Mars Microlander Prototype Precursor

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Abstract

The goal of the current research is to evaluate the ability of a Mars Microlander prototype to perform a soft landing during a drop test. The present focus is the development of a test-bed platform to aid in the development of the various systems of the Microlander. The goal for the Mars Microlander Prototype Precursor was to integrate the same rocket engines, sensors, and computer on a two degree-of-freedom body. With the exception of the Microlander airframe, the MMPP systems will either directly transplant onto the Microlander or significantly aid in the development of Microlander systems. While the microwave sensors were not completed, the other goals of the MMPP were met. A method was developed to ignite the rocket engines under computer control. Also, it was demonstrated that a vehicle can be actuated, at least in an open-loop fashion, with solid rocket motors, in spite of their limitations of single use and non-throttlability.

Executive Summary

NASA's New Millennium Initiative of "faster, better, cheaper" spacecraft has been increasing in importance in solar system exploration. The goal of the current research is to evaluate the ability of a Mars Microlander prototype to perform a soft landing during a drop test. The Microlander is less than 10 kg and its largest dimension is less then 70 cm. This vehicle uses microwave sensors to determine its attitude, altitude, and velocity during descent and solid fuel rockets to control the attitude of the vehicle and the rate of descent. A microcontroller unit controls the sensors and the firing of the rockets.

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While the microwave sensors were not completed, the other goals of the MMPP were met. A method was developed to ignite the rocket engines under computer control. Also, it was demonstrated that a vehicle can be actuated, at least in an open-loop fashion, with solid rocket motors, in spite of their limitations of single use and non-throttlability.

Introduction

Recently the trend in spacecraft has been to move toward smaller vehicles. These spacecraft can carry out new missions that were not possible earlier and can lower the cost of a mission. One current area of development for “smaller, cheaper, faster” spacecraft has been solar system exploration. The Mars Micromission program was announced to develop the capability for delivering small, low-cost payloads to the Martian surface. The program was described in the NASA FY2000 budget:

> “Small “piggyback” spacecraft can be placed in a geosynchronous transfer orbit by an Ariane-5 expendable launch vehicle and than travel independently to Mars. Each of these competitively selected Principle Investigator class missions will deliver up to a 50-kilogram science payload to Mars to collect high-priority global scientific data. NASA, the French space agency CNES, and Arianespace will work together to establish micromissions as an important element of mars exploration and infrastructure. The first micromission launch opportunity is planned for 2003.”

This class of missions will allow a broader study of the surface of Mars by landing multiple missions at several sites, instead of one large mission at a single site. One advantage of this is that researchers pursuing signs of water or life can be free to select riskier landing sites without risking the success of an overall mission. Also, the loss of one lander does not eliminate all of the opportunity for scientific study during that mission window, as happened recently with the Mars Polar Lander.

For these reasons a group at the University of Florida has been working on designing, building, and testing a Mars Microlander Prototype (MMP). The purpose of the project is to demonstrate (i) the ability to build a micromission class vehicle from readily available materials and components and (ii) the ability of that vehicle to land on the surface of a planet. The microlander prototype will be tested by performing a drop test using the aerospace engineering department’s airplane. This project originated with a design presented by Tomas Svitek at the 1999 AIAA/Utah State University Conference on Small Satellites. His design for a microlander eliminates the need for expensive components and takes full advantage of the micromission concept.

The first step in the UF microlander project was to develop a simulation tool to analyze the dynamics and controls of the vehicle. The goal was to create models of the vehicle dynamics and subsystem performance that could be used to predict the performance of the microlander prototype. The simulation was used in the design of the attitude and descent controller and to test the robustness of the design to perturbation of various parameters. It was used to evaluate the drag characteristics of several structural configurations, size the solid rocket engines, determine the required signal conditioning of sensor output, and develop control strategies.

Microlander Configuration

The Microlander Prototype is approximately 70 cm in diameter and 25 cm tall. Its mass is less than 10 kg. The vehicle structure consists of six fins attached to a central hub. An upper platform is situated on the top edge of the fins; this serves as the payload mounting fairing. On the tips of three of the fins will be M/A-Com MA87729-M01 microwave transceivers. These will operate in two modes, frequency modulated and continuous wave, to measure range and speed. Along all six fins and around the circumference of the central hub, forty-two Estes D11-P solid rocket motors are attached. The engines around the hub are used for descent control (i.e., to slow the landing speed of the vehicle). The engines along the fins are off-axis from the lander center of mass and provide moments for attitude control. The central hub will contain a M68HC11 EVBU microcontroller unit that reads in the output from the sensors and sends firing signals to ignite the rockets. Appendices 1 and 2 show AUTOCAD images of the design.

Mars Microlander Prototype Precursor

In the Intelligent Machine Design Laboratory I worked on implementing some of the technologies and behaviors necessary for the MMP on a Mars Microlander Prototype Precursor (MMPP). The goal for the MMPP was to use the microwave sensors, an EVBU/ME11 computer, and model rocket engines to control its speed and orientation as it rolled along the ground. This project was an important step in the development of the microlander because it used many of the same systems and components, just attached to a different body. When the MMPP is completed the only major steps required before flight testing of the MMP will be to test the airframe body and to test the sensors at the speeds and ranges the microlander will experience but that are not possible with the MMPP.

The MMPP will be based on the Talrik robot. For the first stage of the class the robot used hacked servo motors, IR and bump sensors, and the EVBU/ME11. The initial goal was to implement bump and collision-avoidance behaviors.

For the later stages of the class the servo motors were removed and the Talrik body was mounted to a skateboard. Also attached to the skateboard was a boom with mounts for model rocket engines. A bank of up to sixteen of these single firing rockets could be ignited in five independent firings under computer control. The goal was to replace the IR and bump sensors with the microwave sensors. These sensors are 24 GHz transceivers manufactured by M/A-Com. There output is a voltage wave with a frequency proportional to the interference between the sent and received waves. This frequency is around 10 kHz. Each sensor will operate in two modes, FM and CW, to measure both speed and range.

Integrated System

The basic systems of the MMPP are the body, computer, sensors, power, and actuation. The body of the MMPP is based on the Talrik robot body by Mekatronix. Motorola 68HC11 EVBU and Mekatronix ME11 boards comprise the computer for the robot. For stage one of the project, the MMPP used two IR sensors and ten bump switches. When stage two of the project is completed, M/A-Com microwave transceivers will be used for sensors. Two fully hacked servo motors were used to actuate the robot during the first phase. In the later phases the MMPP uses a bank of Estes B6-0 model rocket engines for actuation. Throughout the project an eight pack of AA Ni-Cad batteries will provide power for the computer. In the second phase an additional battery pack is dedicated to ignition of the rockets.

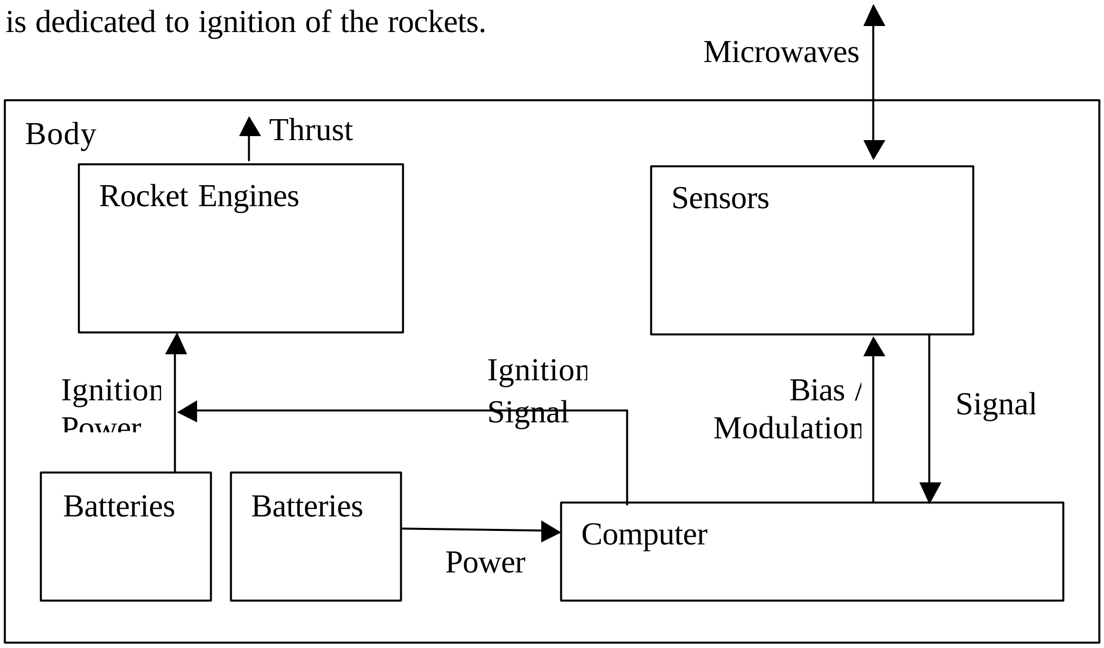


Figure 1: Subsystem Interactions

Mobile Platform

The MMPP platform is built on a Mekatronix Talrik robot body. The body is an approximately 27.5 cm diameter circle with an 11 cm tall bridge across the diameter of the circle. The parts for the body are constructed out of plywood and were cut out on the T-Tech machine in the IMDL. I then assembled the parts using Elmer's wood glue. Caster wheels and servo-driven wheels attach to the bottom of the circular plate. Sensors mount around the rim of the plate and the computer and batteries are attached in the middle of the plate.

This body was chosen for its large size and open working area. Since I already had the EVBU, I chose a robot body that could accommodate this board. Additionally, I wanted to have plenty of room to add the sensors and rocket engines. This might have been difficult in the more compact TJPro body.

For the second phase of the MMPP the servo and caster wheels were removed and the Talrik body was attached to a skateboard. Additionally, a two-foot long boom was attached to the skateboard lying sideways across the board. The skateboard was used because of the high quality wheels (relative to the caster wheels), the extra room it allowed for the rockets, and weight. This was possible because the robot wheels did not need to be driven and only needed to be freely spinning.

Actuation

For the first stage of the project two Futaba FP-S3003 servo motors were used. I decided to use servos because of their ease of use and their proven capabilities for collision avoidance behavior. The FP-S3003's were the only servos I could find in town.

They provide 44.4 oz-in (3.2 kg-cm) of torque at a speed of 0.23 sec/60°. Physically they are 40.4 x 19.8 x 36 mm and 37.2 g each.

These motors were fully hacked. I removed the control electronics and potentiometer and cut off the stop-tab from the gears. The result was that the motors operated as traditional DC-gearhead motors controlled by the motor driver on the ME11 board.

For the second stage of the MMPP, Estes B6-0 model rocket engines will be used. In the specification of model rocket engines the letter refers to the total impulse of the engine. B-engines have a total impulse between 2.5 and 5.0 Ns. The first number in the specification refers to the average thrust of the engine in Newtons. The second number specifies the ejection delay. Model rocket engines have three different stages: thrust stage, coast stage, and ejection charge.

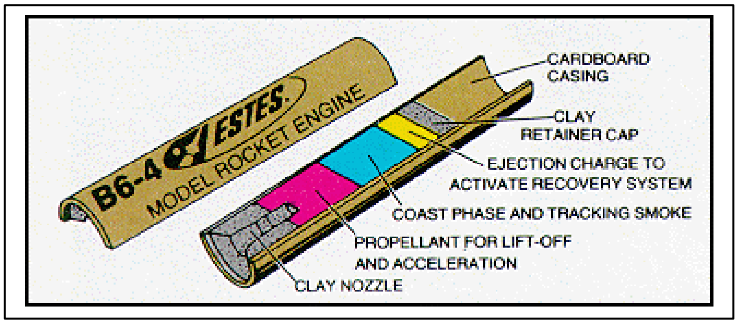


Figure 2: Diagram of Model Rocket Engine

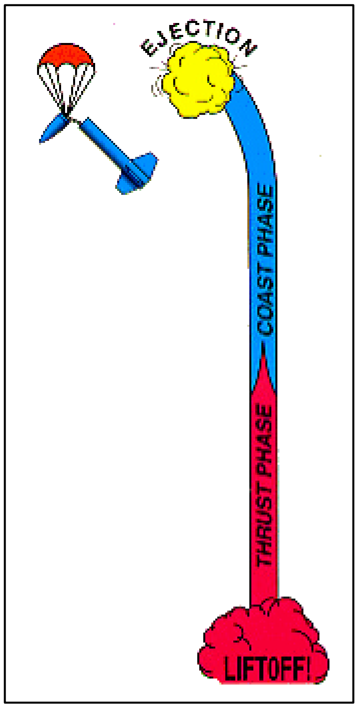


Figure 3: Stages of Model Rocket Flight

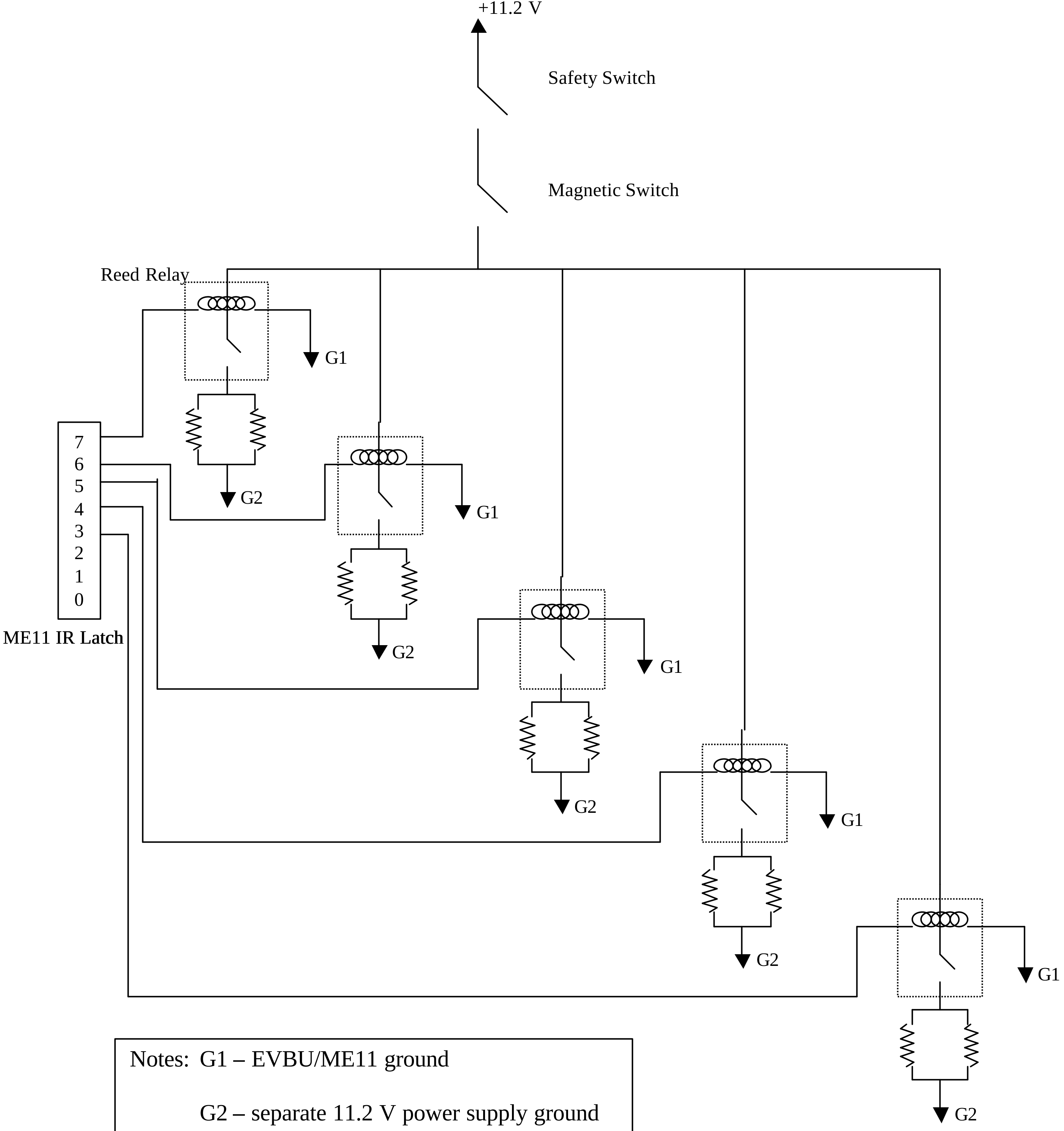
When used in model rockets, the thrust stage provides most of the thrust to initially accelerate the model rocket. The coast stage provides very little thrust and simply gives the rocket time to reach the apex of its flight. Then the ejection charge ignites, and the hot gas expands out the top of the engine and up the body tube of the rocket to push the parachute out the nose cone.

For my robot and the microlander the delay and ejection charge do not serve any purpose. This is why I chose the B6-0, with zero delay. For the Microlander I had hoped to use D11-P for their larger size and because they are plugged with no delay or ejection charge. However, Estes was the only supplier and they have stopped making them.

During the testing and demonstration of the MMPP two brands of engines were used: Estes and Quest. I experienced several misfires with the Quest engines, while only one of the Estes engines misfired. Upon, examination of the misfired Estes engine I realized that the igniter was chipped. However, the misfired Quest igniters were visually the same as the others. Electrically, though, the misfiring Quest igniters had a resistance of approximately 5 Ohms. The typical Quest igniter was 2.5 Ohms and the Estes igniters were 1 Ohm.

The ignition of the rockets is controlled by simply writing data to the IR latch (address $7000). Writing a “1” to one of these bits turns that pin to five volts and closes the reed relay. This allows current to flow through the igniters connected to that relay, and those rockets ignite. Using this latch up to eight groups of rockets can be fired independently. For the Microlander an additional memory-mapped data latch may be required to increase this number.

Figure 4: Ignition Circuitry



Notes: G1 – EVBU/ME11 ground

G2 – separate 11.2 V power supply ground

All resistors are rocket igniters.

Sensors

The MMPP initially had two infrared sensors each consisting of two components: a detector and an emitter. The emitters were connected to the digital output on the ME11. This generates a 40 KHz signal that runs the IR LEDs. The detectors were hacked Sharp IR cans. The hacking converted them from a digital output to an analog output relative to the amount of IR being received. Their output was then connected to the analog port on the EVBU. The amount of IR being received by the detector can be used to determine the closeness of the robot to an IR reflecting obstacle. One sensor is mounted on the right-front side of the body, and the other sensor is mounted on the left-front side of the body.

Additionally, the MMPP has ten bump switches mounted around the rim of the circular plate. They are connected in the following manner.

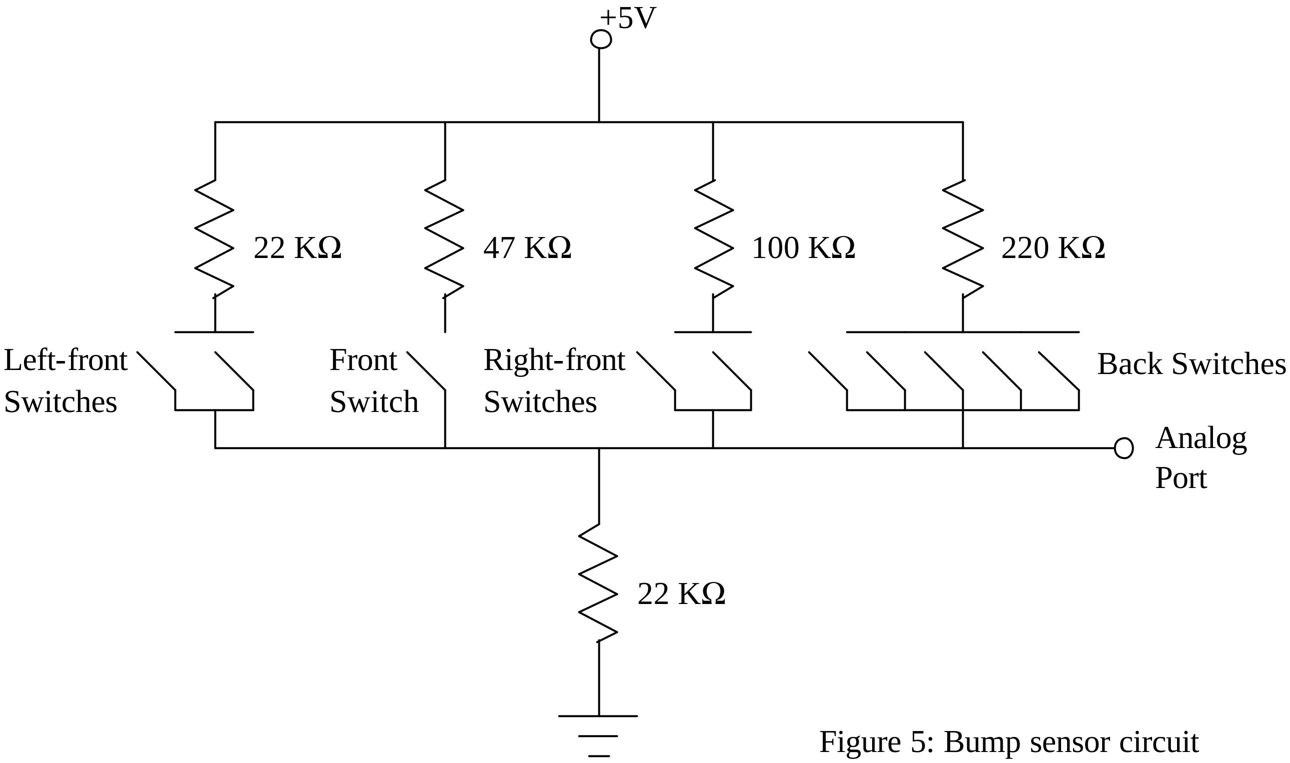


Figure 5: Bump sensor circuit

For the second phase of the project a pair of microwave transceivers will be added. These will be the M/A-Com 24.15 GHz Varactor Controlled Oscillator Transceiver (MA87729-MO1). The output of these sensors is a voltage sinusoid of the same frequency as the interference between the transmitted and received microwaves. Thus, if the sensor is outputting a constant frequency microwave, then the interference is due to Doppler shift in the returned wave. From this the relative speed of the target can be judged. An additional pin on the sensor can be used for electronic frequency tuning. The sensor will measure distance by creating a frequency modulated microwave. In this case the interference is due to the time taken for the wave to travel to the target and back.

At this point the sensor has not been completed. The first step that I have worked on is the Doppler measurement of speed. This requires the measurement of the frequency of the IF return of the sensor. I encountered difficulty in this due to the small amplitude of the signal relative to the DC offset. This meant that the DC needed to be removed before the signal could be amplified. The following figures show what I have attempted so far. I believe that this is on the right path; however, I ran out of time in the semester.

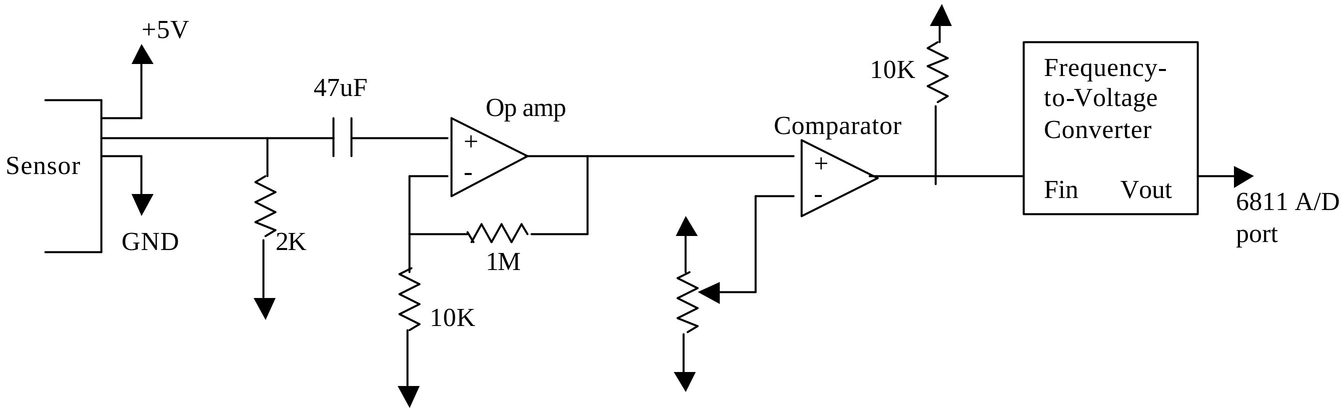


Figure 6: Microwave Sensor Circuit

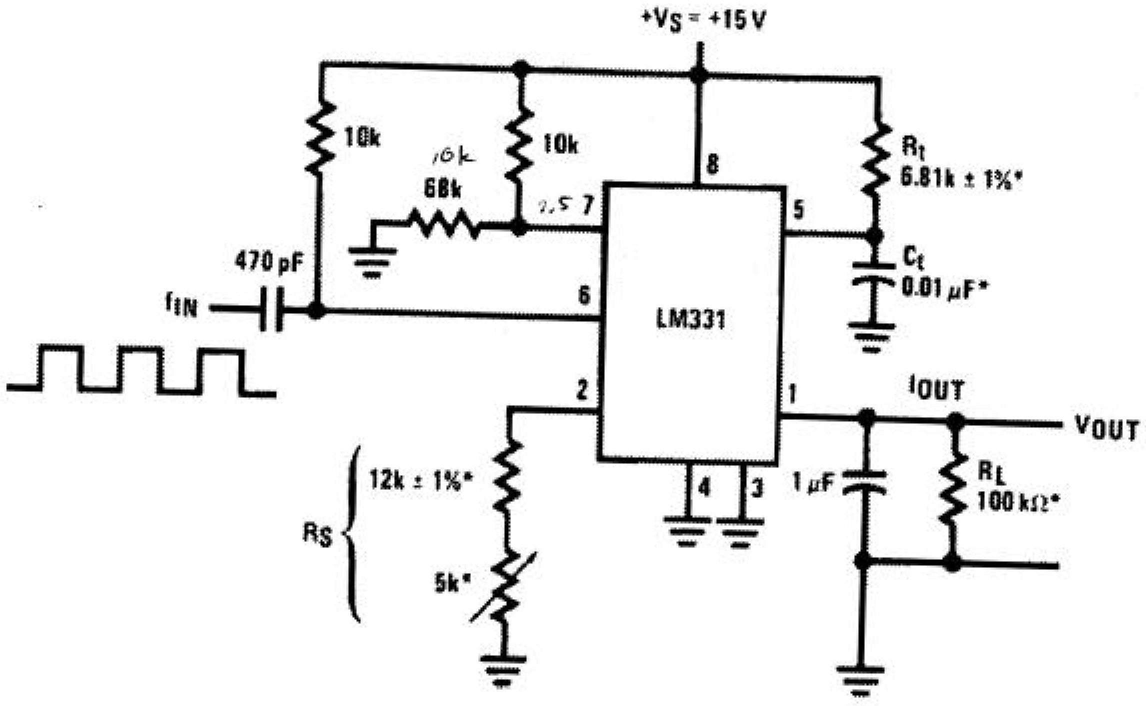


Figure 7: Frequency-to-Voltage Converter

Behaviors

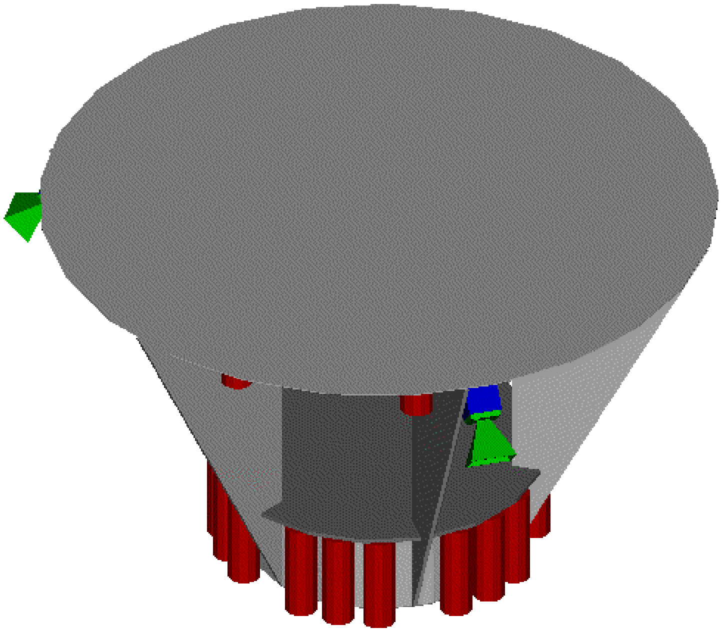
In the first phase two behaviors were integrated into the MMPP: collision avoidance and bump detection. These behaviors cause the robot to change path if it detects an obstacle. The code for these behaviors is included in the Appendix.

Since the sensors were not completed for the second phase, the only "behaviors" that could be used were open-loop, pre-programmed firing of the rockets. Along these lines two programs were developed to demonstrate the two degrees of freedom of the robot's motion. The one portion of the program fired rockets in three steps: 1) a pair of acceleration rockets, 2) another pair of acceleration rockets, 3) a pair of braking retro-rockets. Under this actuation the robot sped up and then slowed itself down in a straight line. In the second portion, the robot fired two pairs of rockets: one pair to accelerate and another pair (each in the opposite direction) to rotate about the vertical axis.

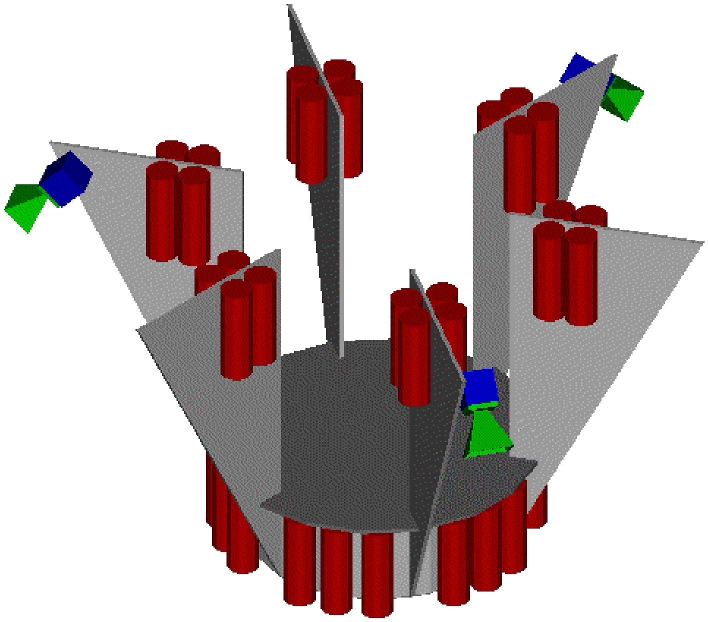
This program showed that the robot could execute desired motions using model rocket engines. This is a necessary step for the MMP project, because it requires the use of these engines to control its descent. The next step will be to show that the rocket engines can be used effectively in a closed-loop control system. Another step will be to work on the ignition of multiple rockets at the same time. So far only ignition of two rockets at a time has been demonstrated. During these tests noticeable differences between the two ignitions occurred. For the MMP a large cluster needs to ignite roughly at the same time. The increase in the number of rockets may cause problems in the ignition delay.

Conclusion

The first phase of the project was completed with Demo #1. The body, IR and bump sensors, and EVBU/ME11 computer have all been assembled. The MMPP successfully performed obstacle avoidance. In phase two of the project, the task of controlling the rockets from output of the computer has been completed. The future work will include reading in the frequency information of the sensor output. This will then allow complete testing of the MMPP. Once the Precursor is finished, the ground testing of the Microlander will continue with further tests of the sensors at higher speeds and ranges than the MMPP's capability. Additionally, the development and testing of the Microlander body will need to be completed. When this is completed the project will move on to flight testing of the Microlander. During this test the MMP will be released from an airplane and will then control its descent to the ground. It is hoped that clusters of small solid rocket engines and combined Doppler/FM radars will be proven as useful systems for future Mars landers.



Appendix 1: AUTOCad drawing of Microlander



Appendix 2: AUTOCad drawing of Microlander with top plate removed

Description	**Part Number**	**Manufacturer**	**Seller**
Microwave Transceiver	MA87729-MO1	M/A-Com	Richardson Electronics 1-800-373-6937
Frequency-to-Voltage Converter	LM331	National Semiconductor	National Semiconductor www.national.com
no Magnetic Contact Switch	49-533	Radio Shack	Radio Shack
5VDC Reed Relay	275-232	Radio Shack	Radio Shack
Rocket Engines	B6-0	Estes Quest	www.launchpad2000.com

Appendix3: Sources of Parts Not Common to IMDL