3D printing rover sPrinter

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Abstract - Mass is a crucial factor if one wants to discover or travel in outer space. If humankind wants to conquer other planets, the element of mass is even more critical. This is where 3D printing comes into mind. It is much easier to create a construction from the sources which can be found on other planets and the technology of 3D printing can be used to build habitats on extraterrestrial bodies. This way one can save space and expenses during space travel. There are some types of additive technologies which can be used, but the most remunerative types are melting the material gathered from the environment. The most effective technologies are sintering or melting using laser beams, or we can use the radiation of the light beams using mirrors or lenses. The primary objective of this thesis is to show the design of a demonstration rover that can travel in hard terrain, gather material from the environment and has the ability of 3D printing so that it can create constructional units for larger structures.

Keywords: rover, 3D printing, Moon, sPrinter, space

1 Motivation

Nowadays many space agencies show a significant interest in having crewed missions on the surface of the Moon. A considerable part of these missions is to establish a habitat on the surface of the object that can defend cosmonauts and astronauts from the high radiation which is present in the outer space. The main problem is the transportation of the objects because only a low fraction of the whole transportation system can be used as a payload. So it makes sense to build some parts of the infrastructure directly on the surface of the Moon.

To build a habitat on the Moon, there is a need for autonomous devices that can prepare constructions for astronauts. The primary motivation of the project is to develop a functional prototype of sPrinter, which is a Moon rover with the ability of 3D printing. The name sPrinter can be originated from the term: Space printing rover. The project was born during the series of lectures Space for education, education for space, which was a project of the Faculty of Electrical Engineering and Information Technology and the European Space Agency.

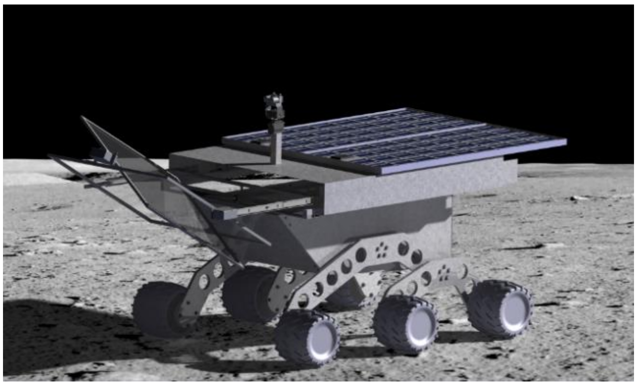

Figure. 1. Illustration of sPrinter.

2 Mechanical design

It was required to design a proper chassis for the prototype of the mechanisms and constructions, and the main objective was to develop the mechanism which has all the needed degrees of freedom of 3D printing. The principle of 3D printing is based on concentrating the sunlight using a so-called Fresnel lens. The design of the mechanical parts of the rover can be divided into five main groups..

2.1 Suspension design

The chassis of the rover is a standard Rocker-Bogie suspension. It has the advantage of functional mobility, and it also can move in hard terrain. Another advantage is that the front arms(called Rockers) on the left and the right side of the rover move in opposite directions while the rear arms(called Bogies) move independently as it can be seen on figure 2.

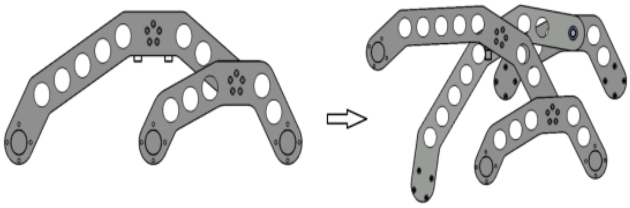

Figure 2.Contrary motion of the suspension system.

The main parts of the chassis are the two central shafts, which are also the main axis of the frame of the rover(figure 3). The design of the shafts is based on the maximal static load in the bearings. Forces F1 represent the mass of the frame, and the forces F2 represent the mass of the central transmission mechanism which provides that the arms move in the opposite direction.

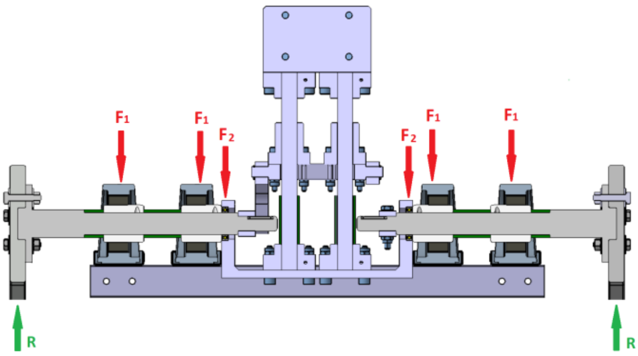

Figure. 3. Load distribution of the shafts.

Based on the loads a numerical model of the shaft was created and was investigated in ANSYS Workbench and using the Finite Element Method(FEM) the stresses in the material were found.

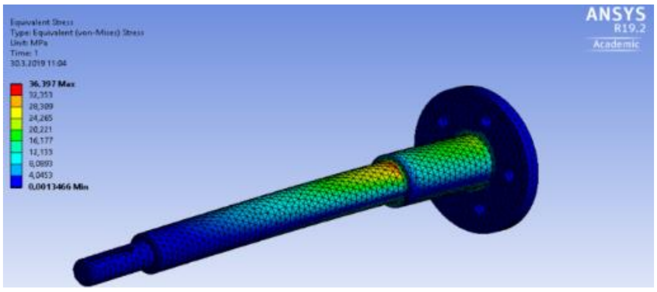

Figure 4. Results of the FEM analysis.

The results of the simulation are shown in figure 4. From the results, we can see that the maximal stresses are under the Yield stress of the material(Duralumin EN AW 7075 T61 was used with the Yield stress of 400 MPa), so the shafts are designed properly.

2.2 Design of the drive system

The mechanical power of the rover is ensured by using electric DC motors (type: PG421) with epicyclic gears. One DC motor is mounted into each of the wheels. Figure 5 shows the section of the assembly of the suspension of the wheels. The figure shows the main parts of the assembly, and these are the following:

- An inner and outer casing
- Shafts
- Plastic tires that have specific geometry to obtain high mobility

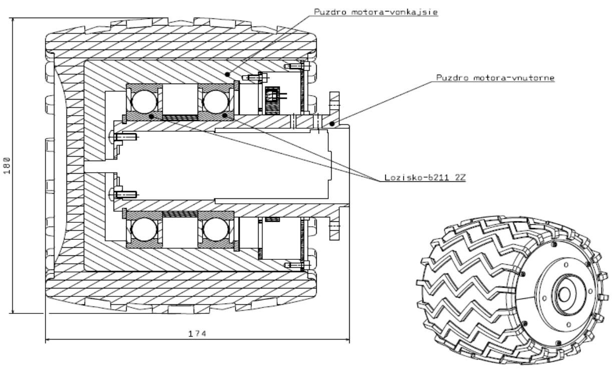

Figure 5. Cross section of the wheel.

The most critical part of the assembly is the coupling of the DC motor and the wheel. A FEM simulation was made based on the basic design, the boundary conditions were set up based on the worst-case scenario load. Also, the highest magnitude of torque was used which can be obtained by the DC motor. The FEM simulation showed that the coupling and the whole assembly is safe.

2.3 Chassis platform design

The drawing of the basic design of the frame is shown in figure 6. The whole structure is made out of duralumin tubes with a square cross-section area, with dimensions of 25x25mm. The importance of the frame is crucial because the bearings of the main shafts are mounted to the frame, thus connecting the chassis with the structure itself. In other words, the frame holds the whole rover together. Moreover, in the rear part of the frame are seated the batteries, and in the front part, the electronics and the control system is nested. The frame of the rover was mounted using bolted joints so later the whole assembly can be taken apart, which is an advantage if optimization will be needed later.

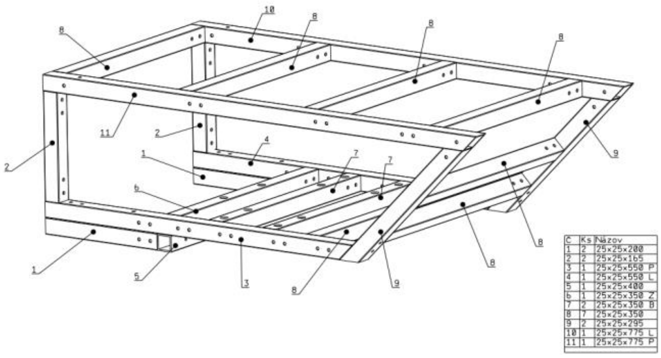

Figure 6. Assembly of the frame.

2.4 3D printing mechanism design

During the design of the mechanism for 3D print, it was crucial that the Fresnel lens could concentrate the light beams effectively during printing. The final mechanism is very similar to classic FDM (fused deposition modeling) 3D printing technology. The device can move the lens in two axes at the same time using threaded rods and stepper motors. Furthermore, the lens can be rotated around these two axes, thus making the whole mechanism more effective. In figure 6 a supportive frame is shown as well, of which the primary function is- as the name implies- to support the motion of the lens, using ball bearings.

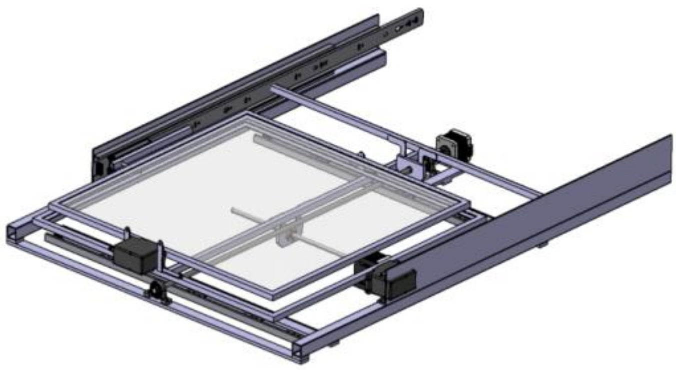

Figure 7. Mechanism for lens positioning

2.5 Mounting of the solar panels

Solar panels have a significant task; hence these parts gather the source of electric energy and charge the batteries of the rover. During the design of the mounting parts of the solar panels, two main factors were considered. Firstly, the light has to reach the panels directly, so the panels need to be mounted on the top of the rover. Another crucial factor is that the panels should not interact with the motion of the lens. The main mounting modules were designed on the upper rear end of the rover; thus the two requirements were fulfilled. Because the solar panels are thin and tend to bend, a casing was designed to stiffen the panels. It is important to mention that the mounting was designed well, and the panels fit comfortably to the mounting pockets.

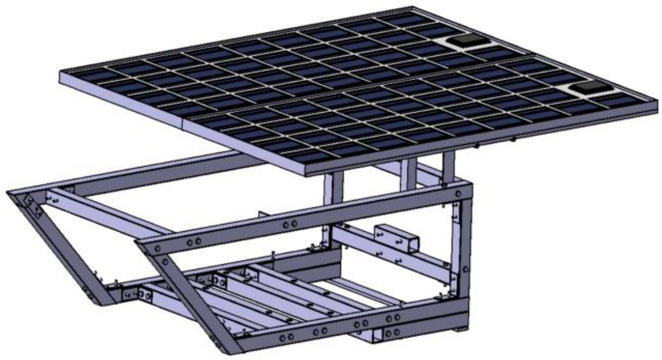

Figure 8. Solar panel mounting.

2.6 Robotic arm design

A crucial part of the 3D printing system is the appropriate layering of the material that is going to be sintered. This method is critical if one wants to create 3D objects. This device is not implemented yet in the system, because the convenient solution is still under development.

The precise layering, respectively the control of the movement of the robotic arm is a complicated task. The electric consumption of conventional robotic arms is not sufficient for the use in space, moreover, as it was already mentioned, the control of these systems is complicated, so there is a specific risk that the system will not work correctly. Considering the previously mentioned concerns, one can see that it is difficult to choose the right type of robotic arm. A proper type can be robotic arm SCARA. This mechanism has simple kinematic properties; thus it is easy to control. Moreover, it has static stability, and it also has low energy consumption.

3 Differential mechanism of the chassis

As it was already mentioned in chapter 2, the chassis is a typical rocker bogie solution. This type of chassis is designed for low velocities, and the system does not include any spring-damper system. The arms on the left and the right side are balanced passively using a differential mechanism. This way the frame can be connected with the chassis through one transverse axis. One huge advantage of this system is that it allows the rotation of the frame around the main shafts while the arms of the chassis stay at rest connected with the ground.

3.1 Design of the mechanism with rotary transmission using a differential mechanism

This solution is based on a commercial differential mechanism which is used mainly in RC cars. Figure 9 shows the mechanism in details. The contrary balancing of the arms(rockers) is ensured by the drive bevel gears which are connected with the main shaft. The shaft is bonded with the arms of the rocker and with the frame of the vehicle. The contrary motion of the drive bevel gears is ensured by the driven bevel gears. Those bevel gears are connected through the carrier. A fifth bevel gear is connected to the carrier from the outside. If the contrary motion of the arms of the rocket is sufficient, the fifth bevel gear stays unused.

Rovers Sojourner, Spirit and Opportunity were based on the previous principle. The only difference between the shown mechanism and the mechanisms used in the mentioned rovers is that instead of using a whole differential mechanism, a set of gears was used.

In our case, the fifth bevel gear ensures one more degree of freedom. This degree of freedom can be used to rotate the frame around the axes of the main shafts. This rotation can be realized using a dc motor and a pinion. Connecting the motor with the pinion to the fifth bevel gear we can start rotating the bevel gear. As the arms of the rocker stay at rest, the whole frame begins to turn with the carrier.

One huge advantage of this system is that the frame can be rotated independently from the rocker-bogie chassis. The drawback of this design is that the backlash of each gear add up and thus a huge backlash of the system is created. The amount of backlash of the system was so huge that an alternative option was needed to ensure the right contrary motion of the arms of the rocker.

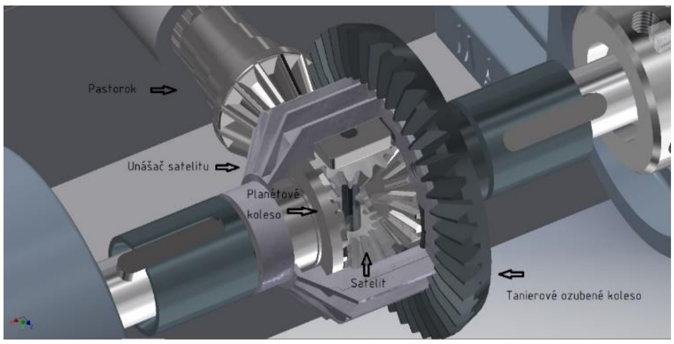

Figure 9 Differential mechanism with all the parts

3.2 Mechanism design with translatonial transmission using a system of crank and connecting rod

The solution consists of a system of a crank and a connecting rod. It is important to mention that this solution does not include any gears. With excluding the gears, we also eliminate the backlash in the system. This mechanism is shown in figure 10. It can be seen that cranks are connected on the main shaft using a clamped joint. The angle between the crank on the left side and the right side is 180 degrees. The other end of the crank is coupled with a connecting rod. The connecting rod connects the crank with the linear round shafts through a clutch, and thus it converts the rotary motion of the rockers to linear motion. The left and the right side of the chassis is connected through the clutch that was mentioned before. As the two sides are connected through this mechanism a contrary motion of rockers is created. The rotation of the frame around the main shafts is ensured using a linear actuator. This actuator is fixed to the upper end of the linear shafts. As the length of the actuator is changing, the frame starts rotating.

The advantage of this solution is that it does not use any gears and thus minimal backlash is created in the joints.

Another advantage is that the parts of this system have simple geometry; thus the production of the parts is simple and easy.

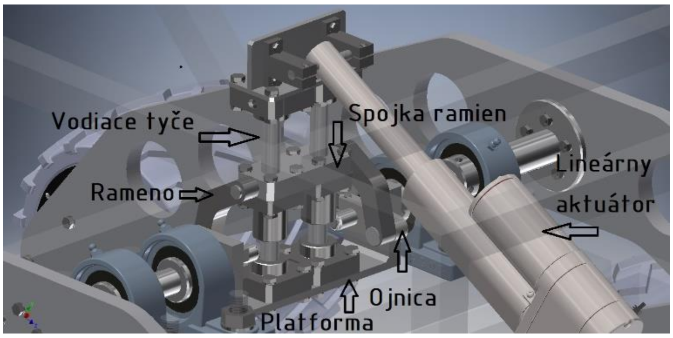

Figure 10. Description of the new mechanism

4 Electronics and embedded system

Parallelly to mechanical development, the electronic - and the control system was developed as well. To fulfill the requirements, a central control system was designed, which based on the commands of the user can control the 3D print, ensures the autonomous operation of the parameters during the print, controls the movement of the whole device and processes the data gathered from the sensors.

4.1 Design of the control system

The control system integrates the separated mechatronical and electrical units to one functioning whole. The task of the control system is to make the logical calculations and to distribute the functions in the form of data and electric signals. The block diagram on figure 11 shows a simplified view of the control system of the device.

The main requirement for the embedded control system is to develop the software in a way that there is a possibility of change in the interpretation of the master system for the later autonomous applications. The master and the slave system will communicate with one another. The primary advantage of this kind of solution is the division of the control in smaller problems, thereby during the development of the autonomous system, there will be an intelligent driver that optimally processes the received commands. Moreover, the developers of the master systems do not need to have a deep knowledge of the connection layout of the system.

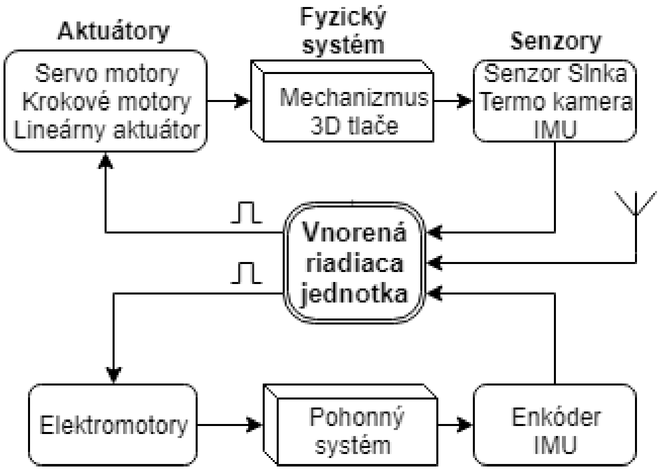

Figure 11. Block diagram of the control system

The core of the embedded system is a microcontroller, namely the STM32F4. This specific microcontroller type is not space graded; hence it is not protected against radiation, and it is not created for space applications. However, it is popular among the basic commercial applications of embedded systems, so it guarantees the professionality and the efficiency of the system.

4.2 Design of the electronics and the actuators

Based on the principles of the 3D printing technology it is essential to ensure the needed degrees of freedom for the system. The implementation of the actuators and their principal use is shown in figure 12.

The horizontal movement(plane x,y) is ensured by a pair of stepper motors. These stepper motors convert the rotary motion of the threaded rods on translational motion of the lens. To obtain the right focal length of the lens, it is needed to rotate the frame itself around the main shafts. This degree of freedom is achieved using a linear actuator, which is depictured in figure 10. The rotary motion around the axes of the lens is ensured by a pair of stepper motors. These motors can define the right angle between the lens and the sunlight.

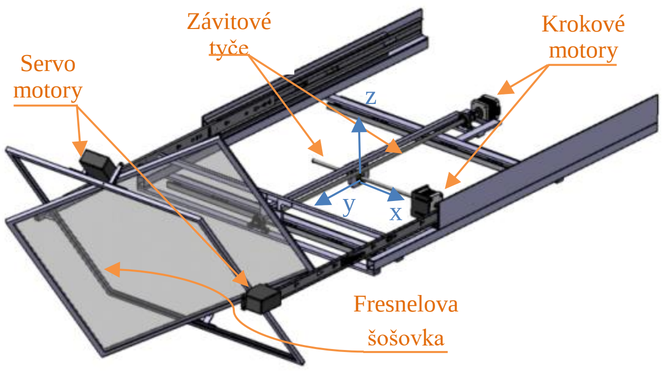

Figure 12. Model of the 3D printing mechanism

4.3 Sensor design

To obtain optimal control and to gain a certain level of autonomous control there is a need to integrate to gain feedback from the 3D printing mechanism, and also from the drive and the trajectory of the vehicle.

To position the lens of the 3D printing mechanism, and also to concentrate the energy of the light beams to the focal point of the lens, it is important to know the position of the Sun. The position of the Sun will be examined using a sun tracker sensor. Later the combination of the sun tracker and a camera system will be used to obtain higher precision. Another important information is the position of the vehicle and the position of the lens(including both rotations and positions). It is also crucial to gain data of the actual angle of the rover frame and the gravitational field of the planet. To gather this kind of data there is a need to have an inertial measurement unit(IMU) implemented to the system. If we are aware of all the information of the system we get a good reference axis system independent from the terrain on which we are going to print.

To control the speed and the motion of the vehicle an incremental encoder was developed and seated in all of the wheels. Data from the encoder is also used for odometry, to optimize the parameters of the motion.

4.4 Control system of the 3D printing mechanism

Now that the feedback of the system is clarified, we can move on to the actual control of the 3D printing system. The main parameter of the process is to focus the energy of the Sun in the right way, so the layers can be printed and stacked on each other.

4.5 Software development of the embedded system

The software was developed in the programming language C and C++. There are specific requirements for software development for control systems of space technological devices, aircraft design, and automotive industry. These requirements were taken into consideration during the development of the control system of the vehicle. Following the rules of these programming steps a stable and fail-safe system was developed. Moreover, some shielding units were implemented to the system including watchdogs and CRC checksum.

5 Conclusion

The primary objective of the project was to develop a functional prototype of a Moon rover with the ability of 3D printing and material gathering. During the design many modifications were made, new solutions were implemented in the design, and finally, the rover was built based on the model. After the construction and some tests, the rover can be tested in more extraordinal conditions. In the present phase, the device can find the focal point and print an object on the area of approximately 10x20 cm. With the rotary motion of the frame and with the layering of the material the rover can print a 3D object of height some centimeters.

During the development phase, we got the opportunity to apply our theoretical knowledge on the design of the rover and also had the opportunity to obtain some extra experience and insight. Because of the complexity of the project, one can only discover and implement additional improvements to the system. A huge benefit of the project that many final theses are already being written based on the project.

The plans include the development and implementation of gathering and layering of the material, and also the further development of the control system to make the rover autonomous.

Acknowledgment

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We would also like to express our thanks for Tatrabanka for their financial support.

Figure 13. Rover during the test phase.

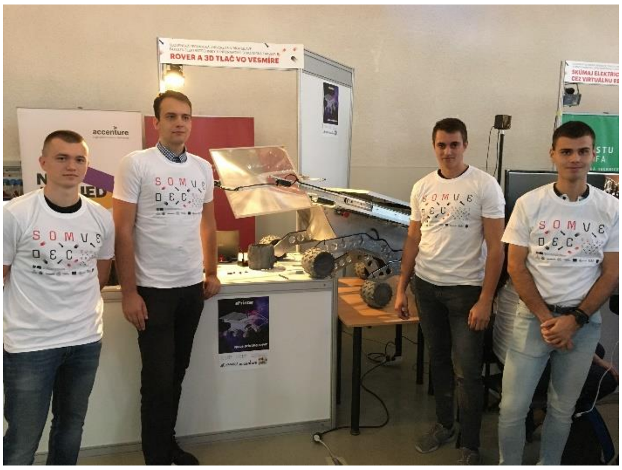

Figure 14. Our team at the Night of Science Bratislava

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