Maker: Twisted Sister Rover

Dr. Andy Zhang, New York City College of Technology

Dr. Andy S. Zhang received his PH.D. from the City University of New York in 1995. He is currently the program director of a Mechatronics Project in the New York City College of Technology/CUNY. For the past 10 years, Dr. Zhang has been working on bringing mechatronics technology to the undergraduate engineering technology curricula and on helping high school students to learn mechatronics through FIRST Robotic Competition events.

angran xiao, New York City College of Technology, City University of New York

Angran Xiao is an assistant professor at Dept. of Mechanical Engineering Technology, New York City College of Technology, City University of New York.

angran xiao
Mr. Alexis Daniel Ortiz, NYCCT

Alexis Ortiz attends New York City College of Technology as a senior student studying for his BS degree in Mechanical Engineering Technology. His foundation of knowledge in mechanics and extensive experience with CAD/CAM programs have aided in his ability to design hybrid mechatronic machinery. His interest in mechatronics stems from his passion for automobiles and technology, with the culmination of these two passions Alexis and his colleagues conceptualized, designed and manufactured the Twisted Sister Rover, a project required for a Machine Design class taken in fall 2013. Alexis's contribution to the Twisted Sister Project was the concept and design of the articulating center drum, as well as the rear body frame design. These components enabled the robotic rover to climb over non-uniform obstacles that existed in its drive path while retaining traction on at least three out of the four wheels during motion. Outside of school he works seasonally at a private tax office in his local town in Long Island. His experience both in and out of school has furthered his innate abilities to plan, organize and lead design projects to proliferate his experience with mechatronic design. Alexis continues his desire for mechatronic design as he is currently working with a team of students to design a CNC router machine.

Bryant Vicente , New York City College of Technology
Anass Baroudi, citytech

Mechanical Engineering student at the City College of Technology

Albino Marsetti, Gruppo Barbara
Rocky Kowchai Marcus Kowchai

Title: Maker: Twisted Sister Rover

Abstract:
The Twisted Sister is a four-wheel mobile robot that can twist its front wheels to navigate the rough terrains. Each wheel is driven by a DC motor. The front wheels can be raised by a DC gearmotor which is connected to a worm gear system. The rover chassis is made of sheet metal cut from water jet. An Arduino robot controller is mounted on the Twisted Sister Rover. A remote controller is equipped with two tiny joysticks. One joystick is used to control the movement of the rover and the other joystick to used to either raise or lower the front wheels. Wireless communication is through Xbee radio modules, one mounted on the rover and one mounted on the remote controller. The project teaches the students on how to integrate mechanical design, electronic design, and software design (programming) into producing new products. It helps the students to realize the importance of hands-on multidisciplinary approach to product design[1-5].

1.Introduction

Modern product design practices require engineering designers to possess multidisciplinary knowledge in many engineering fields, be able to use concurrent engineering approach, and be able to work effectively in teams. As most products nowadays are mechatronics in nature that requires the tight integration of mechanical design with electronics design, and software design to make the product function as desired.

The objective of the rover design project in a machine design class was to give students an opportunity to practice modern product design through hands-on multidisciplinary design activities which required the students to work in teams and to use concurrent engineering approach. The hands-on design activities also provided a platform for the students to learn from their failures. "Failure is the mother of success". Machine design is a capstone course in the mechanical engineering technology department' associate degree program. Students taking machine design class were divided into teams with four to five students in each team. Team leaders were selected by the faculty based on interviews and on students previous class performances. Team leaders then went on to interview his/her fellow students for potential members in his/her team. There were four teams in the machine design class. Once the team was formed, it has thirteen weeks to finish the rover project.

Each team was asked to design a remote controlled rover that can maneuver and navigate in rough terrains. The rover design must be based on the following specifications:

- Use four 12 V DC Motors to design drive train
- Design an appropriate chassis suspension system that allows the rover to climb 3-inch high obstacles.
- Design a wireless communication module to control the robot remotely

The design should include the following:

- Detailed models for each system and assembly for the design.
- A detailed design report
- A physical prototype based on design work.

Twisted Sister is one of the rovers designed by a group of five students. The Twisted Sister won the first place in the end of the semester design competition. What follows document the design process of the Twisted Sister rover team.

2. Mechanical Design

Once the design team was formed, the team's attention turned to the design considerations. Through initial brainstorming, the team settled on certain specific design characteristics. The first was an articulating chassis, and the second was a vertical motor configuration.

2.1 Use of the Articulating Chassis Concept

The articulating chassis was a characteristic that emerged during team formation. The idea was to create a chassis inspired by the custom machines competing in rock climbing competitions across the United States. Using this chassis design, these vehicles are able to negotiate very difficult terrain including enormous boulders and steep, sudden changes in elevation. The decision to use this type of chassis created significant design challenges.

Many configurations were considered for the articulating chassis design. Ideas ranged from a narrow system rotating around a small bearing to a scissor-like design. Naturally, the design required establishing a source for the articulating movement. Having established that the articulation would not be an active suspension component, and be used only to facilitate climbing, it was necessary that the robot be able to maintain articulation during rolling movements (roll on three wheels with the fourth raised). Ultimately, a drum design was selected for the basis of chassis rotation. The forces experienced by a moving vehicle frame are normally dissipated over the relatively long horizontal distance between the lateral boundaries of the frame. That distance is greatly reduced for circular movement. For instance, if a small steel bearing design was selected for the central spine the entire chassis rotation would have to be focused around that very narrow diameter of the bearing. The unification of the chassis halves and the application of mechanical force would be similar to the design in Figure 1. Something we don't expect to survive many "highway" miles. By using a drum or cylinder, the horizontal distance across the body of the vehicle is greatly increased relative to a small steel-bearing counterpart. The drum shape provides area to dissipate commonly occurring vehicle stresses. Additionally, the drum was well suited to the use of a worm gear which provides the opportunity for the robot to maintain its articulated position without electronic assistance.

Figure 1. Articulating Chassis. (courtesy FourWheeler.com[6])

2.2 Vertical Motor Configuration

In order to increase the clearance of our vehicle, a vertical motor configuration was selected. The vertical motor configuration significantly increases the clearance of the vehicle since alignment of the motor shaft and wheel axis is not required. While this requires additional components, the configuration reduces the possibility for getting the vehicle hung up on its undercarriage. However, the vertical configuration of the motor presents a different set of technical challenges.

The first step in selecting the drivetrain motors was to determine the operating velocity of the robot and select motors capable of this performance. The wheel size was the only variable which the team was unable to vary. From the circumference of the wheel, we determined an appropriate number of RPMs for our motors. The deciding factor in motor selection was observation of a direct drive configuration in action. This observation led to the conclusion that we could reduce velocity to increase climbing force. The team opted for a 2:1 gear ratio as an enhancement to our robots focus on climbing. While most configurations would employ a direct drive, the vertical configuration required a perpendicular transfer of power. This was facilitated by use of a bevel gear. To simplify the design process, the standard Tetrix motor mount was employed. The team designed a wishbone around this motor mount and created driveline components as well as shock absorption.

2.3 Design Evolution

Operating in tough terrain, the design must rely mostly on the suspension system. If the suspension system is self-adjusting for such terrain the fixed system must provide some “give” to reduce the compressive forces exerted by the resilient shock absorber springs. In preliminary drafts the addition of a swiveling center joint (Figure 2) was considered to alleviate some of the forces encountered by the suspension system This initial design draft focused on a robot that could physically rotate its front half to adjust its tires/wheels to gain traction on either side (surface traction or traction acquired on obstacle). With the internal rotating joint established, the external components of the robot were configured or aligned on a chassis to ensure the robots balance, provide space for the internal rotating drum and provide an efficient method of applying driving power from the 12 V DC motors.

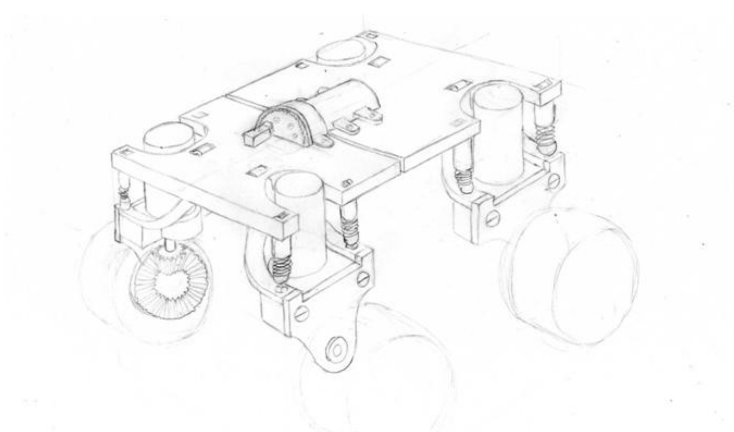


Figure 2, First Draft of the Twisted Sister

The initial design for power transmission between the motor and the robot's wheels was to use direct power transmission (Figure 3) however not much consideration was taken into this design at that time as it presented a problem in applying direct power transmission due to the differences in diameters in both the driving 12 V motor and the driven 4mm axle fixed to the given wheels. If the direct power transmission design was considered, the motors would lie parallel to the driven axle and could present problems when cornering over rough terrain as well as include another subassembly independent of the shock absorbers/wheels.

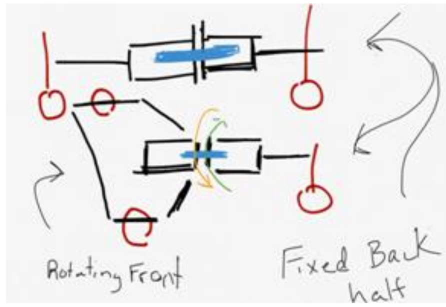


Figure 3, Use of Swiveling Center Drum Concept

To accommodate for clearance problems, the design team decided to employ a set of bevel gears to accommodate for the power transmission. The design of bevel gears allows the 12 V DC motor to apply perpendicular rotating force on the driven gear by the driving gear. The use of bevel gears ensures that the driving motor would and could apply enough power to drive the wheels at an acceptable speed while reducing subassembly components.

The suspension system's initial draft included a wishbone component that was to be bolted through a pin mounted on the top of the chassis frame. The draft presented problems with the inclusion of the relative motion of the wishbone assembly. When the wheel would pass over an obstacle the wishbone would flex, the shocks would compress and the wishbone assembly would rotate about the fixed pin on the chassis. This rotating motion could result in the shock absorbers receiving scratches, damage or physical erosion due to its contact with the steel chassis and steel wishbone.

To stabilize and prevent such problem from occurring in the design, it was decided to use C-channel beams to stabilize and absorb residual stresses applied by both the shock absorbers and wishbone components. The decision to use c channel beams directly affected the initial design as the original chassis had to be adapted for both the size and fitting of such c channels. Three C-channels were used in the suspension system to provide stability between the internal wishbone component and the exterior.

The overall design process involved designing components and subassemblies first to ensure that the subassemblies could be fitted to the chassis. The chassis design was considered initially as a plain rectangle base but quickly adapted to the positioning and arrangement components. The design team felt that since the chassis was the easiest to modify and would have to hold everything together that it should be manufactured last to ensure the design had adequate space to hold all components both physical and electronic.

2.4 Chassis Design

The design of the chassis took many steps and revisions to complete. The adoption of a triangular shaped chassis (See final assembly: Figure 8) aided in designing flange shielding for the rotating center drum. The use of such flanges was met by some difficulties in interference with other flanges. These flanges were corrected and provided spacing under for components to be mounted. The shielding on the underside of the chassis provided a protected core for the drum component as well assisted in guiding the robot over rough terrain. The shielding flanges would guide the rear wheels over the rough terrain as well as reduce friction for easier correction over such obstacles.

The evolution of the chassis took many transformations and eventually had to be manipulated manually due to other considerations presented when installing the electrical components. The few features that remained in the design of the chassis were the locations and placement of the four DC motors, the location of the spines and the spacer holes for the shock absorbers.

2.5 Wishbone Design

The two main types of suspension systems found in cars are dependent and independent. These suspension systems also apply to other vehicles such as semi-trucks. Each type of suspension system utilizes springs and shock absorbers. If a vehicle only had springs it would boat and wallow along with the road making the ride very uncomfortable. Springs come in three types. They are coil springs, torsion bars, and leaf springs. Coil springs are what most people are familiar with, and are actually coiled torsion bars. Leaf springs are what one would find on most American cars up to about 1985 and almost all heavy duty vehicles. They look like layers of metal connected to the axle. The layers are called leaves, hence leaf-spring. The torsion bar on its own is a contraption which gives coiled-spring-like performance based on the twisting properties of a steel bar. It's used in the suspension of VW Beetles and Karmann Ghias, air-cooled Porsches (356 and 911 until 1989 when they went to springs), and the rear suspension of Peugeot 205s amongst other cars[7-10]. Instead of having a coiled spring, the axle is attached to one end of a steel shaft. The other end is slotted into a tube and held there by splines. As the suspension moves, it twists the shaft along its length, which in turn resist. Now imagine that same shaft but instead of being straight, it's coiled up. As one presses on the top of the coil, he is actually inducing a twisting in the shaft, all the way down the coil.

Imagine the suspension just mimicking what it is encountering on the road rather than absorbing it. This is where shock absorbers come in which are technically dampers. They absorb any larger than average bumps in the road, so minimal motion is transmitted to the chassis. In addition, shock absorbers keep the suspension at its maximum travel by pushing it towards the road, which also helps keeps your tires on the road. Many modern cars have a coil-over-oil unit which incorporates both a shock absorber and spring into one product.

Dependent suspension systems get their name because each of the front or rear wheels is dependent on the wheel opposite of it. This type of suspension system is only found on modern trucks and off road vehicles but a number of years ago it was common on cars as well. The major downside to a dependent suspension system is that the wheels are linked, if one wheel is set into oscillation and the other is not, it sets up a gyroscopic torque around the steering axis. This force will start to turn the axle left to right and due to the axles inertia, it will amplify the force of the original oscillation. To put that simpler, if the tire on the right side hits a bump it will directly affect the left side and can even cause a larger effect than the original bump. Another downfall of a dependent suspension system is that it weighs more than an independent system. This is because there are a number of parts that are needed on a dependent system that are not needed on an independent system.

An independent suspension system gets its name because the wheels on either side of the car are independent from one another. The only exception to this is an anti-roll bar that connects the two wheels, to prevent the cars suspension from rolling as it corners. There are a number of independent suspension types such as, coil spring type 1, coil spring type 2, multi-link, trailing-arm, twin I-beam, and transverse leaf spring. The major difference between independent suspension and dependent suspension is that when a car with independent suspension hits a bump it only affects the wheel that hit the bump. This offers many advantages such as, better ride comfort, better traction, more stability and an overall safer vehicle.

The shock absorbers used by the team were 65 mm in length. Each suspension unit incorporated two shock absorbers for maximum absorption and rebounding. Two shock absorbers also made each wishbone suspension unit level with the chassis. The wishbone suspension component was designed to fit around the motor and the bevel gears. The clearance needed for the bevel gears forced the design to become higher than originally expected. The wishbone now acted as a lift kit. Lifting suspension is a popular modification used to try to increase ground clearance. A lift kit doesn't really give you more ground clearance. What it does is increase the height between the axle and the underside of the body. Whilst this does give more ground clearance for the bodywork, the lowest point on the vehicle is still the axles - or on a 4-wheel-drive, the bottom of the transfer case. For this reason, you'll often see trucks and SUVs with lift kits and larger wheels and tires. The lift kit boosts the clearance under the bodywork whilst the larger wheels and tires result in the axles being lifted higher off the ground. Figure 4 shows the wishbone suspension system.

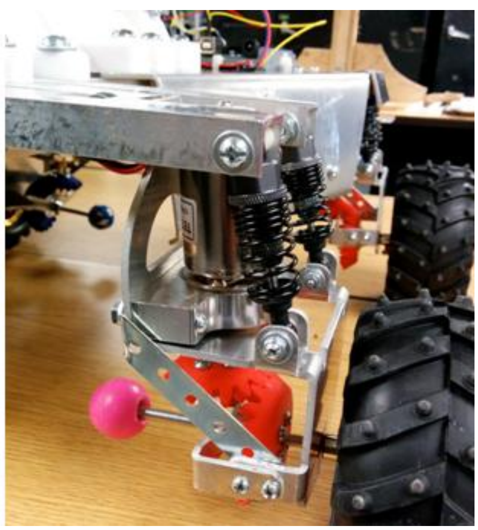


Figure 4 Wishbone Suspension System

2.6 The Spine Design

The Spine of the Twisted Sister is the center piece of the robot. It is used to allow the bot to maneuver over obstacles that are higher than the radius of the robots wheels. A regular robot or car, has to rely on the forwarded forces to get it over a hump or object, and even then the object needs to be lower than the radius of the wheel so that deformation does not occur. With the Spine the Twisted Sister is more effective than the average terrain robot.

Not only does the Spine of the Twisted Sister allow for free independent motion between the front half of the robot from the back, but it also can be controlled using a joystick on the remote. This further adds to the perks of the Twisted Sister. When the robot is met with an obstacle its front wheel can be lifted to the appropriate height and maneuver over the object.

The Spine is turned using a worm gear[11] driven by a Robotzone Gearmotor with 60 rpm at 12 V DC. A worm gear was used because it cannot be driven by the wheel gear. This attribute gives the worm gear a locking effect that is necessary to the design of the Spine. If a spur gear was used the motor will have to constantly be fighting the force of gravity pulling on the mass of the wheel in the air, however the worm locks it in place.

The Spine system consists of three essential parts. Spine1 is attached to the front end of the chassis and Spine2 is bolted on the back part of the chassis. Spine2 is then placed within the tube of Spine1. The elbow of Spine2 is meant to keep it from sliding too far down the tube. The worm wheel is then bolted to Spine2 for two purposes: first to keep it from sliding back out of place, and secondly, so that Spine2 can be driven and rotated lifting the robot wheel in the air.
In building the Spine system a number of things had to be considered. Since the part had to be 3D printed, material and printing time had to be reduced. Material was saved by making Spine2 hollow. A hollow part also provided an opportunity to protect the wires from tangling. Wires were directed through the Spine’s center of rotation to prevent them from entanglement. Figure 5 shows the Spline assembly.

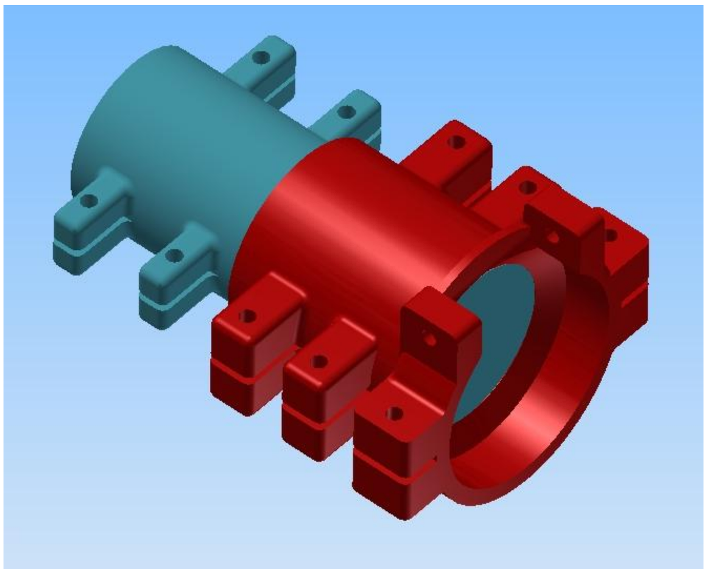


Figure 5 Spline Assembly

3. Electronic Design

There are two major electronic components. One is the Rover controller to be mounted on the rover and the other is the hand-held remote control unit that is used to control the movement of the rover.

Two Arduino microcontrollers[12] were used. One is mounted on the rover and the other is mounted on the hand-held remote controller. Four Tetrix 12-V DC motors[13] were used to create a four-wheel drive rover. The hand-held remote controller sends commands wirelessly through Xbee Radio modules to the rover[14].

Figure 6 is the schematic of the rover circuit design and Figure 7 shows the schematic of the hand-held remote control unit. Two mini joysticks mounted on the hand-held remote controllers control the movement of the rover as well as the swiveling of the two front wheels Three Talon speed controllers[15] were used to control the speed of the four Tetrix DC motors and the swiveling of the two front wheels.

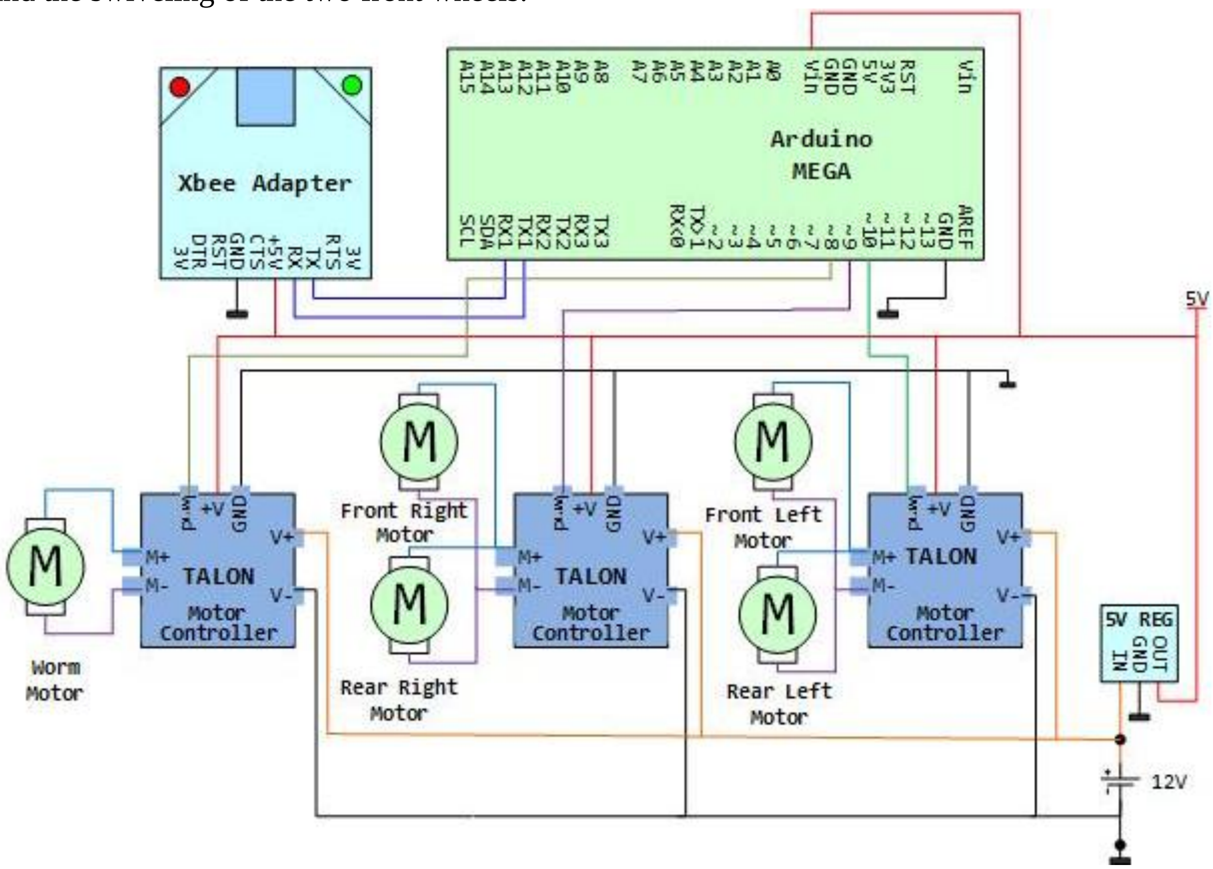


Figure 6 Twisted Sister Rover Control Unit

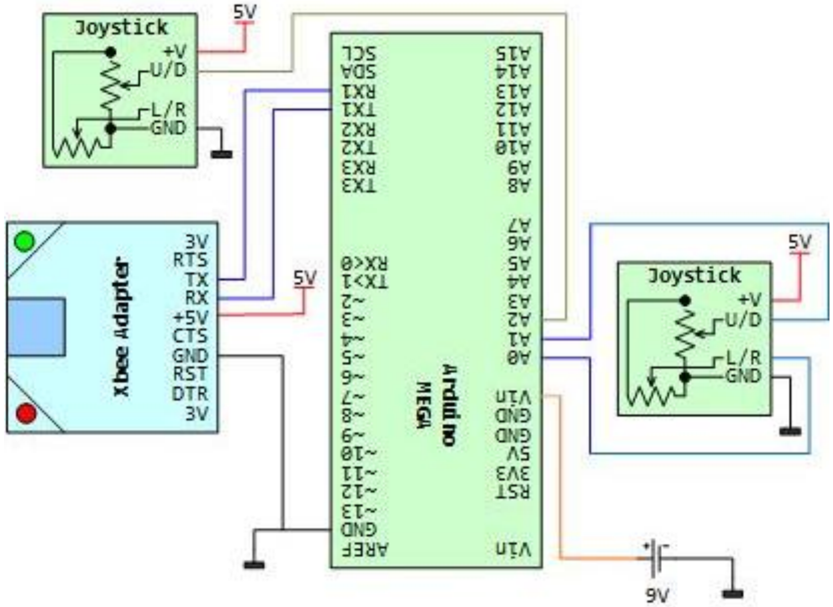


Figure 7 Twisted Sister Rover Remote Control Unit

4. The Results and Team Self Reflections

Many factors attributed to the manipulation and revisions that occurred during the design and manufacturing processes, for none of the members were familiar with machine design and component assembly/construction before this project was presented. Once the design was finalized the team began to assemble their individual assigned components. The difficulties soon rose to the surface as considerations such as tolerances and structural integrity became present as the necessary components available to the team were distributed on a first come-first served basis. As a result many of the first prototypes of the main components were scrapped as they could not encompass fitting the additional components presented.

As the wishbone/suspension system took shape it became immediately apparent that the original design for the wishbone would have to be manipulated as the original shock absorbers were too small to have efficient resilience when compared to the size of the given wheels. The original shock design would buckle under the compression of the 3 inch diameter tire running over an obstacle. As the new shock size had to be considered, there was a necessity to modify the placement of the shocks and their alignment. With bigger shocks the robot had already exceed the approximate height of standing 6 inches above the ground. This consideration is what led the team to design the 3 piece C channel stabilizer, not only did this allow a more fixed suspension but it also allowed the front wheels and back wheels to remain equal in both shape and size.

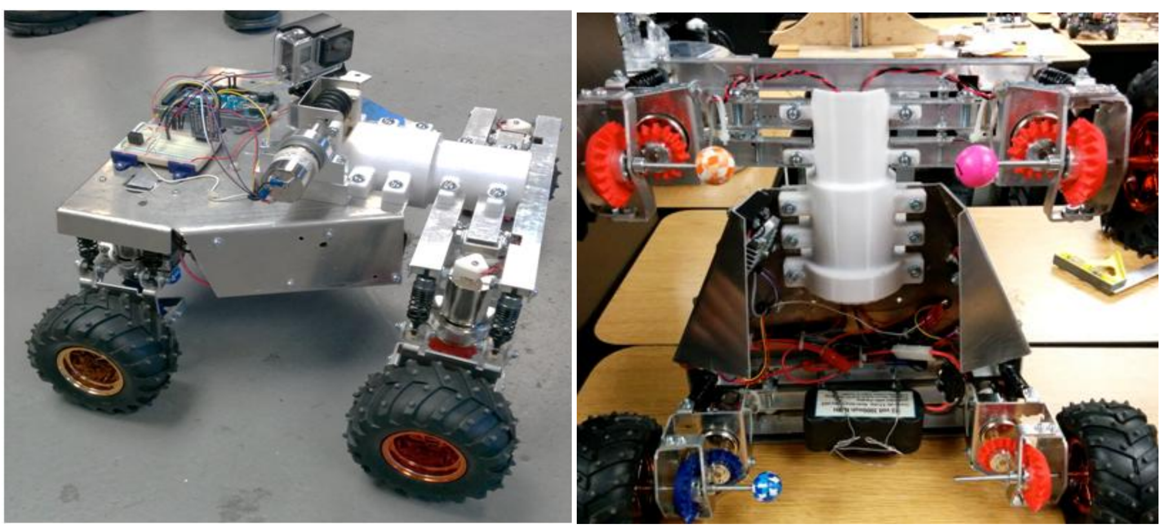
With the design and manufacturing of the spine, the most important component of the design, considerations like accurate hole placement as well as sizing became an issue as the projected model in Autodesk Inventor proved to be fully functional, the 3D printed part left the printer with an offset worm gear that did not make full contact with the perpendicular gear mechanism. The worm gears pinned position had to be manipulated almost immediately to prevent the reprinting or redesigning of the entire part.

The use of the 3D printer presented a unique problem as initially the printers printed 3D parts in batches of 5 or more. Due to the number of pieces being printed at the same time the loss of time became increasingly substantial as redesigning and reprinting would run double the time and also would not start unless other parts were required to print or ready to print. With the team's first attempt to print the bevel gears, the first pair did not print due to the printer jet being low on resin and plastic material, this resulted in a delay due to having to wait for the new filament cartridge as well as wait for other processes/parts to finish on the machine(s). The time it took for components such as the bevel gears and the spine totaled an 80+ hour span to complete the manufacturing of these parts.

Another issue that had presented itself to the design was the motor selected to run the worm gear. After initial testing the selected motor could not run the spine assembly due to its sheer size, and presented the difficulty of selecting a different motor as well as designing a motor mount that would hold this assembly completely fixed. The use of this new motor caused the need for manually drilled holes to be made in the chassis and as a result the robot was deconstructed many times when another component of unique shape presented itself.

Preliminary results show the robot to be a formidable climber. The worm gear functions quite well and generates tremendous interest whenever it is in operation. Figure 8 is shows the final product of the Twisted Sister Rover.

Detailed instructions on how to build the Twisted Sister Rover will be published on www.mtccitytech.org in the future.



a) Front viewb) Underside view

Figure 8 Final Product

5. Conclusion, Self Assessment, and Future Improvement

The challenge of creating a remote controlled robot in thirteen weeks was definitely an experience that brought students together rather quickly, the group efforts encouraged the design teams to both express their individual ideas as well as compromise design specifications to accommodate for changes in design as well as fitting more components in the design. There was some difficulty in securing many components in a small space (e.g. wishbone subassembly) however with some critical thinking, some encouragement and teaching the team quickly accommodated for spacing. Interactions with other design teams proved to be beneficial in expressing ideas and thoughts on design as well as encourage the relative motion analysis for both this team's designs as well as others. The communication exchanges between members also aided in facilitating the adjustments and revisions to designs. The team won the first place in the end of semester competition because of a strong team leader and active participating members that enabled the team to finish the project on time. Students should be exposed more on this kind of hands-on design activities. Something people can only learn through physically "MAKING" things

The Twisted Sister rover was tested through the use of an obstacle course constructed of angled, flat, recessed and uneven terrain arranged with shop materials in a hallway. The task of the rover was to pass through fifteen feet of uneven terrain in the shortest time possible.

The robot did work well in adjusting the front-end ride height to gain traction as well as generate lift along its center of gravity. By doing so the robot was able to lift its front either side of its front suspension assembly by a four-inch vertical. While doing so it was also able to raise it's free end (adjacent wheel) to align and gain traction for uniform forward propulsion.

In relation to the obstacle course set for this test the Twisted Sister rover would be considered a formidable climber in the sense that the robot can reach a raised uneven surface, gain traction and realign its center of gravity to climb over such obstacles. By doing so the rover in this situation could climb or drive over non-uniform obstacles, uneven surfaces, and manipulate its drive path and orientation to overcome almost any obstacle in its path given its design scale.

As mechanical engineering students, their knowledge on microcontrollers and electronics were limited that hindered the students' ability to integrate the electronic design fully into their work. The faculty members are working on creating new courses in mechatronics/robotics that will help future mechanical engineering students to easily interface the mechanical components or systems with microcontrollers and common electronic components in their design projects.

6. Acknowledgements

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References

[1] David E. Goldberg and Mark Somerville, "A Whole New Engineer – The Coming Revolution in Engineering Education", ThreeJoy Associate, Inc. 2014, ISBN13: 978-0-9860800-0-5

[2] Andy S. Zhang, Iem Heng, and Farrukh Zia, "Empowering Students with Practical "Working" Experience through Hands-on Multidisciplinary Design Projects" p1-6, *Journal of Mechanics Engineering and Automation*, David Publishing Company, Vol. 3, No.1, 2013

[3] Fadel, Charles**. "**21st Century Skills - From Industry to Education and Back" October 26-28, 2010, NSF ATE Principal Investigator Conference.

[4] Bellanca, James and Brandt, Ron. "21st Century Skills – Rethinking How Students Learn" Solution Tree Press, 2010, ISBN 978-1-935249-90-0.

[5] Thomas, Douglas and Brown, John Seely. “A New Culture of Learning – Cultivating the Imagination for a World of Constant Change”, ISBN-13 978-1456458881, ISBN-10 145658884. 2011.
[6] http://www.fourwheeler.com/events/129-0510-1993-2005-ttc-winners/
[7] http://www.howstuffworks.com/car-suspension4.htm
[8] http://en.wikipedia.org/wiki/Suspension_%28vehicle%29
[9] http://www.carbibles.com/suspension_bible.html
[10] Machine Elements in Mechanical Design by Robert L. Mott, P.E.
[11] BOSTON GEAR: Gear Catalog pgs. 136 – 156
[12] http://arduino.cc/en/Main/ArduinoBoardMega2560
[13] https://shop.education.lego.com/legoed/en-US/catalog/product.jsp?productId=5000490&ProductName=HiTechnic-DC-Motor-Controller-for-TETRIX&ProductLine=TETRIX-
[14] https://www.sparkfun.com/products/8710
[15] http://www.andymark.com/Talon-p/am-talon-discontinued.htm