

Mechanical Design, Prototyping, and Validation of A Martian Robot Mining System

Yucheng Liu, Jeremy Batte, Zachary Collins, Jennifer Bateman, John Atkins, Madelyn Davis,
David Salley, Cindy L. Bethel, John Ball, and Christopher Archibald
Mississippi State University

ABSTRACT

A robot mining system was developed by the State Space Robotic undergraduate student design team from Mississippi State University (MSU) for the 2016 NASA Robotic Mining Competition. The mining robot was designed to traverse the Martian chaotic terrain, excavate a minimum of 10 kg of Martian regolith and deposit the regolith into a collector bin within 10 minutes as part of the competition. A Systems Engineering approach was followed in proceeding with this design project. The designed mining robot consisted of two major components: (1) mechanical system and (2) control system. This paper mainly focuses on the design and assessment process of the mechanical system but will also briefly mention the control system so as to evaluate the designed robotic system in its entirety. The final designed robot consisted of an aluminum frame driven by four motors and wheels. It utilized a scoop and lifting arm subsystem for collecting and depositing Martian regolith. This subsystem was powered by two computers and used two commercially-of-the-shelf sensors to navigate the simulated Martian terrain. The State Space Robotics team is composed of engineering students with different backgrounds. The present design project provides a multidisciplinary environment for the students to explore and develop their skills in designing, problem formulating and solving, teamwork, communication, project management, and outreach.

Keywords: State Space Robotics team, mining robot, mechanical system design, systems engineering design process, NASA

CITATION: Liu, Y., Batte, J., Collins, Z., Bateman, J. et al., "Mechanical Design, Prototyping, and Validation of A Martian Robot Mining System," *SAE Int. J. Passeng. Cars - Mech. Syst.* 10(1):2017, doi:10.4271/2017-01-1305.

INTRODUCTION

The NASA Robotic Mining Competition allows for innovation in robotics while encouraging science, technology, engineering and mathematics (STEM) and a systems engineering design process. Students with backgrounds in mechanical engineering, electrical engineering, computer science, computer engineering, software engineering, aerospace engineering, and mathematics participated in this project; forming a multidisciplinary design team, collectively known as the State Space Robotics team. Because of the multidisciplinary nature of this design team, the systems engineering design approach, an interdisciplinary approach, and a means to enable the realization of a successful system [1], would be the best fit for this project and therefore these approaches were applied as part of the design and development process. According to NASA, the systems engineering process is a discovery process that begins with the division of systems, evaluation of system requirements, preliminary design review, and followed by a critical design review [2].

As stipulated in the competition rubric, the robot was restricted to a mass no greater than 80 kg, and a maximum size of 150 cm (length) × 75 cm (width) × 75 cm (height). The robot has 10 minutes to maneuver over the regolith, traveling from its starting position, through the obstacle area, to the mining area, then returning to deposit the collected regolith (at least 10 kg to qualify) into a collection bin. It is required that the robot can only be driven via autonomous control and/or teleoperation. It must have onboard power and should only be viewed by the robot operators via the NASA monitors in the control center and any cameras mounted on the robot.

In order to satisfy the NASA mission requirements, two major systems, the mechanical system and control system, were designed independently and integrated at the final stage. In designing the mechanical system, mechanisms and mechanical components proposed in existing terrestrial mining robots were referenced while extra design effort was invested into modifying the chassis system and wheels to adapt to the rugged terrain on Mars. Mueller and Susante reviewed a variety of extra-terrestrial robotic mining

concepts and discussed their associated challenges [3]. Liu designed a mining robot with four composite wheels with improved terrain self-adaption and over-obstacle capacity in the complex and changing deep sea environment [4]. However, our preliminary analysis herein demonstrated that the composite wheels were too deformable to provide satisfactory traction and mobility over Martian regolith. Kato and Hirose proposed a quadruped walking robot that has high performance as a working machine and could be used for humanitarian mine detection and removal [5]. Mechanical system design of that walking robot discussed by the authors was referenced in the present design.

Interaction between the mechanical system and the control system is another critical issue in this design. Kubow and Full discussed the role of the mechanical system in control through a designed 2D dynamical model of a hexapedal runner [6]. Integration and coordination of mechanical and control systems within a design system were demonstrated through a dexterous robot hand design by Osswald and Worn [7].

These foundational ideas from the literature were used to better establish an effective and friendly interface between the mechanical and control systems. It is expected that this project will provide NASA scientists and engineers with innovative crowdsourced ideas and solutions for future Martian mining applications. Meanwhile, participating students aim to develop new working skills and knowledge beyond their typical engineering curricula.

Faculty advisors from the departments of Computer Science and Engineering, Electrical and Computer Engineering, and Mechanical Engineering also participated in this project to provide guidance for achieving all the proposed design goals for both the mechanical and control systems. The interactions between student team members and faculty advisors within this design project represents the most-favored pedagogical model for teaching design, project-based learning [8] and will lead to better pedagogical practices for improving design learning.

SYSTEMS ENGINEERING DESIGN PROCESS

The systems engineering process is a systematic approach for ensuring that a complex system is successfully managed to ensure that all subsystems are successfully integrated. This process includes goal setting, decomposition of complex systems into manageable sections, and consistent communications between the sub-teams. This approach was followed in this project to ensure that the robot mining system would be completed on time while satisfying all of the proposed mission requirements.

Two major systems, the mechanical system and control system, were designed independently for this mining robot. The mechanical system was further divided into two subsystems: frame system and collection and deposit system. Fig. 1 displays the architectural hierarchy of this mining robot. The detailed design process for the mechanical system (highlighted components) will be narrated in following sections.

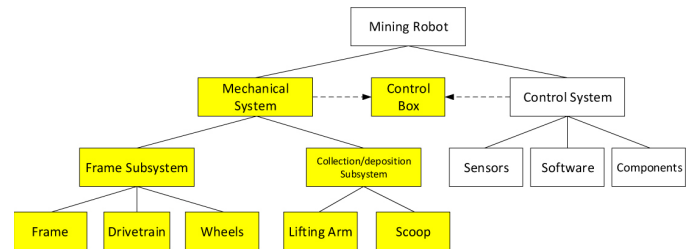


Figure 1. Architectural hierarchy of the mining robot

FRAME SUBSYSTEM

The frame subsystem of the proposed mining robot includes the chassis, drivetrain, and wheels. Two major design goals had been established for the chassis to which the robot is attached; namely, it must be lightweight and reliable. At first, a chassis model made of carbon fiber reinforced composites had been prototyped in order to reduce the overall weight to its full extent. Unfortunately, preliminary field testing of this concept demonstrated that this composite chassis model could not offer enough rigidity when it was subjected to the varying loads generated when the mining robot traveled on the simulated Martian terrain and maneuvered the regolith. Therefore, it was decided that the chassis should be made of wrought aluminum, more precisely, 5.1 cm × 2.5 cm aluminum box tubing. Compared to the carbon fiber composite material, the aluminum is only slightly heavier, but it offers much higher strength and durability, could support the robot, and provide outstanding stability. Pre-drilled box tubing was purchased from VexPro, which had 0.4 cm holes drilled one centimeter apart, was utilized in order to make the assembly process and further modification easy and swift. Fig. 2 shows the designed chassis fabricated from the pre-drilled box tubing.

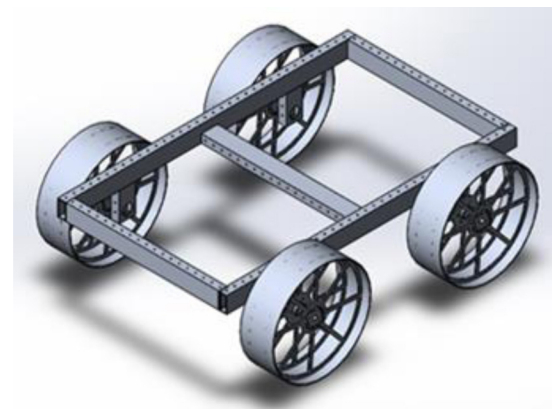


Figure 2. Chassis and wheels (motors and gear boxes not shown)