# M.A.R.K. (More Applied Random Knowledge) rover

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## Abstract:

*Sending a robot to Mars is an expensive undertaking. Therefore, it is imperative that the design and construction of such a robot be held to high standards and meet the demands of operating on Mars. A robot sent to Mars must be both capable of doing tasks independently as well as be able to navigate Mars' rugged terrain. The MARK rover is a system designed to meet both these requirements.*

*The MARK rover features a chassis driven by four motors connected to wheels and a suspension system to keep the central electronics board as stable as possible. The suspension features two identical arms on each side connected on the back end by a linkage system; when the back of an arm moves up, the back of the other arm moves down. This, coupled with the large off-road tires allows the rover to travel over sand, rock, and gravel that would be experienced on Mars. On-board microcontrollers are programmed to make the rover fully autonomous. The MARK rover is programmed to receive a beacon signal, and use a compass to travel in that direction. It also uses ultrasonic sensors to see and avoid any obstacles that are too large to travel over.*

*After extensive testing it can be concluded that the MARK rover design is a strong candidate to successfully and autonomously travel over a Mars-like environment.*

## Goals:

The purpose of NASA's Colorado Space Grant Robotics Challenge is for teams to creatively design rovers fit to navigate and explore Mars. In order to simulate the challenging terrain and obstacles of navigating on Mars, Great Sand Dunes National Park provides a similar environment of sand and rock for testing.

The goal of the MARK rover project was to create an autonomous simple but highly effective rover built to navigate in sandy and rocky conditions, using a combination of high clearance and ultrasonic sensors to go over or to detect and avoid obstacles. The rover also needed to navigate using a compass and beacon system.

# The Design:

### Initial design:

The MARK rover features a main baseplate to which all electronics are mounted, keeping the center of gravity as low as possible given the high clearance provided by the tall arms. Sensor mounts are connected to the front of the baseplate. An axle runs under the baseplate, connected with brackets, and goes through the arms on either side of the baseplate, serving as the point around which they rotate. A linkage arm and ball-bearing system in the back elevated from the baseplate with a riser block provide a mechanical connection between the base plate and the two arms so that if the back of one arm moves up, the back of the other arm has a relative downward motion, providing a suspension system for the robot. The two arms have two Wild Thumper wheels each from Sparkfun; wheels that have proven reliable at the challenge in the past.

One of the most important features of the design of the MARK rover is that the linked rotating arms allow the base plate containing the electronics to stay as level as possible, even when going over large obstacles or rough terrain. This is especially important for the compass since the compass readings are not accurate when it is tilted. It is also beneficial for stability and balance concerns.

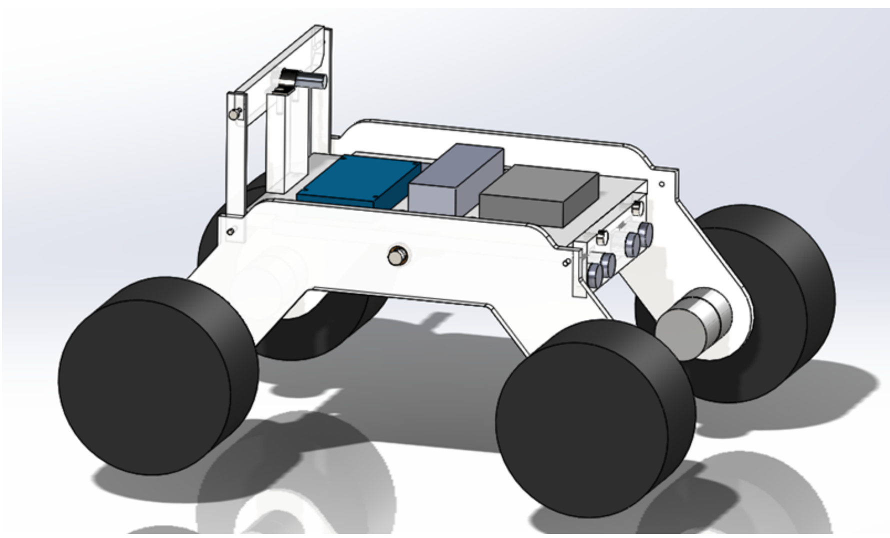

Figure 1: Initial CAD model of the MARK rover

### Design changes:

Not many modifications were made to the initial design, but a few issues with initial testing lead to some minor changes:

The compass could not get a correct reading due to the nearby electronics and the electric fields they created. In order to solve this issue, a column was cut out of polycarbonate and the compass attached to the top, elevating the compass above the main body of the robot and weakening the effects of the fields below, making the compass readings much more accurate.

The pictured sensor mounts above in Figure 1 were too far back, causing the ultrasonic sensors to sense the front of the arms and treat them as obstacles. A first design solution involved small strips of aluminum sheet metal bent into arms. This solution failed because the new mounts were far too flimsy and any vibration of the robot caused extreme vibration and movement of the sensor mounts due to the large moment arm being created by the mass of the sensor on the end on the thin beam. A second design, simple rods with a rectangular cross-sections cut out of polycarbonate, proved much more sturdy and reliable.

Figure 2: Photographs of the MARK rover used at the challenge

## Fabrication and Assembly:

Many of the main components including the baseplate, arms, linkage arm, riser, compass mount, and sensor mounts were all machined out of polycarbonate. Polycarbonate was chosen because it is easy to obtain, cheap, light, machines easily, and is highly flexible and strong.

Since a high degree of precision was necessary when machining the arms in order for the motors to mount correctly, they were fabricated in a Computer Numerical Control milling machine. This was also much faster than machining it in a traditional vertical mill and it allowed repeatable machining of  the arm design which contained many curves, again difficult to make on a traditional mill. The repeatability and high speed of this machining choice also provided the opportunity to fabricate a third arm for back-up.

The main axle and short linkage axle were made from aluminum rod stock which is also light, cheap and easy to machine, while providing enough strength and stiffness to integrate the baseplate, arms, and linkage system effectively.

A decision was made to order wheels instead of designing and fabricating them in order to use a reliable wheel known to be successful at past challenges, as well as saving time to work on more unique components of the design.

Many various fasteners and washers were also bought and used to correctly join, align and space the different components, especially along the aluminum rods.

## Electronics and programming:

MARK is controlled by a main brain arduino. This arduino communicates with the beacon receiver module in order to understand which direction to go. Four spur gearmotors are controlled by a sabertooth 2X5 dual motor driver. The driver receives a PWM signal from the arduino and turns it into power for the motors. The entire system is powered by a single 11.1 volt lithium polymer battery. A HMC5883L 3-axis magnetometer is used in conjunction with the beacon receiver to allow the robot to find its way to the beacon. Two ultrasonic sensors are used.

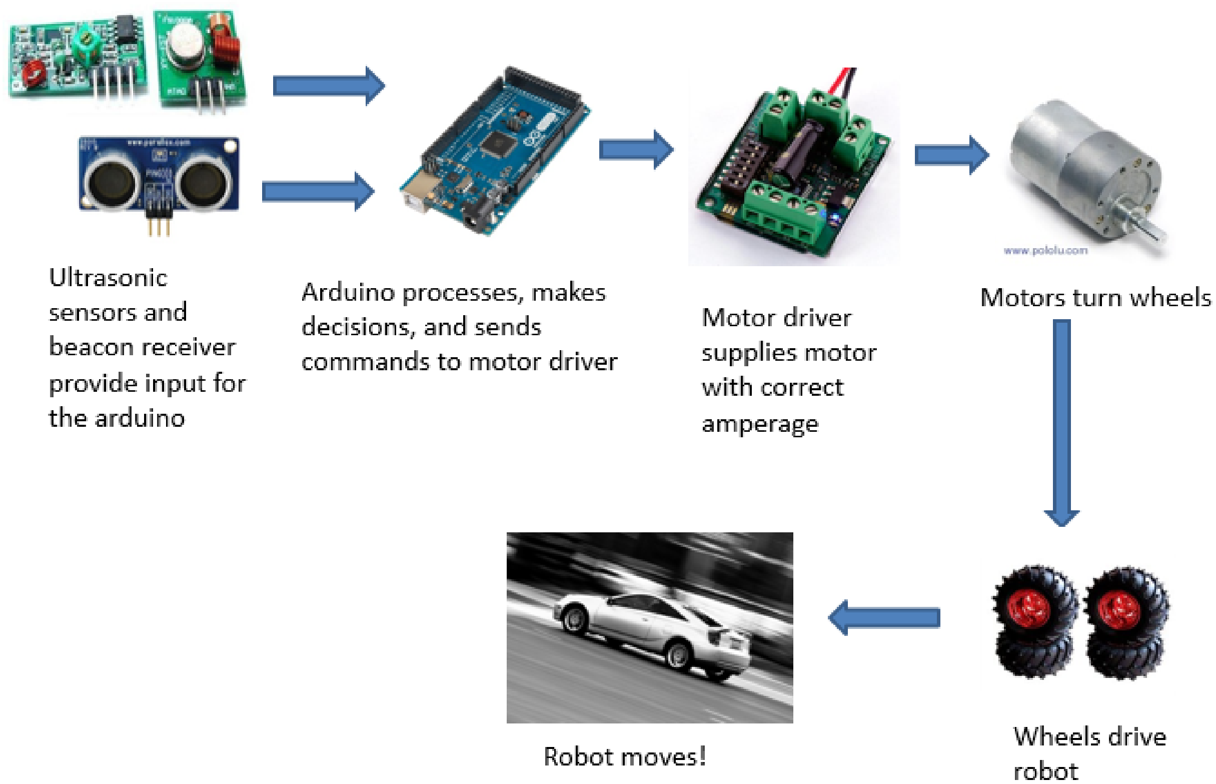


Figure 3: Block diagram

The robot uses a very simple algorithm to find its way to the beacon. When the robot is first turned on, a loop starts. The first action the robot takes is to find the beacon signal. Then the robot uses the beacon signal and the compass to turn towards the beacon. The robot then drives forward while checking each ultrasonic sensor, one at a time. If the robot does not see anything, it continues forward. When the robot sees something, it will turn away from the object until it is clear in front of the robot. The last thing in the loop is for the robot to drive forward for a specified time period. As the loop starts over, the robot turns to face the beacon again. This algorithm is illustrated by the flowchart below, in Figure 4.

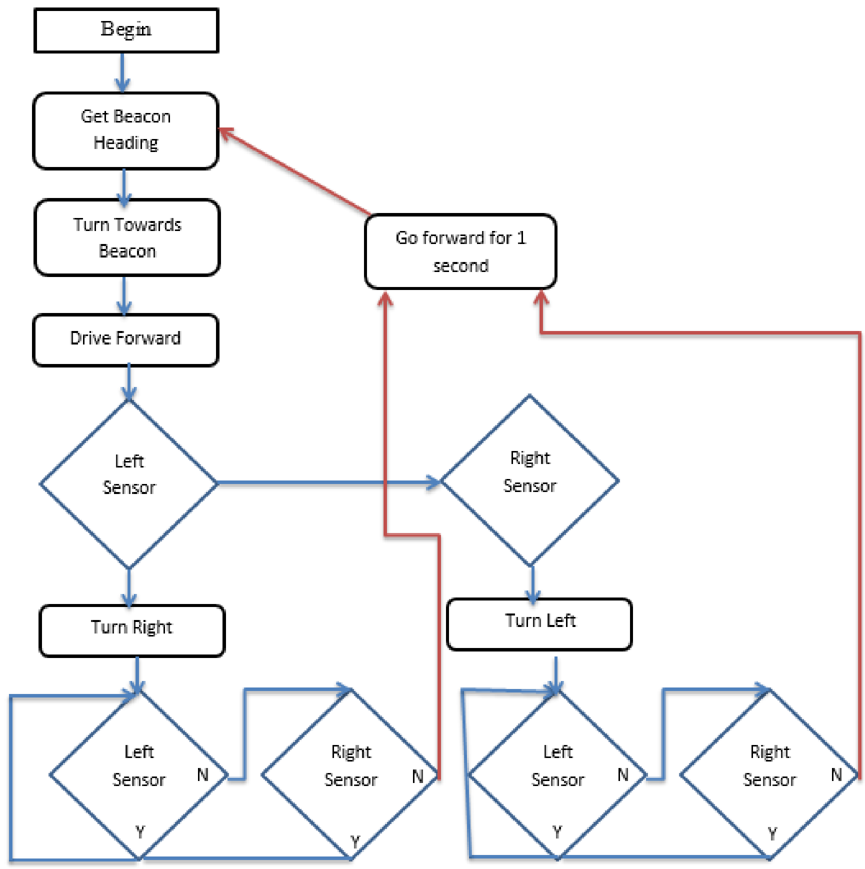


Figure 4: Flowchart

## Testing:

The team decided that the most important mechanical things to test were functionalities including: the ability to drive straight, turn, drive over obstacles, and go up or down an incline or steps. These different functionalities also needed to be tested on various ground surfaces. In order to test the mechanical abilities of the robot separately from the navigation and obstacle avoidance, the robot was tested both using a remote control system and later using a simple programmed loop consisting of straight runs and turns.

On surfaces such as concrete and grass, the robot handled going straight well and kept up a good speed, but it struggled on turns as rubber nubs on the wheels resisted turning on the concrete and grass also provided a resistive force during turns. Fortunately neither concrete nor grass are found on Mars, so this is not necessarily an issue. A trial going up concrete steps also proved unfruitful due to the wheel base being too short to make it onto the next step, but again, there are no perfectly shaped steps on Mars and with some more tweaking of sensor placement the rover could either know that it could go over the obstacle, or avoid it. The wheelbase is still something to consider for future designs though, especially if used in an area with rock formations similarly sized to steps--deceivingly easy to go over.

In the sand, gravel, and beds of medium-sized rocks, environments more typical of those found on Mars, the robot both went straight and turned well. The suspension system created by the rotating arms and linkage connection helped smooth the movement of the robot and keep the baseplate level as the rover bounced over medium sized rocks and traveled over large divots in the sand.

On the programming side of things, it was important to test the compass readings and the sensor's ability to detect obstacles, as well as the full algorithm shown in Figure 4.

Much of the obstacle avoidance testing was done indoors due to rainy weather. The rover successfully detected and navigated around objects like podiums and backpacks set upright, but if the rover headed straight for a wall, the sensors would alternate seeing an obstacle in very short time intervals as it tried to turn left and right in and endless loop. In the future, adding a function to move backward could help solve this issue. In testing the team hoped this issue would only arise for an "infinite object" like a wall since it did not have trouble navigating around a square-column podium twice the width of the rover.

There were also issues testing the compass inside; the team wonders how different metal structural components in the buildings might have affected it, but the compass did a fairly good job keeping the robot on the desired trajectory overall, and did better outside although there was still some drift.

Overall, the testing of mechanical and programming systems as well as the integrated performance of the complete rover lead the team to feel confident heading to the challenge.

## Conclusion:

The CSU Green team was very satisfied with the performance of the MARK Rover at the Robotics Challenge this year. MARK was able to complete all of the given obstacle courses; including navigating over ditches and logs as well as around large wooden walls with the vision from the ultrasonic sensors. Unfortunately, just before attending the competition the arduino that was powering the beacon navigation for MARK failed. Luckily the team had a backup compass navigation system in place and was still able to perform at the challenge.

The largest issues MARK had in the competition were turning in the sand navigating around objects. Turning in the sand proved difficult for the rover; as the wheels spun in a stationary position MARK often dug deeper and deeper into the sand, occasionally getting stuck. Possible fixes to this problem were to have the rover moving while turning (running the motors at different speeds) rather than simply turning the motors on one side forward and the other side backwards.

The other large issue was with navigating around objects. MARK did great most of the time, using the ultrasonic sensors to guide itself around flat objects. Occasionally, however, the rover would get stuck try and go one way around an object, still see the object, and then try and go around the other side. This would result in a loop where the robot got stuck going back and forth and never actually made it around the object, similar to issues found in previous testing. This was fixed by having the robot turn further and move further away when in obstacle avoidance in order to get significant clearance from the object and make it around.

When compared with last year's ARK rover, the MARK was a significant improvement in this year's robotics challenge. While the ARK was not able to complete most obstacle courses on account of the unreliable track system, MARK completed all courses with ease.

## Message to next year:

The CSU Green would like to give some advice to next year’s teams based on experiences with this year's robotics challenge. A simple design is crucial to meeting the cost, weight, and time requirements in order to get a working bot finished by the challenge. It is far better to have a simple design that can be built upon and made stronger after the groundwork has been laid than a robot that cannot compete in the challenge because the design was too challenging and nothing ended up working. Unforeseen challenges will arise and everything that was planned on being quick and easy can end up taking longer than was thought. Especially with the busy schedules of college students.

A huge part of the success from this year’s team was also the use of CAD software to fully model the entire bot before building it. This allowed the team to know exactly how the robot would look and work before building it. Changes to the CAD could be made quickly and easily. This saved a great deal of time building versions of the rover that would not be used.

Overall, the Robotics Challenge is a great learning experience and a fantastic opportunity to have some hands-on experience with robotics. So above all, enjoy the time and learn lots about robotics!