Autonomous Rover and Lander System

Travis Histed, Ben Gindl, Sean Throckmorton, Luke Slominski
Colorado State University
Dr. Azer Yalin
E-mail
7.20.2010

Abstract

The project focused on the design and implementation of an autonomous rover and lander delivery system. The project goal was to develop a system capable of being dropped from altitude, reaching terminal velocity, deploying a parachute, releasing this chute just before ground impact and orientating the rover payload for deployment. The rover would then egress the vehicle and proceed to autonomously navigate the terrain. The project incorporates a rover used in a previous COSGC robot challenge which has been modified to integrate with the lander mechatronics.

1. Design and Development

The project consists of two main parts: the rover and lander. The rover is comprised of a pre-fabricated RC car chassis retrofitted with a custom electronics package. The lander is a tube design that utilizes gravity to orient the rover for deployment. Both systems will be discussed in depth in the following sections.

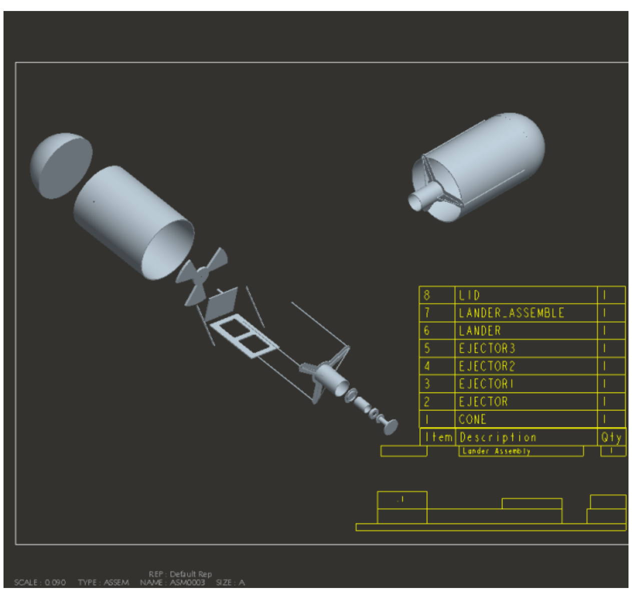

Figure # 1: Basic layout of landing platform

1.1. Rover

1.1.1 Chassis

Originally several designs for the chassis were considered. The team laid out several options for traction, steering, and mechanically powering the vehicle. These included self righting designs, tank tracks, slip steering, four wheel steering, etc. and eventually came to a conclusion. It was decided early on in the planning stages that a smarter robot, rather than a brute force robot, was of more interest to the group. This shifted our design focus from developing a proprietary base to working more on sensors and software. In order to allow the team to more quickly advance to the point of being able to program, a pre-fabricated RC rock crawler was chosen as the base. The advantage of this is that the rock crawler is ideally suited to rugged terrain right out of the box. This takes mechanical issues out of the equation and allows for an ideal electronics and software test bed. It should be noted that a major design constraint of the rover was to keep the weight no more than 1.5 kg; so as to stay within the entry weight for the COSGC Rover Challenge.

1.1.2 Sensor Mount

Initially the design for the sensor mount was to just use the plastic car shape that came with the pre-fabricated RC rock crawler. Upon our first tests with the sensors mounted, we came to the conclusion that a better spaced and structurally sound sensor mount was needed.

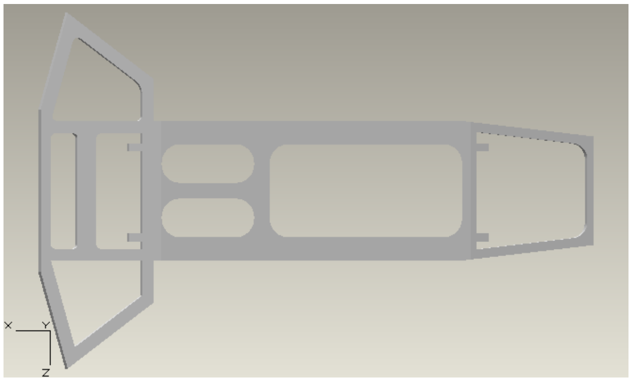

Figure # 2: New sensor plate designed to improve viewing capabilities

A design was worked up and approved by the team to use High-Density Polyethylene (HDPE). We were able to design the piece in Pro-Engineer® cad modeling and manufacture it using the CNC machine in the CSU MIL.

1.1.3 Sensor Selection

A combination of sensors was selected based on our budget and design goals. The sensor package needed to provide the robot with information regarding its heading and location relative to its goal, a sense of terrain geometry in front of and behind the vehicle, and the vehicle angle on a slope.

1.1.4 Sonar

We chose to employ a single forward facing MaxBotix® LV-MaxSonar-EZ0™ sonar sensor due to its ease of programming, price, and quality of information gathered. The sonar sensor sends a pressure wave into the environment and then measures the reflected waves. The sensor reports back this reflectance as a value. Using this value the vehicle can discern an objects size and distance to the object. Possible drawbacks to this sensor were poor reflectance from less dense objects such as bushes, and interference from blowing sand.

1.1.5 Infrared Sensor

Four Sharp® GP2D12 Analog Distance sensors were chosen for the vehicle, three in the front and one facing rearward. The sensor varies its voltage output as a nonlinear function of infrared wave reflectance from the object. This sensor is solid state and is not hampered as much by blowing sand and environmental noise. That said it provides a less clear reading of objects than the sonar based sensor.

1.1.6 Compass

A single digital compass module was selected to be integrated into our circuit board. We chose the Honeywell® HMC6352 on a breakout module from Sparkfun.com for its 0.5 degree resolution and simplicity of integration.

1.1.7 Accelerometer

The MMA7260Q was chosen to calculate the rovers tilt, in order to maintain the rover within a stable operating level. The accelerometer has four settings for sensitivity (± 1.5, ± 2, ± 4 and ±6 g's). The sensor measures the differences in voltage depending on it's orientation to the Earth's gravitational field.

1.1.8 Processing

All sensor information and logic is processed on a custom printed circuit board servicing dual ATmega164P AVR®'s from Atmel®. This particular AVR® was chosen because of its high number of programmable input/output pins available (32), on board analog to digital conversion capability, and our lead programmer's experience the AVR® platform. One chip receives and packages only sensor information and then sends it to the second chip which handles high level decision making and logic. This decision information is then expressed through vehicle control via the H-Bridge. The two chips also monitor each other and can reset one another in the event of a software crash.

1.1.9 Software and Logic

Previous programming work completed for the robot challenge was inexplicably non-functional. This meant for the team that integrating the sensors and basic vehicle control had to be re-invented. This was a huge amount of work undertaken mainly by Sean Throckmorton, who became our coding expert.

Once the software could interpret these sensor inputs they could be integrated into a high level decision matrix that dictated rover behavior using interrupt style programming.

1.1.10 Output

The transceiver, servos, and drive motors compose the robots output components which are driven by the main microcontroller. Each function must work simultaneously, while the rover gathers information it must output the proper actions.

1.1.11 Transceiver

A Parallax 433 MHz Radio Frequency transceiver is used to communicate between the base station and the rover. The transceiver is able to send out and collect radio frequencies to and from the base station; however the principle output function of the transceiver is to send out the “marco” signal. This will be controlled by the microcontroller, only sending out every one second or so.

1.1.12 Testing and Results

As of June 30, 2010, the pre-fabricated chassis based rover and all other manufactured pieces were completed All of the sensors are integrated in software and all mechanical pieces are complete. Actual testing commenced shortly afterwards.

After extensive testing, we found out that the compass and accelerometer were not entirely integrated. The accelerometer was programmed simply enough but the circuit board was not designed to encompass the data. We were also unable to decipher what was wrong with our compass.

For our final drop we unfortunately were unable to utilize either sensor.

1.1.13 Software Development

As a team, we are fairly new in the software, programming, area of microprocessors. The group’s experience has come from Colorado State University’s Mechanical Engineering department’s Mechatronics course and last years work during the Colorado Space Grant’s Rover Challenge.

After much thought amongst the group about which type of code would be best for the project (C, C++ or Basic), the team decided to go with Basic. Our software was created using the MCS Electronics - BASCOM AVR compiler and actually programmed to the microprocessor with Atmel AVR tools, AVR Studio 4.

1.1.14 Lander Avionics

The Lander’s software was in comparison to the Rover, a breeze. The Lander’s programming controls the payloads detachment from the tether, the parachute deployment and the lid release.

For the payload release, the Lander’s chip holds a pin high (holds a voltage) and is on a time delay (allowing for the payload to rise into position). Once the balloon and payload are in place, the time delay will let the pin to go low (no voltage on pin) allowing the tether to release.

After the release the programming continues onto the next time delay following the same principles as before, holding a different pin high. Once the time delay is finished and the pin goes low, the sequence will fire an electronic match and ignite the black powder, deploying the Lander’s parachute.

The final part of the Lander’s software incorporates the use of a sonar sensor and motor combination. The combination has the chip receives analog data from the sonar into one of its Analog-Digital Converters (ADC), while simultaneously holding a third pin high. The analog data is then converted into a digital value, using these values we were able to set up a trigger value (about 10 feet from the ground). During the fall the sonar would be seeing decreasing values but once this trigger value was “seen” by the sonar, it would allow the pin to go low. Immediately after the pin goes low, the motor runs for two seconds, successfully pulling the lid’s release pins free.

1.1.15 Rover Software

The Rover’s software was very difficult for the team to complete and get all components working properly. The programming integrates four types of sensors and a servo motor.

The team wrote codes for Infrared sensors, a Sonar, a Compass and an Accelerometer (four Sharp® GP2D12 Analog Distance, one MaxBotix® LV-MaxSonar-EZ0™, one Honeywell® HMC6352 and one Freescale® MMA7260Q).

The Infrared code has the servos turn based on values recorded from two angled front Sharp® GP2D12 Analog Distance sensors. Using the ADC values provided by the chips, we created trigger values. If either sensor saw a value bigger then the trigger value it would turn opposite the sensor that saw the value (i.e. Left sensor is triggered, servo to turns to the right and avoids object)

The Sonar helps control the forward or reverse velocity of the Rover. Again using the Atemga644p’s ADC pins, the Sonar values are used to determine if the rover’s velocity is high, low or reverse. The sonar has two trigger values instead of the infrareds one. If the sonar sees values bigger then the High trigger, the rover drives on high. If the value is in between the High and Low trigger values, it drives at medium. And finally if the value seen is less then the Low trigger, the rover goes into one of the reverse sub routines.

The compass code would have effectively made the rover drive north, using the I^2C protocol. The accelerometer would have been used to keep the rover from tipping, using one of the ADC pins on the Atemga644p. Sadly, we were unable as a group to figure out these two components of the software and did not utilize them in the final drop.

1.2. Lander

The lander was designed to deliver the rover safely from altitude by employing multiple stages of energy absorption and a passive orientation system.

1.2.1 Lander Concept

The basic concept for the lander was to employ a tube large enough to house the rover on an off center swivel which would allow the rover to always roll right side up no matter the orientation of the tube. The swivel would be mounted to a bulkhead which would provide major structural support to the tube as well house the electronics and chute release actuators. When falling the tube and rover within the tube are oriented vertically with a lid on top attached to the parachute. A foam crush zone is located on the bottom of the system. The lid on top of the tube houses the parachute, pyrotechnic charges to fire the parachute and release springs. Once the lander avionics package senses ~ 10ft from ground the actuators, located on the bulkhead, pull pins which release three rods that run the length of tube and connect to the lid. The rods pull through guides which stabilize the system as it lengthens via conservation of momentum and then are jettisoned along with the lid, shock cord, and parachute. This also leaves the top of the tube open allowing the rover to exit the tube after landing.

Once the tube crash lands on the crush zone and falls over, the off center swivel spins to the lowest position due to the moment created by the weight of the rover. The rover disengages itself from the swivel by driving off the hitch under its own power.

1.2.2 Tube Construction

Several options were considered for tube construction ranging from carbon fiber to sheet aluminum. Ultimately Garolite was recommended by a faculty member and was chosen to be the tube material. Garolite is a phenolic plastic which exhibits properties similar to sheet aluminum but is much easier to handle. Two sheets were laminated using two part epoxy and riveted together to form our tube.

The bulkhead was constructed using a machined piece of 1/8th inch aluminum. The purpose of the bulk head is to provide a stiff mounting area for the swivel, and to house the release mechanisms and avionics package. Two sealed bearings were mounted on either side of the bulkhead to support the axle on which the platform swivels. The bulkhead also stiffens the tube.

1.2.3 Release Mechanism

The release mechanism allows the lander to clear itself from entanglement in the parachute and open the tube so the rover can exit by jettisoning the chute and lid at approximately 10 feet from impact. A pin release system was developed that allowed a small motor driven off the 9v power supply to simultaneously pull three pins that held three rods which ran the length of tube and were connected to the lid to which the parachute is attached. The pins are connected to the motor via nylon cords which the motor winds in.

The lid is constructed from 1/8th inch aluminum plate machined to our specs. The rods are connected to the lid in brass bushings which also house the preload springs. A pin is mounted opposite of the parachute tube which keeps the rover from swiveling during descent, which in testing proved to allow a clean release by balancing the center of mass.

The rods are spring loaded which aids in a quick release and keeps the pins under constant pre-load to alleviate the risk that they fall our prematurely. The rods also have a guide system in place which stabilizes the payload as it extends from the lid.

Releasing the lid along with the chute solves the issue of opening the door for the rover and reduces mechanical complexity.

1.2.4 Parachute Deployment

The parachute is housed in a 3'' diameter schedule 40 PVC pipe mounted on top of the lid. The chute itself is a 60'' diameter Sky Angle chute from Apogee Engineering. A pyrotechnic charge is used to drive a piston which expels the chute and shock cord. The piston also protects the chute from burns, though a piece of sacrificial material is necessary to completely protect the chute. The piston is attached to the midpoint of the chute guy lines and the shock cord, which is attached to the center of the lid.

1.2.5 Platform and Hitch

The rover is mounted to a platform which swivels on two bearings and is attached to the bulkhead.

A custom lathed axle goes from the bearings to the platform. The platform is constructed from machined 1/8th inch aluminum plate. A hitch system was designed around the idea that the rover itself could provide the mechanism for detachment. One part of the hitch is bolted to the platform, while the other half is located on the skid plate of the rover where all major suspension components join. The rover's suspension is compressed and this force holds the rover on the hitch. When it is time for the rover to exit the lander, the rover simply drives forward and slides off of the hitch, extending its suspension once disengaged. The compressed suspension also has the added benefit of lowering the rover's center of mass, thus accentuating the moment effect on the platform.

1.2.6 Avionics

The lander avionics system controls vehicle release from the weather balloon, chute deployment, sonar, chute and lid release, and signals the rover when it is safe to exit the lander. The system runs on a single 9v lithium battery that is regulated to 5v for our digital circuitry. An ATMEGA168 microcontroller from AVR was chosen based on its analog to digital conversion capability, pin count, and availability. All programming was done in BaseCom language. MOSFET's were employed to switch on and off our high current 9v circuit (which ran motors and pyrotechnics) with our digital signals. Sonar was handled via the analog to digital conversion circuitry of the chip. The system is turned on and off with an official rocket switch. The avionics circuit board is mounted between the swivel platform and the bulkhead.

2. Testing

Testing individual components began early with the first tests being conducted on foam selection.

2.1. Foam Selection Testing

Our crush zone is a key part of our project. Its main purpose is to absorb part of the impact energy from the free fall after the lid separates. Our goal is to have the foam compress seventy-five to ninety percent of its shape. It must be strong enough to provide adequate deceleration yet weak enough to allow compression. We want as much plastic deformation as to avoid any spring like force from occurring after impact. We used a composite design to achieve these properties.

The outside foam shell is made of inexpensive charcoal packaging foam. Its main purpose is to connect the different materials to each other and to the lander . The charcoal foam is cheap, lightweight, and does not interfere with the composite inside of it. We fill it with our different layers, weakest in front and strongest in back, then slid the sides over the lander and used pipe clamps to fasten it.

The shape is very important. We used a parabolic shape to achieve our desired properties. It is 17 inches tall with a 12.4 inch diameter. The parabolic shape allows the cross section of the impact area to increase as the foam compresses. This causes the absorption energy to increase with time allowing easy deformation and good deceleration. The shape also helps the lander be more aerodynamic which helps the free fall orientation. Finally it also guarantees the lander will tip over after impact.

It was made in three sections. Two sections were joined to create the parabolic shape. A cylindrical section was joined underneath to add extra length. We used a simple overstitch to connect the sections. It provides adequate strength and a decent look. The sonar is fastened to the tip with screws. A hole was left at the tip to allow the sonar wires to connect to the chip.

We conducted many tests to determine what type of foam is most desirable for our project. We wanted material with a high modulus of elasticity that would plastically deform easily. We tested 3 types of foam in the structures lab. There was strong insulation foam, spongy spray foam, and hobby foam. We took cubes of each type and put a load on each one. We measured the force the cubes applied and how much shape returned after the load. We did this at different loads and load feed rates. We determined the hobby foam was the best choice because it had plenty of plastic deformation and did not take as much load. The other two foams took a high load to be compressed thus were too strong for our needs.

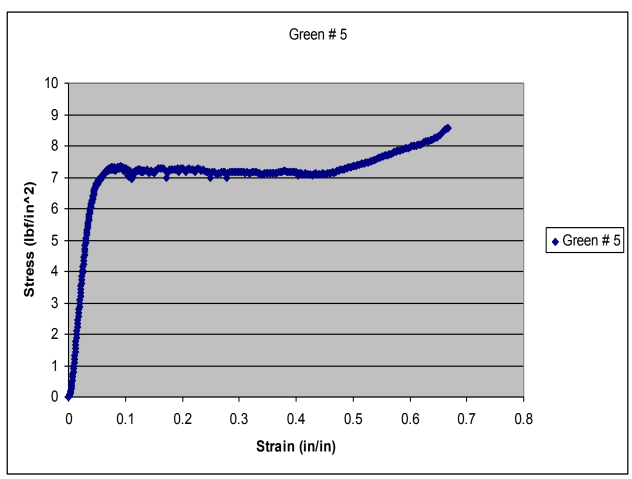

Figure #3 Plot of stress vs. strain to identify the material properties of energy absorbing foam

At first we tried using solid shapes of the hobby foam for impact. We learned that it did not compress well with a large thickness. We decided to cut the hobby foam into cubes and mix it 50/50 with paper strips. The paper strips help further decrease the deceleration. We left a set a solid three inch tall piece of hobby foam at the very bottom of the charcoal foam to stop the foam from compressing too far.

2.2 Release System Testing

The pin release system is a critical system that needs to be very reliable and repeatable. Originally the system was built with very tight tolerances and in preliminary tests it was found that these tight tolerances made the device difficult to configure and sensitive to disturbances. Also in the early development stages memory wire linear actuators were chosen to pull the pins. This method was not used due to amperage requirements and power output. It was decided to use a small gear reduction motor and cables to pull the pins.

Once these design points were chosen, actual drop testing commenced. It became apparent during the first tests that the 9v power supply was not strong enough to pull all three release pins simultaneously, so a staggered timing pattern was developed so that the motor would only pull one pin at a time.

As testing progressed it was noticed that reducing the tolerance on the system was allowing the brass pins to slant slightly in the rod and bind. This was alleviated by moving to a larger diameter pin which also pulled through the aluminum rod more smoothly. This change, couple with the move to a more power dense battery (lithium vs. alkaline) allowed the motor to pull all three pins at once. The advantage to pulling all pins at once is a clean release, if a bad release happens, i.e. a pin hangs up or lags behind the others, the lander tended to rotate. A rotation of more than 15 degrees from vertical was deemed a failure. Another factor that affected the release was where the rover was positioned in the tube, which changed the center of mass. Also off center is the parachute tube, which is fixed to the lid. Tests on the effect of the rover were conducted to characterize its behavior. It was discovered that letting the rover rotate freely during free fall would dampen 2nd order oscillations, but led to random release results. By fixing the rover to the side opposite of the parachute tube the system was balanced on the chute attachment point. This change allowed for consistently positive releases. By placing a pin on the lid and slot on the platform, the platform could be held in place and then allowed to rotate once the lid was released.

2.3 System Testing

Once the crush zone and the release system were operating the lander system was integrated and tested. LED's were used on the avionics circuit to simulate release and chute firing. A bridge in between the Natural Resources College was chosen as the test site due to its height and proximity to the lab. The system would be armed and then lowered to just above the sonar trigger range. Once the software had gone through its release routine, the system was lowered until sonar read ground and the pins released. Again the success of the test depended on how clean the pins released.

During this phase of testing many small glitches were discovered and fixed, and a great deal was learned about operating the system in the field.

2.4 Parachute Testing

Parachute testing was conducted to insure that the packing configuration required to fit the chute in our ejection tube was satisfactory. After acquiring permissions from the property owners we threw a bucket weighing the same as our system with the chute attached off of the CSU parking garage. The chute unfurled every time but just barely. We learned from these tests that the parachute would require at least 100 feet to properly deploy and inflate.

To eject the cute the team chose to use a pyrotechnic system which drove a cylinder as detailed earlier. CSU PD was kind enough to donate their expertise and materials in the testing process. The first test conducted was on the effectiveness of our circuitry to fire an igniter. We had several options, including nichrome wire, bulb filaments, and e-matches. The experts recommended we try e-matches first, which worked so well that no other testing was needed. The next tests were to determine our charge. An ideal ejection would be forceful enough to push the chute out of the ejection tube and clear the lander but not so powerful that the chute would stress the system. A charge of pyrogen equivalent to half the charge in a 12 gauge shotgun shell was chosen. This size charge provided the ideal ejection speed and consistency we required. The piston also passed the test and showed no signs of rotation or jamming, while at the same time providing acceptable flame protection.

2. First Drop Attempt

With the cooperation of CSU PD and Atmospheric Sciences the drop test was scheduled to be conducted at Christman airfield in North West Fort Collins. It was calculated that 525 cubic feet of helium and two latex balloons were sufficient to lift our lander and rover payload to 500 feet (500 feet is the ceiling height the FAA has set for a tethered object). This plan required the design and fabrication, as well as software and electronics integration, of a pin release system to detach from the balloons. A .8 second freefall was calculated to be the minimum free fall to clear the tether and allow maximum chute deployment time.

The team assembled at the airfield and balloon filling began by 10 am. During filling of the second balloon Fort Collins police arrived on the airfield to conduct driving maneuver drills. Our test had been double booked. We were asked to move to end of the airfield with our equipment. During the move it became apparent that the heat and increasing winds were stressing our balloons and time was running out. Once the team was re-grouped and prepping to launch booth balloons popped within 5 minutes and so did any hopes of launching in the immediate future.

3. Second Drop

The team performed a second drop in March 2011 form the top of the CSU parking garage (~40 feet). Due to the low height, the parachute was dummy rigged onto a boom that extended approximately 5 feet over the edge of the garage. The lander and rover were armed and the launch sequence proceeded as programmed for the balloon drop, the only difference being that the drop pin was pulled manually.

The system fell and oriented correctly as the parachute caught around 20 feet from the ground. The sonar system detected the ground and released the pins, however there was not enough room to jettison the lid and chute assembly. The rover remained intact on its platform but did not move off of the platform (it was discovered that the battery was not fully charged).

A third drop is being planned as soon as the system can be reassembled. Minor changes to the lander code (increasing the sonar range from 10 feet to 20 feet) as well as making sure the rover battery is 100 percent charged should result in much better performance.

4. Lessons learned

Our launch procedures were poor. While the launch procedure and checklist for arming our system were well researched and planned, we had no clue what we were doing with our balloons. More research into every aspect of our launch was needed. Our second launch procedurally went well, but the rover battery was not topped off fully.