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SPACE SOLUTIONS GROUNDED TO EARTH

Key words: spin-off, autonomous robot, scientific mobile platform.

Abstract: Scorpio X is a sample of mobile robot that is designed to operate in difficult terrain. It is capable of preforming multiple tasks, depending on installed modules, thanks to fully modular design. It utilizes multiple solutions developed for space exploration and adapts them to Earth's environment. Additionally, these kinds of robots have big potential in the commercial market, as industry moves in direction of automatisation. In this article, we describe technical details of Scorpio X mobile platform and propose possible commercial applications.

Technologie kosmiczne w projekcie naziemnego drona

Słowa kluczowe: spin-off, autonomia, robot, platforma badawcza.

Streszczenie: Scorpio X to mobilna platforma oparta na zawieszeniu wahaczowym. Scorpio X ma modułową konstrukcję, która znacznie rozszerza możliwości robota. Jednym z modułów jest manipulator o 6 stopniach swobody. Głównymi cechami manipulatora jest wysoka precyzja dzięki zastosowaniu przekładni harmonicznych i wysokiej trwałości dzięki zastosowaniu rur z włókna węglowego. Manipulator jest w stanie podnosić przedmioty o wadze do 5 kg. Innym modułem jest autonomiczny moduł napędowy, w którym zastosowano kamerę stereoskopową ZED 2k umożliwiającą wykrywanie głębi obrazu dzięki podwójnej soczewce. Ponadto Scorpio X jest wyposażony w dodatkowe kamery do obserwacji otoczenia i bezpiecznej nawigacji. Głównym komputerem łazika jest NVIDIA Jetson 152, który ma specjalne jednostki obliczeniowe do obsługi tak zwanych sztucznych sieci neuronowych potrzebnych w algorytmach autonomii. Na platformie znajdują się 2 sieci danych – CAN i Ethernet. Sieć CAN kontroluje wszystkie silniki w kołach, a także obsługuje manipulator ze względu na niskie wymagania transmisji danych, a sieć Ethenet jest odpowiedzialna za komunikację z bazą, transmisję obrazu, a także wsparcie dla mniejszych modułów (np. czujników badawczych). Dodatkowy modułowy robot Scorpio X to czujnik używany do badania środowiska, w którym znajduje się robot. Dostarcza informacji o czynnikach atmosferycznych, a także o glebie, którą łazik może odebrać za pomocą specjalnych wskazówek na manipulatorze i analizować takie próbki na pokładzie. Możliwym zastosowaniem Scorpio X jest zatem praca w trudnych warunkach, w których życie ludzkie może być zagrożone. Scorpio X dzięki swojej specjalnej konstrukcji i wdrożonym rozwiązaniom ma duży potencjał jako korporacja spin-off.

1. Core robot systems

Scorpio X is a modular, versatile platform designed for exploration in difficult terrain. It includes our solutions from older Scorpio versions with many additional features, such as more advanced, reliable electronics, image recognition, a more accurate robotic arm, and a wide range of scientific sensors.

The Scorpio project has already gained recognition among international experts. This is the only construction of this type from outside the USA, which received an invitation to NASA. Scorpio X was tested in the Jet Propulsion Laboratory and was presented to NASA engineers.

1.1. Driving unit

The Scorpio X robot has been equipped with dependent suspension based on actual NASA robots. In our design, we reduced the rear boogie to a single wheel to make our suspension work better at higher velocities. Both rockers are connected together through a differential beam running across the entire robot. As the main material for driving module, we chose aluminium, because of its high strength to mass ratio. When designing wheels for our robot, we decided to incorporate further mass reduction though creating rims through milling out of material called polyamide. Our tires are very unique looking compared to solutions from other teams. We incorporated a soft-type wheel out of abrasion resistant fabric – Cordura. As an upgrade of our wheels, we plan to enhance the durability of our tires by replacing Cordura with Aramid fibres, also known as Kevlar. The filling for the tires was also changed. Previously we used Styrofoam granulate, but it was susceptible to fast kneading. This year we replaced Styrofoam with memory foam to eliminate that drawback. To move our robot, we use 250W BLDC motors mounted inside each wheel. Each motor has HAL sensors to precisely determine velocity of the motors [1].

1.2. Robotic Arm

Scorpio X is equipped with a manipulator with 6 degrees of freedom shown in Fig. 1, which allows one to pick up an item weighing up to 5 kg. The manipulator's construction was built around wave gears, which are a key element of the project. They are characterized by very small angular play, large ratios, and low weight in relation to the loading torque. Thanks to them, the manipulator has very high accuracy and precision of operation. Other main elements of the manipulator are worm gears, milled aluminium components 7075, pipes with carbon fibre, original toothed bushes printed in SLS technology, and original effectors. The manipulator drive has been implemented by transferring the rotation from DC motors with a high rated torque to the gears, thanks to the toothed bars. The effector is made mostly of 3D printing and a screw mechanism. Depending on the terminals used in the manipulator, it is possible to either operate the elements precisely or lift heavy objects. The manipulator control mechanism is based on inverse kinematics. Thanks to it, the range of movements of our manipulator is comparable to the work of the human hand. Basic technical data is presented in the Table 1.

Fig. 1. Robotic arm module

Table 1. Technical parameters of robotic ARM

Weight	~10 kg
Dimensions of the folded manipulator	700x200x250 mm
Maximum overhang	1000 mm
Maximum lifting capacity	5 kg
The maximum width of the effector's grip	100 mm

Tasks that the manipulator can do among others:

- Lifting items up to 5 kg;
- Precise operation of buttons, switches, and knobs;
- Typing;
- Opening doors; and,
- Precise delivery of items.

Thanks to the construction solutions mentioned above, we obtained a manipulator characterized by exceptional work precision and smooth motion while maintaining high resistance to overload.

1.3. Power Systems

The nature of the assigned tasks requires that the robot has the ability to perform fault free, off-grid operation for the entire duration of the task. The electrical system of the vehicle was designed and assembled with the aim to meet this expectation. All of the robot's active systems are powered from "a power block" consisting of four identical lithium-ion batteries connected in parallel. The capacity of one battery is 4000 mAh, which gives the robot's overall capacity of 16000 mAh. The time of operation of over 2 hours of the chosen solution was determent empirically. Over-discharge protection is implemented in the form of a voltage meter connected to battery terminals. Measurements are displayed on the LCD indicator located on the mast. The separation of the power source from the rest of the robot circuitry has been done by utilizing a solid state relay. The status of the switch is determent by the position of the emergency stop button located on the top of the robot's body. Power lines running through robot are split into 2 systems. The first one is designed to permanently connect high power demanding devices and consist of terminal blocks mounted on DIN rail. The second one is integrated into CAN bus management board. It is designed to supply power and the CAN bus signal to interchangeable and experimental modules. That is why it was equip with more sophisticated protections such as fuses [1].

1.4. Architecture of Electronics

Each of the electronic components is divided into two parts: the motherboard and its top overlay. The motherboard includes a microcontroller (STM32F4), a raspberry Pi Zero (optionally), and a stable and well-protected power supply including surge stoppers, galvanic isolation, under/over voltage and over current protections. The top overlay customizes the whole unit to provide exact functionality depending on its purpose. This kind of approach gives us a possibility to unify the software layer that can be reused between components which is making the whole design better, more reliable, and saves a lot of time. The mandatory protections in the power supply make the component more resistible to human error and unforeseen system impacts. As a robot's main computing unit, we are using Nvidia Jetson TX2, which is coordinating all other modules and providing necessary computing power for more demanding autonomous algorithms [1].

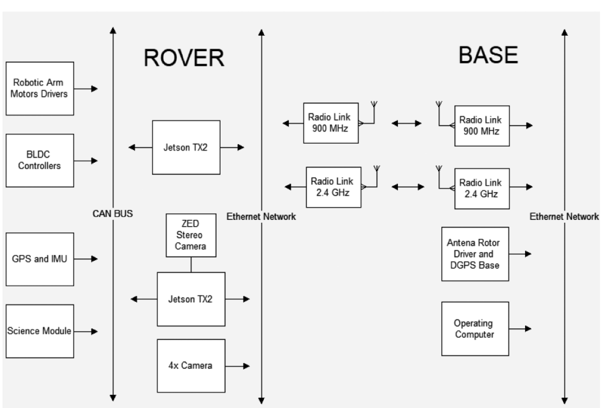

Fig. 2. Architecture of electronics

The rover utilizes two networks connected by Jetsons – see Fig. 2. The first one is the CAN bus, and it is responsible for sending crucial data to motor controllers and robotic arm control system. Second one – Ethernet network which is used to transmit commands and vision from cameras to and from the rover.

1.5. Vision

In order to improve visibility, a special frame for the mast camera has been designed to allow rotation in the axes. This allows significant visibility improvements and minimizes problems associated with poor visibility. The construction consists of a special plate with an axially hollow shaft on which the torque from the motor is transferred, which is responsible for the rotation about the yaw axis. Thanks to the hollow shaft, the problem of breaking the electric beam due to rotation has been reduced. Thanks to the coupled camera rotation with the Megatron ETS25 absolute encoder, we can precisely control the position of the camera. The second element is the frame, which is placed on the board. It allows one to adjust the camera position in the pitch axis. The mast camera is equipped with an optic zoom, which allows us to preform extended surroundings scans if needed. Apart from the mast camera, our robot incorporates several others vision systems. The main camera for navigating is a ZED 2k Stereo Camera, which is used for autonomy and navigating. As redundancy, we use a Geovision GT-BX1500 camera with a fish-eye lens. On robotic arm, we use 2 cameras each directed at a different angle of the effector to achieve vision depth. Almost all cameras are connected through POE (apart from ZED – USB) to simplify cable management.

1.6. Navigation

A traditional GPS receiver has been replaced with two GNSS modules mounted on PCBs of our design. The first one mounted in the base station and the second one is mounted on the robot. They work together with real-time differential GPS measurement method using corrections from the base station. Each board is equipped with an IMU and a barometer. A magnetometer determines geographical direction, and the barometer helps to correct the altitude. GNSS receivers use more satellite systems, i.e. GPS, GLONASS, and BeiDou, which affects the accuracy of the measurements and a period of time necessary for fix catching.

1.7. Communication

To ensure proper communication between robot and base station, we have incorporated 2 systems operating in unlicensed frequency bands – 900 MHz and 2.4 GHz. All telemetry data, logs, and control commands are sent via 900 MHz. This solution helps us to maximize the useful range of the system responsible for messages necessary for the proper operation of the robot. For streaming live camera feed, we are using 2.4 GHz, because the wider bandwidth gives us more flexibility for the vision systems. In order to establish reliable connections between the robot and base station, we have installed 2 directional antennas on top of the mast. We have also integrated our communication systems with GPS, which helps us to maximize signal power at the receiver's end by tracking relative position of robot in accordance to the base's position with directional antennas. The rotor mechanism with two degrees of freedom allows manual adjustment of the orientation of the transmitters installed in the base station in relation to the robot's position. In the case of a non-line-of-sight scenario, we can achieve communication through NLOS propagation [1].

1.8. Mobile Laboratory

To thoroughly analyse and characterize the environment, our robot is equipped with numerous environmental sensors, as well as probes allowing for soil analysis. The sensors are located on the mast and on the manipulator to monitor the environmental parameters of the environment, even during the passage. These include the following: temperature, humidity, wind direction and speed, UV index, radiation (Geiger counter), particulate concentration (PM 2.5), and the concentrations of carbon dioxide and methane. The received data is sent to the computer for analysis and interpretation.

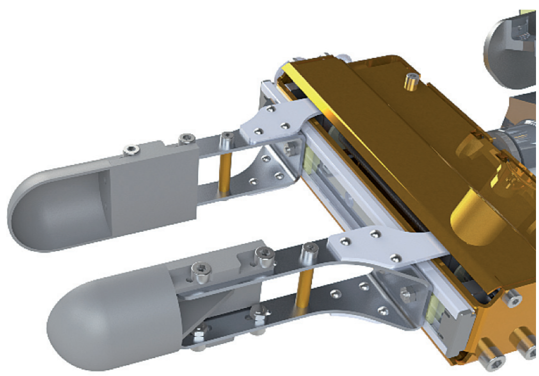

Fig. 3. Schema of the effector for soil sampling

The manipulator is equipped with an effector that allows taking a soil sample and placing it in a special container for in-situ analyses – Fig. 3. The box contains water and electrochemical sensors to assess pH and conductivity. We put emphasis on safety and ecology, and that is why the container is properly sealed so that the water used for the analysis does not enter the tested environment. Water can also be replaced by other analysis solutions, depending on the research needs. To identify the chemical elements important in the natural sciences, the scientific team constructed a DIY spectrophotometer. The collected sample is placed in the spectrophotometer chamber, where the measurement takes place. Thanks to the use of UV and IR lamps, it is possible to cover ultraviolet and part of the infrared spectrum of the tested sample. The obtained results are compared with the database in order to identify valuable chemical elements. The effector will also be able to measure the temperature and humidity of the soil during collection by direct contact of the sensors with the surface.

1.9. Client application

A client application was created to operate the device. It is designed to be easy to use even by inexperienced people. Learning how to use it does not take long, and it is also very intuitive, which is important especially in stressful situations, when it is necessary to make quick decisions about performed activities. An example of a client application layout is shown in Fig. 4 [1].

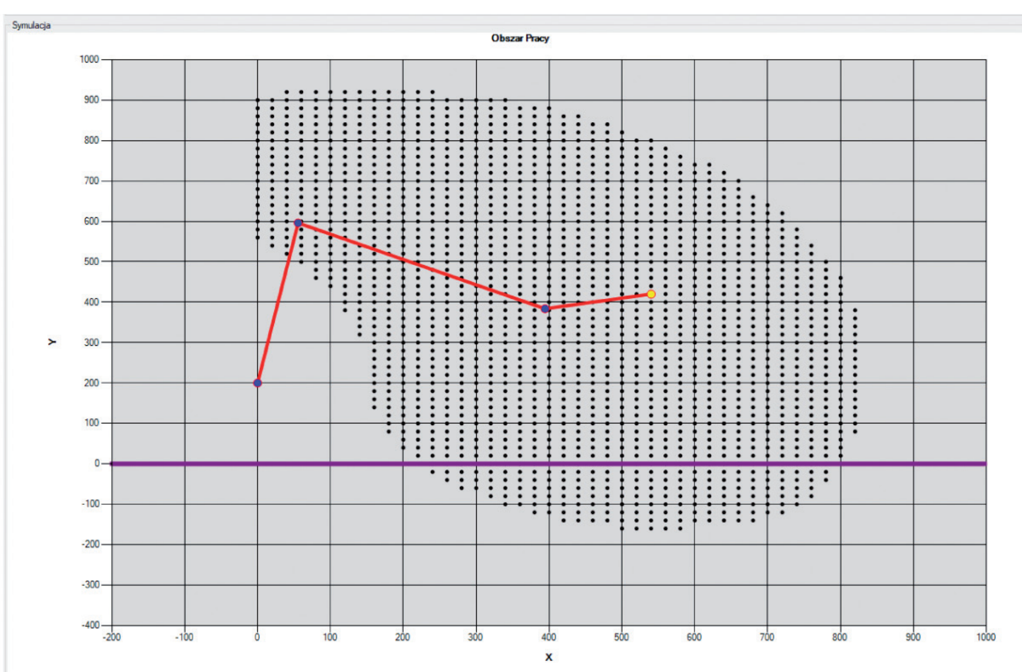

Fig. 4. The client application interface

2. Possible use

Currently, the Scorpio project is increasingly inclined towards the possibility of the commercialization of its construction. Thanks to the technologies used in space engineering, we have obtained a unique robot, adapted to driving in difficult and demanding terrain, while simultaneously capable of performing a series of activities. A manipulator with 6 degrees of freedom and operating on the basis of inverse kinematics enables us to remotely execute precise movements, such as writing code on the keyboard, and opening and closing drawers. The lifting capacity of about 5 kg allows moving objects over longer distances. Another module of the Scorpio, which increases its commercialization potential, is the laboratory module, which consists of a series of sensors and devices allowing for the analysis of the soil sample.

Robots for the above-mentioned tasks are commercially available. Our design clearly stands out from the others, mainly through the use of solutions mentioned in the technical part and implemented in the space industry. We conducted a thorough analysis of the commercially available robot market. The first group of devices were ground drones, serving to disarm mines in war zones. They are designed mainly for urban areas; therefore, they have a low suspension, which excludes their use in more demanding areas. Another group of constructions that we have analysed were robots that could help people to work in underground mines. Here, the market is much more narrowed, and it is focused mainly around prototype robots constructed by research centres. The lack of this type of construction on the market and the growing demand for it is confirmed by the fact that, last year, we signed a cooperation agreement with one of the companies belonging to Jastrzębska Spółka Węglowa – Hawk-e. The company was established to implement products developed as part of research and development related to unmanned technologies. This company is interested in our construction in terms of its use in the mines owned by Jastrzębska Spółka Węglowa [2, 3].

Conclusions

Scorpio X (see Fig. 5) is currently a prototype; therefore, it is constantly being improved in accordance with current trends in the robotics industry by implementing, among others, neural networks or an autonomous driving module.

Therefore, Scorpio can be used everywhere where an activity or environmental analysis should be carried out while protecting people's lives and health from possible dangers. These are, for example, underground mines, potentially explosive areas, or active volcanoes.

The business model of our construction was presented during the Entrepreneur Challenge section at the international Robotex competition in Estonia. The judges' committee consisted of people associated with business, marketing, and spin-offs, as well as start-ups. Our design won the highest marks during the two days of the presentation and won the first place in its category.

Fig. 5. Scorpio X overview

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