Implementation of Motion Simulation Software and Visual-Auditory Electronics for Use in a Low Gravity Robotic Testbed

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Abstract

The Jet Propulsion Laboratory (JPL) is developing the All-Terrain Hex-Limbed Extra-Terrestrial Explorer (ATHLETE) to assist in manned space missions. One of the proposed targets for this robotic vehicle is a near-Earth asteroid (NEA), which typically exhibit a surface gravity of only a few micro-g. In order to properly test ATHLETE in such an environment, the development team has constructed an inverted Stewart platform testbed that acts as a robotic motion simulator. This project focused on creating physical simulation software that is able to predict how ATHLETE will function on and around a NEA. The corresponding platform configurations are calculated and then passed to the testbed to control ATHLETE's motion. In addition, imitation attitude control thrusters were designed and fabricated for use on ATHLETE. These utilize a combination of high power LEDs and audio amplifiers to provide visual and auditory cues that correspond to the physics simulation.

1 Background

Near-Earth asteroids have recently come under consideration as possible targets for manned spaced exploration. In April 2010 the President suggested that NASA investigate performing such a mission as early as 2025 [5]. It is easy to see why because there are several compelling reasons for sending astronauts to a near-Earth object (NEO). Tom Jones [3] breaks these down into five distinct categories: accessibility, experience, science, survival, and resources.

NEOs are highly accessible destinations due to their short distances from Earth and relatively low traveling speeds. This not only lessens the amount of time required to reach these bodies, but it allows for highly visible and dramatic exploration. In a similar vein, these short missions offer valuable operations experience that would allow researchers to demonstrate new technologies and learn more about manned space travel. These would

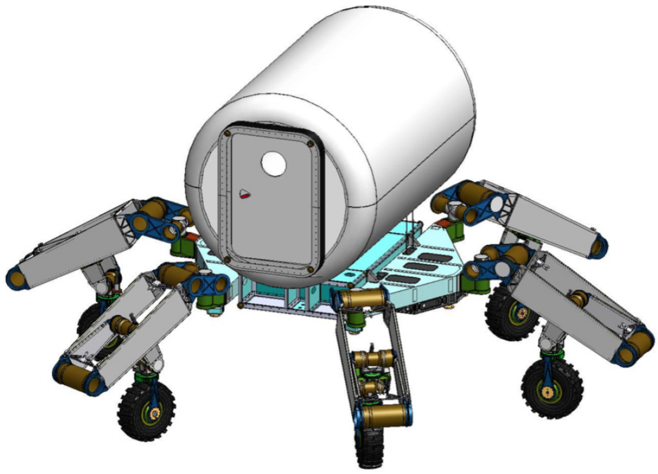

Figure 1: The ATHLETE robot.

be crucial stepping stones on the way to a sustained human colony on the Moon or Mars. There are also significant economic incentives for asteroid exploration due to a myriad of possible raw materials [1]. It should also be noted that our very existence stands to gain a great deal from studying NEAs. In addition to telling us much about our origins, they would allow us to prepare our planetary defenses for diverting future hazardous asteroids.

However, asteroid exploration presents its own set of challenges, which must be overcome before landing on such an object can be attempted. Fortunately, these are not dissimilar to obstacles that face other types of space exploration. Extreme terrain presents mobility issues for both landing and movement on a NEO surface. This difficulty is exacerbated by the micro-gravity environment that is found on these bodies due to their minuscule mass. Robots lend themselves well to a task such as this because of their mechanical abilities to traverse a variety of surfaces. This makes them ideal as cargo-handling vehicles for humans. One issue that arises from this is the significant weight of traditional vehicles that can carry heavy payloads in rough terrain. Since this is so closely tied to the cost of a mission, it is important to find ways to minimize the weight of a robotic vehicle.

2 Current Work

The Jet Propulsion Laboratory is currently developing a robotic vehicle for solar system exploration as part of the NASA Exploration Technology Development Program. ATHLETE, the All-Terrain Hex-Limbed Extra-Terrestrial Explorer (figure 1), sports six wheels attached to the end of six fully articulated limbs [8, 9]. This design attempts to solve many of the mobility problems associated with soft or otherwise extreme terrain. Rather than requiring powerful motors to overcome these traps, ATHLETE can utilize its limbs as legs to essentially "walk" out of these situations instead of using its wheels. This greatly impacts the design requirements for the entire vehicle; not only can the wheels and motors be substantially reduced in size, but each limb need only support a fraction of the entire vehicle. This results in the entire mobility system being about 25% lighter than a conventional chassis. In addition, the large number of degrees of freedom present in each limb also allows each one to be used as an arm when needed. This is facilitated by a quick-disconnect tool belt of useful end effectors.

The ATHLETE team has constructed several prototype vehicles, termed Software Development Models (SDM). Although these are a fraction of the final production size, they allow the team to refine and experiment with the robot's design. In order to further test these models, the team is currently building a "flying" platform (figure 2), which will act as a motion simulator for ATHLETE as it moves in a micro-gravity environment. The simulator consists of an inverted Stewart platform [4] constructed from winches and cables that suspend the robot from above. This parallel link manipulator attaches to the top of ATHLETE at six fixed points and operates similarly to a precision crane. Manipulating the six winch motors (and thus the cable lengths) with software gives the robot six degrees-of-freedom; this allows it to move around within the simulator's work envelope. Since ATHLETE weighs several thousand kilograms and stands a few meters in height, translating and rotating it is nontrivial. As a result, the testbed is over seven meters high and spans most of the building in which it is housed. Overall, the desired operation scheme is to give appropriate control signals to the manipulator so that it will mimic ATHLETE's true motion in a micro-gravity environment.

3 Motion Simulation

3.1 Inverse Kinematics

One of the primary goals of this research was to develop software that can manipulate the testbed so that it simulates ATHLETE's kinematics in a low gravity environment. Thus, by constantly adjusting the robot's position and orientation, the inverted Stewart platform is able to emulate the motion that would be typical in an asteroid environment. However, this requires one to find a mapping between winch rotations and the platform's position and orientation, also referred to as the inverse kinematics. Fortunately, calculating the inverse kinematics for a parallel robot is relatively simple since the manipulator lengths determine the resulting state of the end-effector. However, since this particular parallel robot is "inverted" and utilizes gravity, we must also ensure that the cables remain taut. At the most basic level, this calculation is essentially determining the Euclidean distances between the attachment points on the pillars and those on ATHLETE itself.

There are a few minor peculiarities that arise when determining the inverse kinematics. The most significant of these is dealing with the dynamic cable attachment points. Although the robot's own attachment points are fixed, the point at which any of the cables meet a pulley is dependent upon the end-effector's current state. As ATHLETE

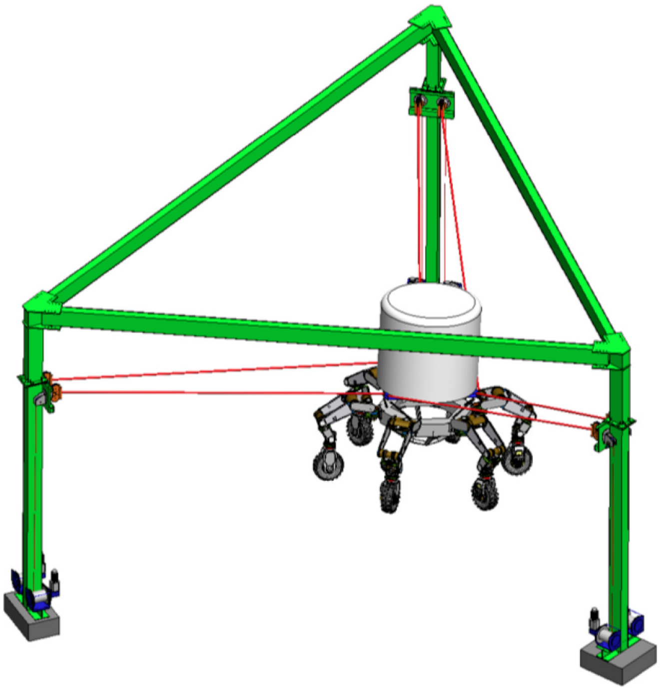

Figure 2: The inverted Stewart platform testbed.

moves around the simulator, these changing attachment points result in slight cable length differences that must be accounted for when determining correct winch positions. Fortunately, this can be solved with rather simple right triangle geometry. The other sources of error are somewhat harder to account for but are less significant to the overall cable length. These include how the cable wraps around the winch as it is wound and the fleet angle the cable makes from the winch to the pulley.

3.2 Software

The motion simulation software was built using the C++ programming language along with a variety of open-source frameworks. In addition, the code is entirely cross-platform so that the final program can be deployed on Linux, Windows, and Mac operating systems. 3D rendering is handled with the Irrlicht framework [2], which offers an extensive engine for displaying and animating relevant meshes. This allows the user to easily visualize ATHLETE's position and orientation as it moves around the simulation environment.

The Irrlicht renderer was integrated with the Qt application framework [7] for this software so that it could feature a robust graphical user interface (GUI). The Qt framework was also essential for handling networking and threading in an efficient and cross-platform manner. These various visual elements came together to form the user interface shown in figure 3. The user is given control over ATHLETE's translational and rota-

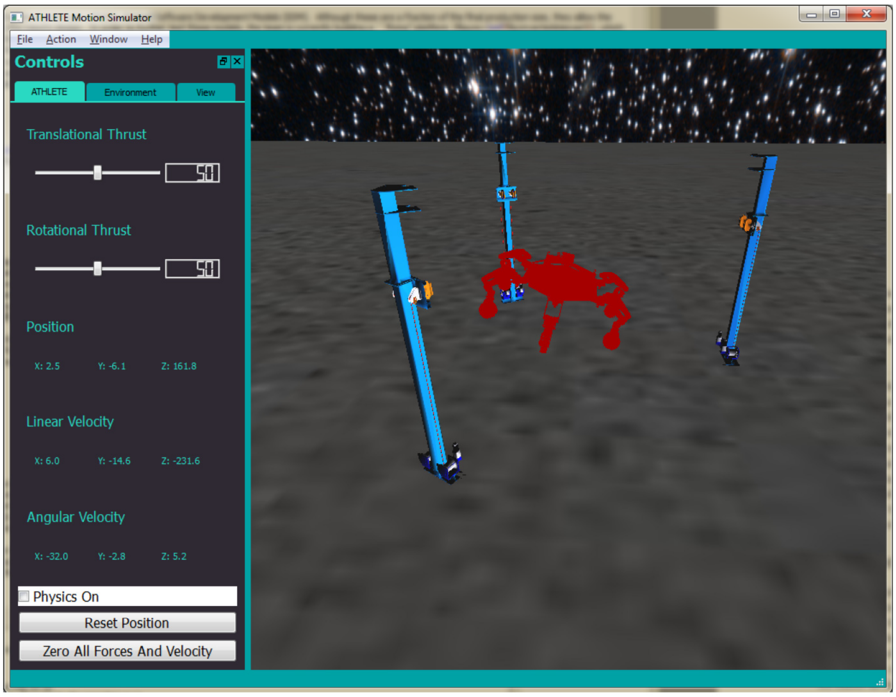

Figure 3: The software graphical user interface.

tional thrusters in addition to the view camera. Furthermore, various widgets in the control dock allow access to the environmental and application variables. Since this interface was formatted in Qt, it can be easily modified to add future features to the software.

Physics simulations and calculations are handled with the Bullet Physics library [6]. This open-source package offers a wide range of useful algorithms, including simple ballistics and efficient collision detection. The motion simulation is generated in real-time and environmental factors, such as gravity and solar pressure, can be adjusted on the fly. However, since ATHLETE's simulated motion is mirrored by the physical testbed, it is possible for the winch motors to fall behind. For this reason, ATHLETE's simulated position and orientation can be adjusted as needed to adapt to the current state of the inverted Stewart platform. The software is designed to communicate with the winch motor control server over a network connection. This allows the timestep between physics calculations to vary and for the simulation to get information on the platform's true position.

4 Imitation Attitude Control Thrusters

In order to create a more immersive and convincing simulation, this project also focused on designing mock control thrusters. A typical robotic lander would utilize thrusters in order to adjust the vehicle's attitude and assist in landing. However, the goal in this case

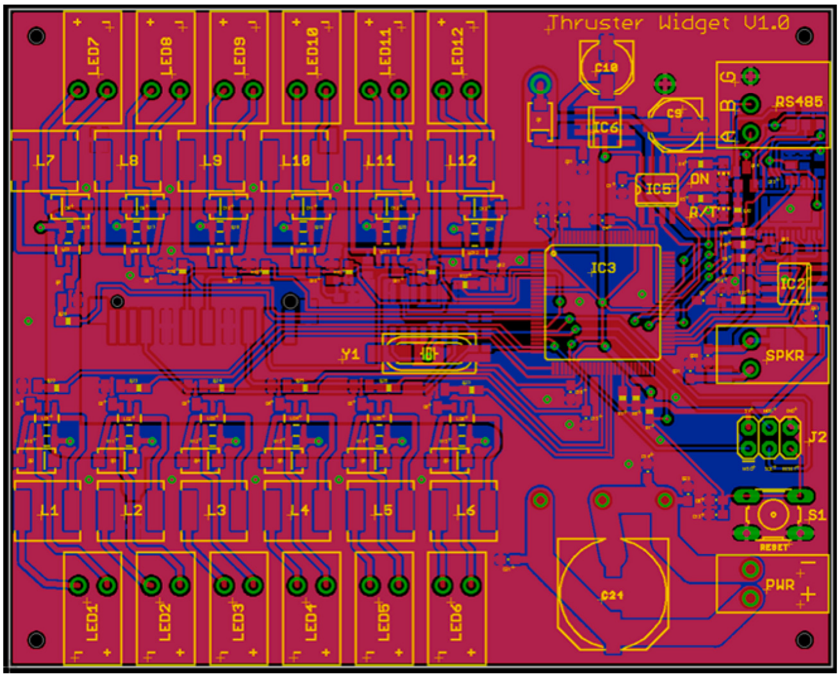

Figure 4: EAGLE layout of the PCB.

is to imitate the visual and auditory cues that such a device would produce and sync them with a motion simulation. This requires strong visual aids, in the form of emitted light, and matching sounds to draw further attention to these sources. In addition, these functions must be accessible from a computer so that they can be triggered when needed.

The electronics (figure 4) were developed and laid out on a printed circuit board (PCB) using the EAGLE editor and include both digital and analog components. Each board controls twelve high power LED modules with variable intensity through the use of pulse-width modulation (PWM). In addition, each board is able to produce sound from a ten Watt audio amplifier connected to a conical speaker. The behavior of these functions is dictated by a central microprocessor, the Atmel AVR ATmega2560, which is able to supply the twelve necessary PWM signals. Since this chip does not have an onboard analog to digital converter (ADC), a separate 12-bit ADC is connected via SPI to generate audio signals. The needed sound files are then stored on an SD card and read with SPI also.

This design allows several boards to be used together in order to control a large number of imitation thrusters. There is an RS-485 transceiver located on each board so that a chain of these devices can be controlled from one central signal line. However, since each board can draw several Amperes of current, this project used only three of these boards to limit power consumption. The power is supplied from ATHLETE's 55 Volt battery and thus must be stepped down to a more reasonable 12 Volts with a high-efficiency DC-DC buck converter.

5 Conclusion

This project designed software capable of simulating ATHLETE in a low gravity environment and transferring this motion to an inverted Stewart platform. The simulation was further complemented by the addition of imitation attitude control thrusters. Future work on this project could include further improvements to the physics simulation through the use of more accurate collision meshes and a fully articulated robot model. In addition, the imitation thrusters would benefit from fully completed housings and diffusion filters.

Acknowledgements

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