Design Report
Team Name: SKA Robotics (SSA WUT), Sirius II

Contact: ska.robotics@gmail.com
https://instagram.com/ska_pw?igshid=YmMyMTA2M2Y=
https://www.facebook.com/SKA.PW/
Academic Institution: Warsaw University of Technology; pl. Politechniki 1, Warsaw, Poland

Academic Consultant: Jan Kindracki, Warsaw University of Technology, Jan.Kindracki@pw.edu.pl
SKA Robotics is part of a Students' Space Association (SSA WUT, big organisation of students designing various space projects, like rockets, rovers, stratospheric balloons and satellites), which is based at the Faculty of Power and Aeronautical Engineering at Warsaw University of Technology (WUT). SKA Robotics (since 2015, previously named ERiS) was found in 2008, when first works on the creation of the rovers have started. Our association has a long-lasting experience, reaching URC 2009 with rover Scarab, Husar rover, three generations of rover ARES, which participated in URC 2016 and ERC 2014, 2015 and 2016, and Rover Sirius, which participated in ERC 2018, 2019, 2020 2021 and URC 2019.

The second rover of the Sirius program is Sirius II, which has been under development for over a year. Its development was planned to have ended before summer 2021, however due to delays related to pandemic and remote work, the rover is still under development. In our team there are 44 members, from different faculties and fields, stages of studies (from early BSc to late PhD), countries, united by the passion to the space and rovers.
### Active Members List:

<table>
<thead>
<tr>
<th>Name</th>
<th>Major</th>
<th>Duty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gabriel Brzeziński</td>
<td>Automatic Control and Robotics</td>
<td>CTO</td>
</tr>
<tr>
<td>Aleksander Przybyłkowski</td>
<td>Aerospace Engineering</td>
<td>CFO</td>
</tr>
<tr>
<td>Konrad Brzózka</td>
<td>Computer Science and Information Systems</td>
<td>Software Expert</td>
</tr>
<tr>
<td>Jakub Fabisiak</td>
<td>Mechanics and Machine Design</td>
<td>Mechanics Expert</td>
</tr>
<tr>
<td>Mateusz Szymański</td>
<td>Automatic Control and Robotics</td>
<td>Electronics Expert</td>
</tr>
<tr>
<td>Daryna Budiakivska</td>
<td>Photonics</td>
<td>Sirius Project Team Leader</td>
</tr>
<tr>
<td>Rafał Baczewski</td>
<td>Aerospace Engineering</td>
<td>SKA Robotics Team Leader, PR</td>
</tr>
<tr>
<td>Mateusz Janaszkiewicz</td>
<td>Aerospace Engineering</td>
<td>Manipulator Team Leader</td>
</tr>
<tr>
<td>Filip Olechowski</td>
<td>Automatic Control and Robotics</td>
<td>Communication Team Leader</td>
</tr>
<tr>
<td>Tomek Żebrowski</td>
<td>Automatic Control and Robotics</td>
<td>Interface Team Leader</td>
</tr>
<tr>
<td>Wojciech Steć</td>
<td>Electronics</td>
<td>Science Team Leader</td>
</tr>
<tr>
<td>Mateusz Dawidiuk</td>
<td>Mechatronics</td>
<td>Platform Team Leader</td>
</tr>
<tr>
<td>Wojciech Makurat</td>
<td>Aerospace Engineering</td>
<td>Cameras Team Leader</td>
</tr>
<tr>
<td>Jan Kłos</td>
<td>Mechatronics</td>
<td>Suspension Team Leader</td>
</tr>
<tr>
<td>Paweł Laskowski</td>
<td>Aerospace Engineering</td>
<td>Geology</td>
</tr>
<tr>
<td>Aleksandra Skrzeszewska</td>
<td>Mechanics and Machine Design</td>
<td>Geology</td>
</tr>
<tr>
<td>Mateusz Karpiński</td>
<td>Aerospace Engineering</td>
<td>Administration</td>
</tr>
<tr>
<td>Damian Kamiński</td>
<td>Mechanics and Machine Design</td>
<td>Mechanics</td>
</tr>
<tr>
<td>Sylwia Miernik</td>
<td>Aerospace Engineering</td>
<td>Mechanics</td>
</tr>
<tr>
<td>Maciej Stępień</td>
<td>Mechatronics</td>
<td>Mechanics</td>
</tr>
<tr>
<td>Bartosz Bieliński</td>
<td>Aerospace Engineering</td>
<td>Interface Software</td>
</tr>
<tr>
<td>Adam Jeliński</td>
<td>Mechatronics</td>
<td>Mechatronics</td>
</tr>
<tr>
<td>Franciszek Gniot</td>
<td>Informatics</td>
<td>Mechatronics</td>
</tr>
<tr>
<td>Hubert Tronowski</td>
<td>Electronics</td>
<td>Advisor</td>
</tr>
<tr>
<td>Michał Hałoń</td>
<td>Automatic Control and Robotics</td>
<td>Advisor</td>
</tr>
<tr>
<td>Tomasz Miś</td>
<td>Technical Informatics and Telecommunication</td>
<td></td>
</tr>
</tbody>
</table>
TEAM INFO

Team Photo
We use Excel and workflow automation tools for work management, which help us integrate the Gantt chart, tasks list, and information about members’ time availability. Currently, our project is divided into over 80 atomic tasks, and new items are regularly added. The presented Gantt outlines the key tasks that are currently being performed.
Sirius rover team consists of 7 sub-teams, all of which are responsible for one of the sub-systems of the rover. Each sub-team has its own leader managing the workflow and ensuring integrity with other parts of the rover. Coordinators, CTO and experts overlook all works to help unexperienced members in their tasks.
MANAGEMENT

Workplace:

Our rover is designed in SOLIDWORKS software. Parts are manufactured by outside manufacturers and in our main workshop shown in the picture, where the whole construction is assembled. After preliminary testing in our team’s rooms the rover is brought outside where it’s driveability is tested. Robotic arm tests and Operator trainings are carried out using specifically designed control panel.
Funding:

Funding is divided into 2 separate categories: free funds and rover development funds. Team has 5000$ of rover development funds allowing for further improvement of the construction. Only 1000$ is required for achieving rover’s final form, henceforth this area is completely secured. Construction costs were fully covered with the help of a grant from Polish Ministry of Education and Science („Koła Naukowe Tworzą innowacje” [eng. Students’ Associations Create Innovations], ~11800$, both already spent and remaining). Team has 3000$ of free funds which will be used for covering part of travel expenses. Whole cost of transporting rover and team members and their accommodation in the time of the travel will sum up to approximately 3500$. Missing funding will be acquired from the University and outside sponsors, which will cover any unexpected costs. In hardly probable case when such funding won’t be acquired, then team members are ready to cover the remaining transportation costs themselves.
Logistics:

Rover will be disassembled into subsystems which then will be put into small packages. They will be transported by car alongside team members. Packages will be secured using safety belts and straps. Delivering parts of the rover by car ensures it’s final integrity and allows for constant monitoring of it’s whereabouts. The rover assembly will be performed at the location using tools brought inside another car. The whole journey from Poland is supposed to take around two days using private cars of team members.
ROVER DESIGN

Mobility System:

The rover consists of lightweight aluminium frame, making its body, holding electronics container (currently made of aluminium-PMMA boxes, soon to be replaced with 3D-printed boxes). Suspension is made of beryllium copper as a spring-like rocker arm, connected with no kinematic pairs, basing purely on its elasticity. Each wheel has its own drive, powerful and small BLDC motor from Maxon Motors, paired with encoders to control each wheel independently. Wheels are planned to be custom-made with 3D-printed elastic tire. Beryllium copper suspension is experimental solution, designed to ensure enough stability and traction while at the same time it simplifies construction. Major drawback is its heavy weight, mitigated by reducing weight of other components (aluminium frame, polymer electronic container, etc). Maxon motors were used in team's previous rover and proved to be reliable and powerful enough to traverse rover in different terrains and soils. 3D-printed tires are designed to improve longevity of current fabric-and-foam tires, while ensuring similar traction.
ROVER DESIGN

Mobility System:

The main inspiration of the Sirius II was to build rover of a similar structure as Sirius I (previous SKA Robotics rover) but implementing changes in systems crucial to ensure reliability and easiness of maintenance and repairs. Most unique system of Sirius II is its suspension – spring-like rocker arms made of copper beryllium (due to its good combination of mechanical properties), removing kinematic pairs and reducing number of parts, leading to simplified construction. It underwent excessive numerical analyses (FEM) to ensure proper deflection and great tensile strength. As always, the team chose 4-wheeled construction with elastic suspension as it proved to work better within conditions of rover challenges organized worldwide, rather than popular 6-wheeled rover with rocker-boogie suspension based on actual Martian rovers.
ROVER DESIGN

Mobility System:

[Description of images and diagrams related to rover design]
Mobility System:

**Mass:** up to 50kg (with heaviest manipulator, depending on configuration can be lower than 40kg);

**Size:** 0.8x0.8 [m] with height from 1 to 1.5m (adjustable antenna mast);

**Max. theoretical static load on rover:** up to 480kg (suspension yield point);

**Safety factor from full speed front/side impacts:** 2-3 (suspension yield point);

**Max. speed:** 1m/s (with adjustable software limiter);

**Max. traversable slope:** ~40 degree (hard surface), 20-30 degree (loose soil/rocks);

**Important features:** ability to turn in place, low centre of mass;

Rover specifications allow it to traverse reliably through uneven surface of different cohesion. It’s relatively small size and ability to turn in place allow movement in narrow passages as well as attain proper angle for taking photos. Wheel grip and motors power as well as general rover robustness will ensure possibility of transportation all task-related objects.
Role of the main on-board computer is performed by NVIDIA Jetson device. Cameras and motor drivers are connected to Jetson Nano which allows for reliable communication between sub-systems. RoboClaw and ODrive drivers are used for controlling the movement of the rover and its robotic arm. DC/DC step-down converters are used to delivered power to logic system. Battery module has output voltage of between 20V to 29V depending on State of Charge of batteries. Due to nature of selected motors there is no need for additional voltage converters. Kill switch is mounted on top of the rover to provide easy access in case of emergency.

Thanks to that organization of electronics we can be sure of efficiency of modules, which has been tested in previous years. Usage of one main computer does not provide redundancy. The main computer tends to heat up, and reliable cooling system tests are yet to be performed. Overheating and voltage drops might lead to shutting down the microcomputer.
Electronics and power system:

Our point is to improve electronic design that existed in our previous rover. The idea is to implement module-like system, with easily replaceable elements. In order to increase safety a power controlling board is being developed. It will enable implementation of self-designed Battery Management System, apart from one already implemented in battery packs by the manufacturer.
ROVER DESIGN

Electronics and power system:
Electronics and power system:

- **Electronics weight without motors**: 4kg;
- **Estimated battery duration**: 2 hours of constant operation;
- **Important features**: easily accessible kill switch, which allows to turn off all systems in dangerous situations, modular and interchangeable design;

Electronics systems are placed in the sealed containers, protecting them from environmental hazards, like rain and heavy sun, allowing the rover to operate in different weather conditions (excluding heavy rains). A set of 6 Li-ion batteries properly powers rover during whole duration of a task, without the need to change them even when manual intervention is allowed by rules. Battery Management System (BMS) in each battery pack ensures State of Charge (SOC) of each cell does not drop below safe level.
The manipulation system of Sirius II rover consist of 5DOF robotic arm with gripper. It is made mainly of aluminium with some 3D-printed parts (not subjected to heavy loads) and underwent excessive numerical analyses (FEM) to reduce weight while ensuring robustness and tensile strength. Manipulator stages are powered by worm geared DC motors and linear actuators, while gripper fingers are operated by trapezoid screw on DC motor. Manipulator is equipped with sensors including encoders to properly implement inverse kinematic algorithms for precise movement and steering, as well as cameras to observe manipulator vicinity.

Extensive FEM analyses ensured manipulator ability to withstand 5kg object load, at cost of heavy and big worm gears. It is mitigated by reducing weight of other parts and systems to keep rover within mass limit. 5 degrees of freedom does not allow as much operating possibilities as 6 DOFs, but it has been proved enough for the team’s operator to perform tasks during rover challenges, while it also simplifies construction and ensures better robustness.
Manipulator (made as a Master’s thesis of one of team members) was meant as a second iteration of previous manipulator, including its majors features but improving reliability, precision, endurance and weight limit. Main objective was to make assembly easier – resulting in lowering maintenance time. Another point was implementation of sensors and encoders to mitigate worst drawback of its predecessor – hard steering and low precision – by allowing implementation of inverse kinematics. Extensive FEM analysis ensured maximum possible mass reduction allowed by manufacturing restriction and strength requirements.
ROVER DESIGN

Manipulation system:
Manipulation system:

Mass: 13 kg;
Size: 1.5x0.2x0.1[m] (fully extended arm);
Max. lifting height: up to 1.2 m;
Max. Weight of the load: 5 kg (fully ascended, possible pulling of heavier objects if partially supported on ground);
Important features: inverse kinematics, multiple cameras, easy mounting and dismounting

Manipulator arm is both precise and robust so it is well suited for both panel-manipulation type tasks and transportation/collection type tasks. It is capable of picking up all objects described in manual, as well as pulling the refuelling cart (over weight limit but its weight won’t be exerted on manipulator arm). Precise operation on panel will be supported by inverse kinematics algorithms. Easiness of mount will allow quick switch from science payload in Moon base during task.
The drilling system is designed as a platform mounted on a linear module, allowing the platform to drill into the soil. The soil samples are extracted by a steel auger and transported through a polymer pipe. The soil is extracted directly to a rotary (sealable) container, holding four slots for different samples, which can be. Each sample is divided into four parts, which undergo various chemical tests for the existence of life and geological structure. Reagents are applied by a specialized injector, containing a leakproof tubing system, driven by a precise stepper motor. The whole subsystem is protected by a safety casing which ensures that the no-spill policy is followed. Additional elements are the temperature and humidity sensors, patented spectroscope for the testing of the solid samples and discovering their chemical composition. Unfortunately, container requires cleaning after each 4 samples. Used chemical substances also require specific utilisation procedures that must be fulfilled.
Science Payload:

❖ The current injector is another iteration of the device, with highly reduced friction along with improved reliability;
❖ We are able to detect ammonium cations (NH₄⁺), Phosphorus (P), Potassium (K) calcium carbonate (CaCO₃), proteins;
❖ We are able to drill up to 150 mm;
❖ Among used chemicals: Hydrochloric acid (HCl), Nitric acid (HNO₃), Sodium cobaltinitrite (Na₃Co(NO₂)₆), Phosphorus indicator;
❖ Some chemicals have low concentration to ensure safety of the usage and easier utilisation process.
Science Payload:
Science Payload:

- **Mass:** 7 kg;
- **Size:** 0.5x0.7x0.3 [m];
- **Max. Depth of collecting samples:** up to 150 mm (soft or semi-hard soil, sand);
- **Estimated battery duration:** 2 hours;
- **Important features:** can perform 4 reactions simultaneously, safe, no-spill ensured, easy mount and dismount;

We managed to create a device that can test the soil samples for the presence of life and their general chemical composition (with spectrometer), sensors help to test the temperature and humidity of the samples, spectrometer and additional cameras allow to take picture and record videos of the extruded samples. Easiness of dismount will allow quick switch too manipulator in Moon base during task.
Ground station equipment and communication system:

Rover's antennas are raised to an adequate height in order to avoid signal disruptions by physical obstacles, allowing continuous and reliable communication with the rover, especially behind hills and inside craters. The design is based on the carbon fiber tubes, to provide lightweight construction with sufficient strength and stiffness.

For the communication between the rover and the ground station, Ubiquiti Rocket routers were used. By using 2 frequency bands: 2.4 GHz and 5 GHz, reliability and redundancy are achieved.

Operators interact with the rover through remote web frontend. It is developed using vue.js framework, which allows it to run on any device with a web browser. The modules of software that are supposed to run in the Ground Station are responsible for manual teleoperation, displaying of camera feeds and autonomy status control.
Sirius rover can be steered with the pad, directly from the laptop or move in the autonomous mode. In case, when some critical situation arises, kill switch can be used – it stops all systems, communication as well. For image recognition Luxonis cameras are used. Such cameras are used by our team for the first time, however their working characteristics seem promising and might provide similar results to previously used cameras which were much bigger and heavier.
ROVER DESIGN

Ground station equipment and communication system:
Communication system has been tested in industrial and field regions, showing very good results. On a plane terrain, we can communicate within 100 metres and further, uneven terrains make results worse, but insignificantly. In the industrial regions, we are able to preserve the control over rover within at least 50 metres whilst buildings are between the ground station and the rover. We are sure, that we will be able to control our rover through all 40-meter task field.