tested to face the challenges of different gravity, atmosphere, and terrain. Finding an optimal vehicle that will effectively tackle these challenges requires researchers to model and test several different rover engineering design concepts. Frictional force and surface area grip are two factors that will vary between different models in this project. This project tests three designs of EV3 robots on different surfaces to determine which design would work best on all terrain rovers like those that explore the Red Planet.

Hypothesis

Since the Gripp3r has more surface area grip and flexibility than the Track3r or Ev3RStorm robot design, then it will have the fastest time on the terrain courses.

Rationale:

For my project, I am testing which robotic design of the Ev3 robot is the best for exploring different environments. In this project, I built 3 robots and timed them to see which one goes the fastest on sand, grass, and concrete.

The hypothesis is based on the forces of friction, which I postulate will give better stability in uncertain terrain. The Gripp3r has serrated tread tracks and an extra wheel. As the tracks grip the surface of the course, the robot will be propelled forward due to this. Although the Gripp3r design is like that of the Track3r, the Track3r lacks the wheel on top. This wheel will add flexibility and play a large part in the control of the movement of the robot. The Gripp3r's ability to grasp uneven surfaces and move as an all-terrain vehicle will give it an advantage over its competitors with a basic set of wheels or normal tractor treads.

This research is scientifically important because scientists sometimes need to test assorted designs when solving a problem. This is called iterative design in engineering – formulate, test, evaluate, repeat- basically trying different prototypes and fixing things until you get the right design. Projects like the Mars Curiosity Rover have followed this iterative design process because the robot had to be able to travel across many different types of terrain on another planet. Before choosing the right design, the Curiosity project's scientists had to review and test many prototypes. This project tests different prototypes of robots for the best performance on different surface compositions.

Background

Many engineers and scientists are discovering new ways to build intelligent robots for modern challenges. Robots are needed for a variety of tasks, from an automatic vacuum cleaner to rescuing a person in dangerous circumstances, such as in rubble after an earthquake. Another challenge is space travel, and exploration on another planet such as Mars. I have been interested in space science since before moving to Norway, I grew up in Central Florida near the Space Coast. I had the opportunity to visit Kennedy Space Center (KSC) often and see rocket and space shuttle launches since I was small. At the KSC, I was able to see and go inside the rockets that had been to space, and to learn how they were put together. I also learned about the history of space exploration and the different missions. This inspired me to focus my robotics project on the Mars Rover designs.

Mars has several engineering challenges that must be faced before a human mission to the planet will be successful. These challenges include dust, radiation, atmosphere, and terrain. I focus in this project on terrain.

Exploratory vehicles known as "rovers" are sent to Mars to collect information about the planet and send it back to Earth. Table 1 has some background on the explorations missions to Mars from the US National Aeronautics and Space Administration (NASA). (1)

Table 1 : Mars Missions Timeline

Mission	Date	Accomplishment
Mariner	4 7/14/65	First successful fly-by
Mariner	9 11/71 - 10/72	Orbit of Mars
Viking 1&2	6/76 - 1987	Orbiter and First lander on Mars
Mars Global Surveyor	9/97 -	Science mapping of Mars
Mars Pathfinder	7/97 – 9/97	First rover on Mars
Mars Odyssey	4/01	Discovered water
Mars Exploration Rovers	5/2011; 2/2019	Spirit and Opportunity Rover
Perseverance Rover	2/2021	Expected touchdown on February 18, 2021

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On Mars, conditions are, of course, different than the Earth. Table 2 shows some of these different conditions on Mars. (2)

Table 2: Conditions on Mars versus Earth

	Mars	Earth
Atmosphere	95% CO_2, 5% N_2, Ar & trace gasses 0.007 atm pressure	78% N_2, 21% O_2, 1% trace gasses 1 atm pressure
Gravity	3.7 m/s^2	9.8 m/s^2
Calendar	24.6 hr day (sol) 687 sol year 4 seasons	24 hr day 365.25 day year 4 seasons
Moons	2 (Phobos and Deimos)	1 (Luna)
Terrain	More topographic relief than Moon or Earth Elevation range: +27 km (Olympus Mons) to -4km (Hellas Basin) No Liquid water Polar Ice caps Negligible magnetic field	Elevation range: +8.9 km (Mount Everest) to -11 km (Mariana Trench) 70% water Polar Ice caps

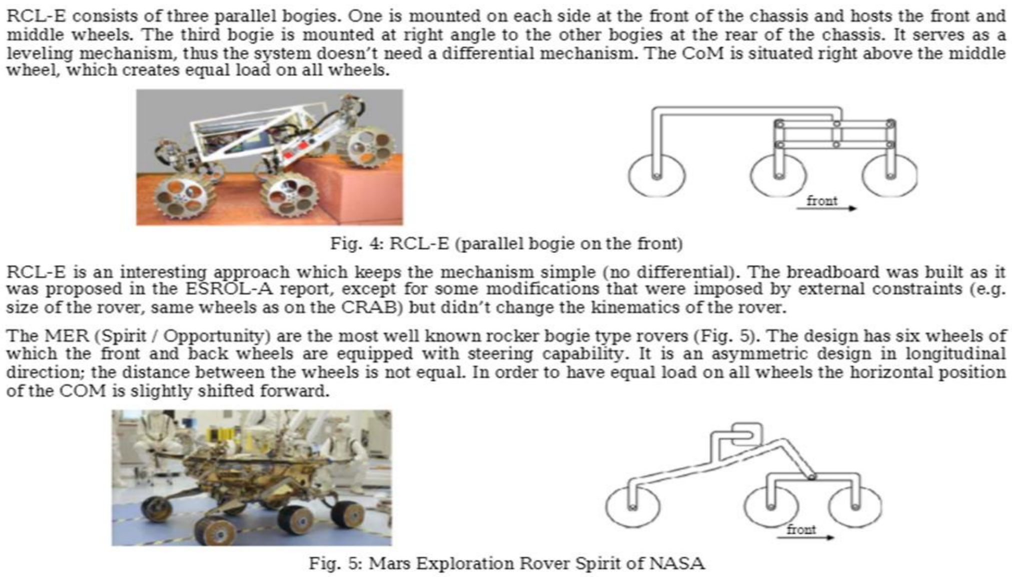
One of these conditions is gravity. Gravity is a component of friction, which is the force that is involved in the wheel to surface interaction that governs the movement of the rover vehicles. Friction arises due to roughness of two surfaces that have made contact. The two main types of friction are static friction and kinetic friction.

When comparing Mars and Earth, the gravity on Mars is 3.7 m/s squared while on Earth it is 9.8 m/s squared. The coefficient of friction depends on the gravitational constant. Because gravity is lower, the force of friction will also be lower. Lower gravity on Mars means that braking and turning will be more difficult than on Earth. On Mars it will take longer to stop and vehicles will have to turn very slowly to avoid slipping. Mars also has more topographic relief than the Earth and has an elevation range of 27 km, whereas the highest point on Earth is 8.9km. There is no liquid water and a smaller magnetic field on Mars. (2)

All of these factors pose problems for scientists to overcome that require tests on every aspect of the robot. Researchers at NASA and globally are using iterative design process in developing the Mars Exploration Rovers. (1)

Illustration 1 shows an example of what the testing of prototype rovers looks like in real life from a group in Switzerland. (4)

Illustration 1:



RCL-E consists of three parallel bogies. One is mounted on each side at the front of the chassis and hosts the front and middle wheels. The third bogie is mounted at right angle to the other bogies at the rear of the chassis. It serves as a leveling mechanism, thus the system doesn't need a differential mechanism. The CoM is situated right above the middle wheel, which creates equal load on all wheels.

Fig. 4: RCL-E (parallel bogie on the front)

RCL-E is an interesting approach which keeps the mechanism simple (no differential). The breadboard was built as it was proposed in the ESROL-A report, except for some modifications that were imposed by external constraints (e.g. size of the rover, same wheels as on the CRAB) but didn't change the kinematics of the rover.

The MER (Spirit / Opportunity) are the most well known rocker bogie type rovers (Fig. 5). The design has six wheels of which the front and back wheels are equipped with steering capability. It is an asymmetric design in longitudinal direction; the distance between the wheels is not equal. In order to have equal load on all wheels the horizontal position of the COM is slightly shifted forward.

Fig. 5: Mars Exploration Rover Spirit of NASA

For my project, I used the following materials to start the experiment.

<u>Materials</u>

LEGO EV3 robotics kit	Stopwatch
Concrete surface 1.5 meters	Ruler
Grass surface 1.5 meters	Data log notebook
Sand surface 1.5 meters	Computer with Mindstorms EV3 App

Methods

To carry out this experiment, the Mindstorms Ev3 App for iOs was used. This app was purchased from Google Play and installed on a personal Macbook laptop. Programming instructions found online were used to program a simple forward motion. (5) The remote included with the Mindstorms was used as a method of controlling the robot's movement.

To make the program, I used the green motor icon on all four motors. I composed a 180-degree rotation on both wheels. This is described in the programming instructions online. (5)

After the programming was complete, the Track3r robot was assembled using the instructions in the EV3 manual. (5) After constructing the robot, I measured out 1.5 meters of sand, grass, and concrete. I used a meter stick to ensure accurate results. The start and finish were marked with painter's tape.

The Track3r was placed at the start line with the power on and the program appearing at the top of the track list. The center button on the SmartBrick was pressed to activate the program and the remote control was used to activate the robot.

The stopwatch was started at the time of the robot's departure. The robot moved forward on the terrain course and the time on the stopwatch was monitored. Once the robot crossed the finish line, the timer was stopped.

This sequence was repeated on the three courses. The same procedure was repeated 10 times for each robot with data recorded in a notebook each time.

The Track3r robot was then disassembled and reconstructed into the Gripp3r and Ev3rStorm. The next robot design was the Gripp3r, built from instructions in the EV3 manual and some pieces were used interchangeably. The last robot design tested was the Ev3rStorm, also built from the EV3 instruction manual. (5)

The data was transcribed from the notebook into the laptop and analyzed using Microsoft Excel. Graphs were also created using Excel. The averages were calculated from the data using Excel functions.

All elements of the final project report including text, graphs, tables and pictures were created by the researcher.

Risks: Some components of the LEGO EV3 kit are a choking hazard for small children and can be considered hazardous.

Prototype Models

TRA GRI EV3RS

Figure 1: Robot designs built with EV3

Variables:

Independent Variable:

The independent variable in these experiments are the different types of wheel designs on the three models. The surface area grip of each design will vary based on the type of wheel used.

Another independent variable is the surface composition tested – in this case, sand and grass versus concrete. Concrete was designated as the control surface for statistical comparisons between robot performances on sand and grass surfaces.

Dependent Variable

The dependent variable is the amount of time it takes for the robot to reach the finish. This will be measured in units of seconds. As the independent variable, the robot's design, changes, so will the time on the course. The time to complete the course will also be affected by the surface composition of the course.

Controlled conditions:

To keep the experiment consistent and valid, and to be able to compare results between robotic designs there were a few things that needed to be controlled. The controlled aspects were the EV3 base of robot design for the Track3r, Gripp3r, and Ev3RStorm. The same Ev3 set was used throughout the course of the experiment. This was to ensure that there are no unknown factors coming into play such as other pieces from different LEGO sets.

The software running the robot was also the same for all robots. The program which was coded by the researcher was used for all three robots. This program was created on the Mindstorms app for Mac and programmed onto the smart brick attached to the robot.

The length of the course is also standard. The robots were all tested on the same courses. The amount of sand, grass, and concrete used for the course was controlled. No other surfaces were used, and the courses were kept the same throughout the entire experiment.

Results

Figure 2: Average time results of robot prototype trials on different surface compositions

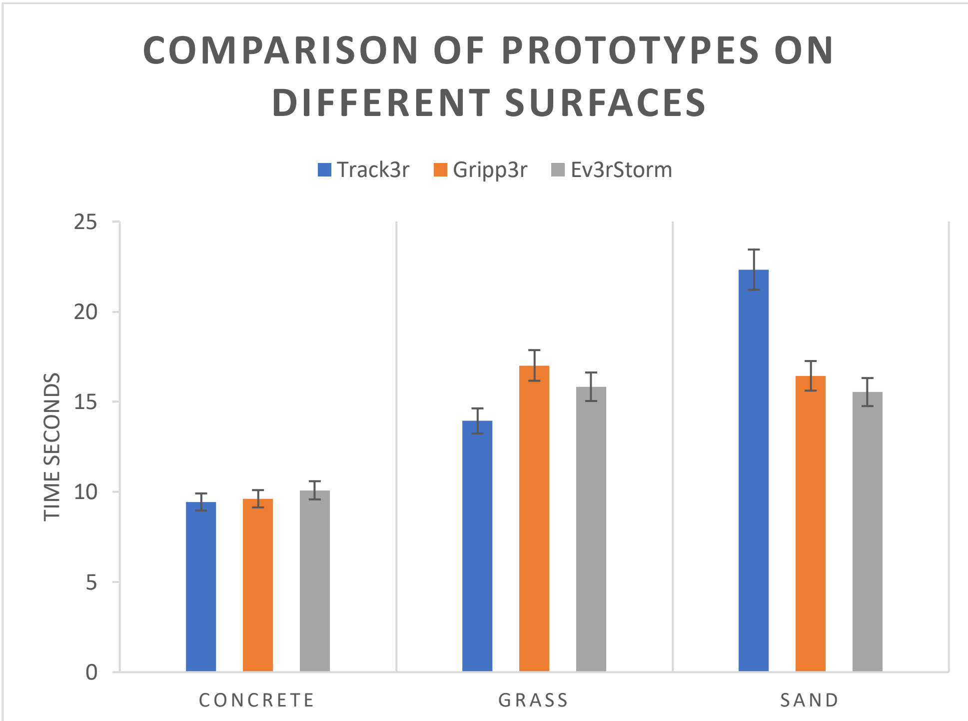


Table 3: Data summary of trials of prototype robots on sand, grass and concrete courses

	sand	grass	concrete		sand	grass	concrete		sand	grass	concrete
Track3r				Gripp3r				Ev3rStorm			
1	20.92	13.42	9.15	1	13.02	18.12	8.75	1	13.12	13.56	12.32
2	21.32	15.00	9.71	2	14.12	17.32	9.32	2	16.54	14.56	9.12
3	19.12	14.39	8.10	3	18.92	19.15	9.45	3	14.98	16.76	7.32
4	25.66	13.43	9.53	4	14.18	20.12	10.01	4	15.07	17.63	9.43
5	19.67	12.95	9.10	5	14.12	15.84	8.75	5	16.43	18.57	11.93
6	20.35	13.45	10.01	6	20.92	16.46	9.32	6	16.79	12.35	10.83
7	21.65	15.67	9.54	7	12.32	17.43	9.35	7	17.96	14.56	10.32
8	23.34	13.46	9.56	8	19.32	15.84	9.87	8	13.12	15.32	9.43
9	29.94	12.96	9.85	9	20.01	13.42	10.23	9	17.63	16.72	8.76
10	21.34	14.65	9.89	10	17.47	16.46	11.14	10	13.75	18.33	11.43
avg	22.33	13.94	9.44	avg	16.44	17.02	9.62	avg	15.54	15.84	10.09
stdev	3.26	0.93	0.56	stdev	3.21	1.89	0.72	stdev	1.80	2.09	1.56
SEM	1.03	0.29	0.18	SEM	1.02	0.60	0.23	SEM	0.57	SEM	0.49

Table 3: Ten trials for each of the three robots in 1.5m of sand, grass and concrete were conducted. Data is expressed as time in seconds, measured by electronic stopwatch.

Evaluation of Results

I tested how much time it took for three different robots to reach endpoints on different surfaces. The results depicted in Figure 2 show that all three robots had around the same time on concrete, with an average of 9.44s for the Track3r, and 9.62s for the Gripp3r and 10.09s for Ev3Storm.

On grass the Track3r had an average time of 13.94s as opposed to 17.02s from the Gripp3r and 15.84s from the Ev3rstorm.

In the final race across sand the Ev3Storm average time was 15.54s, followed by the Gripp3r with 16.44s, and the Track3r was 22.33 seconds.

With this data we can determine that the fastest robot on sand was indeed the Ev3rstorm. Upon further investigation on other rovers at NASA, I found that the best design for different terrains is the wheel robot, not the tractor style. See Figure 3 below. This is the case with the Mars Curiosity rover which remains on the red planet today.

Improvements and Extensions

When running the robot on the sandy surface, I found that sand and other debris got caught in the motor and SmartBrick ports. One issue was continuously cleaning the robot out and worrying about damage to the machine. A design prototype that lifts the EV3 brick and motors up higher off the ground would be the next improvement to try.

In a broader sense, scientists must consider this when exploring other planets, especially Mars, with it having its sandy terrain. This experiment could be expanded further and to a larger degree as mentioned earlier. Sensors, different movements, more robots, and many other factors could be included in further research. This project is currently being extended in projects such as the CRAB at NASA, shown in figure 1.

Another broad impact my project can have is with the military. In order to keep soldiers safe in various places around the world, such as deserts, mountains or even underwater, scientists and engineers must come up with the most efficient designs for vehicles to move around in different terrains.

Conclusions

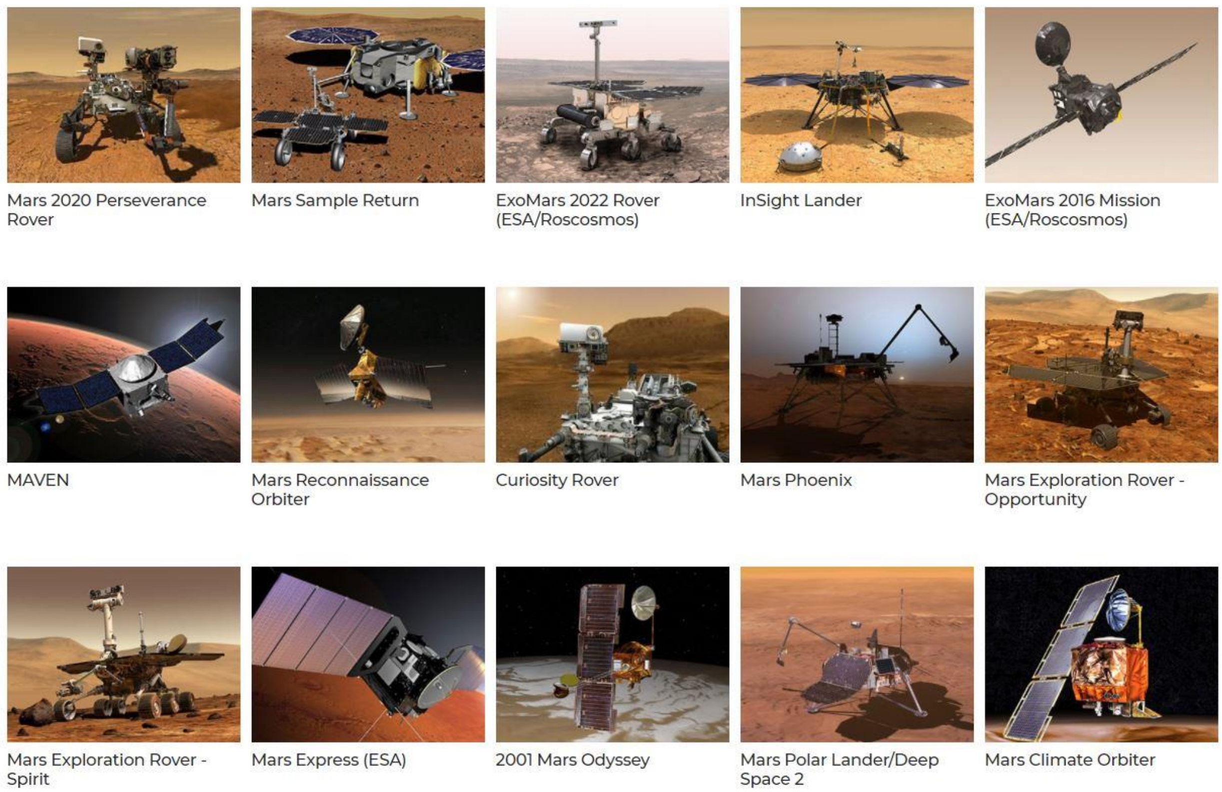
The data show that the Ev3rstorm was the fastest on the sand course, therefore being the most maneuverable robot. It is only at the final race across sand where the Ev3Storm gains a small advantage compared to the Gripp3r, whose time was in the 16 second threshold, and a massive one compared to the Track3r which had 22 seconds. I noted that the Gripp3r is heavier than the other models, making it have more frictional force since gravity pulls the robot down. I learned about frictional force in these experiments.

With this data we can determine that the best robot prototype for sand exploration was indeed the Ev3Storm. Upon further investigation on other rovers at NASA, I found that the best design for different terrains is the wheel robot, not the tractor style. See Figure 3. This is the case with the Mars Curiosity rover which remains on the red planet today.

Future Studies

To continue this research project, I will try this experiment with Ev3Storm prototypes that lift the brick further off the ground, add inclines to the course, and use sensors (color, infrared, etc.) to work around obstacles. For detailed analysis, more trials should be conducted and perhaps more extensive programming for the different prototype models. Researching on multiple surfaces is a good start, but most rovers move in multiple directions, performing multiple tasks at the same time. Turns, arm movements, even sensors can be useful in an experiment such as this one. The independent variable could be changed to accommodate even more robotic designs and surfaces, proving one robot’s superiority over the others, or displaying strengths and weaknesses among them.

Figure 3: Some real-life prototypes of Mars Explorer vehicles (1)



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