



Design of a mobile robot to support workers in high-risk environments

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Abstract. This study presents a design concept for a hybrid tracked mobile robot intended to replace human operators in high-risk environments, including exposure to hazardous chemicals, gas storage facilities, high-temperature zones, and areas prone to fire and explosions. The structural design of a mobile robot with a combined propulsion system was developed and analyzed. Design and modeling were performed in SolidWorks. The study included layout design calculations and assessments of obstacle-traversal stability, robot mobility, and slope-climbing capability. It also involved the selection of appropriate sensors and auxiliary equipment. The RoSafe robot model was developed within the framework of the DTAV.04/25-NN ministerial project. The robot features a hybrid chassis configuration comprising two primary tracks and four auxiliary tracked legs. The complete 3D and 2D design documentation specifies overall dimensions of 1311 × 649.2 × 350.3 mm and a calculated mass of 130 kg. In addition, a table of technical specifications is provided. The robot is equipped with gas sensors (O₂, CO, CO₂, CH₄, and H₂S), temperature sensors, smoke sensors, surveillance cameras, a mapping system, bidirectional communication with the control center, and manipulator mechanisms. Particular attention during the design process was given to obstacle-negotiation capability, stability on inclined surfaces, compactness, and operational convenience, ensuring practical applicability of the system. This work represents the initial stage of development, and the results provide a foundation for subsequent pilot production and testing aimed at the practical implementation of the RoSafe robot model.

Keywords: mobile robots, occupational safety and health, hazardous factors, harmful factors, working environment, Solidworks software

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МАШИНОСТРОЕНИЕ

Научная статья

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Исследование и предложение по разработке модели мобильного робота для поддержки работников в условиях повышенного риска

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Резюме. Цель – разработка проекта гибридного гусеничного мобильного робота для замены человека в условиях повышенного риска: при воздействии химических веществ, на объектах хранения газа, в зонах с высокой температурой, а также в огнеопасных и взрывоопасных средах. Объектом исследования является конструкция мобильного робота с комбинированным двигателем. Проектирование и моделирование выполнялись в среде Solidworks. В ходе работы проводились расчеты компоновки, устойчивости при преодолении препятствий, подвижности и подъема по склонам, а также подбор сенсорного и вспомогательного оборудования.

В результате проведенных работ получена модель робота RoSafe, разработанная в рамках министерского проекта DTAV.04/25-NN. Робот имеет гибридную конструкцию ходовой части, включающую две основные гусеницы и четыре вспомогательные гусеничные ноги. Получены полные 3D- и 2D-проекты с габаритными размерами 1311×649,2×350,3 мм и расчетной массой 130 кг, а также составлена таблица технических характеристик. Показано, что разработанная модель оснащена газовыми датчиками (O₂, CO, CO₂, CH₄, H₂S), температурными датчиками и датчиками дыма, камерами наблюдения, системой построения карт местности, двухсторонней связью с центром управления и манипуляторными механизмами. Отмечено, что особое внимание при проектировании уделено способности преодолевать препятствия, устойчивости при движении по наклонным поверхностям, компактности и удобству эксплуатации, что обеспечивает высокую прикладную эффективность устройства. Выполненная работа представляет собой начальный этап исследований, результаты которого являются основой для последующего запуска опытного производства и проведения испытаний с целью практической реализации модели робота RoSafe.

Ключевые слова: мобильные роботы, охрана труда и здоровье, опасные факторы, вредоносные факторы, рабочая среда, программное обеспечение Solidworks

Финансирование. Данное исследование было поддержано Научно-техническим исследовательским проектом Генеральной конфедерации труда Вьетнама, проект № DTAV.25/04-NN.

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INTRODUCTION

In the current context, mobile robots are playing an increasingly important role in various fields, from industry, military, health and education. One of the issues of concern is to bring science and technology, robotics deeply into labor production, to support the replacement of human labor in heavy, toxic jobs, monitor and warn of unsafe incidents during work. The application of robots will allow workers to remotely access dangerous areas, collect data, observe the scene and support faster and safer decision making through the central operating system.

In jobs such as chemicals, oil and gas, mining and waste treatment, workers are often exposed to potentially high-risk environments: toxic gas leaks, extreme temperatures, smoke, and fire and explosion risks. Direct exposure in these conditions leads to the risk of work accidents, health damage leading to illness or even death for workers. Therefore, the application of mobile robots to support workers working in high-risk working environments is considered a necessary research direction. Therefore, within the scope of this research, the authors propose to research and design a mobile robot model as a basis for manufacturing in the next stage to realize the urgent requirements set forth.

In the world, some typical studies can be mentioned as the research project on mapping gas distribution, navigation and various sub-tasks of locating gas sources, this activity is performed by attaching gas and chemical sensors on mobile robots [1], or research on

designing robots to work in greenhouses with integrated monitoring sensors to effectively support humans and monitor the growth process of crops [2]. In the manufacturing sector, in some jobs where humans directly operate with high risk of toxicity such as welding fumes, checking the quality of welds in pipelines, where light, visibility and working space are limited, the choice of robots is considered a safe and effective solution [3, 4]. In rescue operations or security monitoring of boiler systems, coal mines, tunnel collapses, and earthquakes, research and application directions for robots have also been used and demonstrated their independence, flexibility, and accuracy when accompanied on these robots are a series of modern sensor devices [5–7].

In Vietnam, some typical research projects include the research and design of robots to monitor wastewater pipes to help survey activities be faster [8] or the research on the application of robots in non-destructive testing when assessing fuel tank corrosion [9]. In order to help workers work in the stages of transporting and gathering materials with large volumes, and performing labor requiring heavy lifting, the research, design and manufacture of AGV robots has solved and supported the replacement of workers in these jobs [10].

The content of this study is:

- studying technical requirements and proposing the selection of robot models to meet the criteria for supporting, warning, and monitoring workers working in high-risk working environments;

- proposing and designing a complete RoSafe (Fig. 1) robot model with high mobility, integrating many features, easy to operate and system stability, along with a proposal for a list of components and sensors;

- providing a scientific basis and design calculation theory to transition to complete manufacturing in the next stage.

TECHNICAL REQUIREMENTS AND SYSTEM ARCHITECTURE SELECTION ANALYSIS.

FUNCTIONAL REQUIREMENTS FOR THE ROBOT MODEL. ANALYSIS AND SELECTION OF SYSTEM ARCHITECTURE

Selection of the robot's movement mechanism. Choosing the method of movement for the robot is one of the factors that determines its ability to adapt to terrain and its stability in the operating environment. Previous publications show that if choosing a wheel-based mechanism, it has advantages in speed and simplicity in calculation and manufacturing, but the ability to overcome terrain and move on uneven and ruined environments is limited [11]. Meanwhile, the method of moving the robot using legs (legged) has better flexibility and ability to overcome complex terrain, but

is complicated in mechanical manufacturing, difficult to control and high cost [12]. Different from the two above moving methods, the tracked mechanism is considered a neutral solution and a suitable choice that allows the robot to move stably and effectively on rough, uneven terrain, with the ability to climb stairs, overcome rubble, and with a relatively simple mechanical and control structure, easy to manufacture [13, 14]. Studies on the design of mobile robots for rescue, search, and industrial transportation have chosen the tracked or hybrid tracked mechanism, which has shown high efficiency in terms of stability, mobility, and performance response⁶ [15–18].

In this research proposal, the authors have studied, consulted and inherited some research on mobile robots with 2 main tracks and 4 auxiliary tracks, typically: mobile robots serving patrolling, surveillance with cameras in narrow spaces, can move on stairs, rough terrain^{7,8}; development and application in bomb and mine clearance inspection activities in dangerous environments through remote control [19]; or studies published in RoboCup competitions have proposed solutions for application in entertainment activities, rescue,

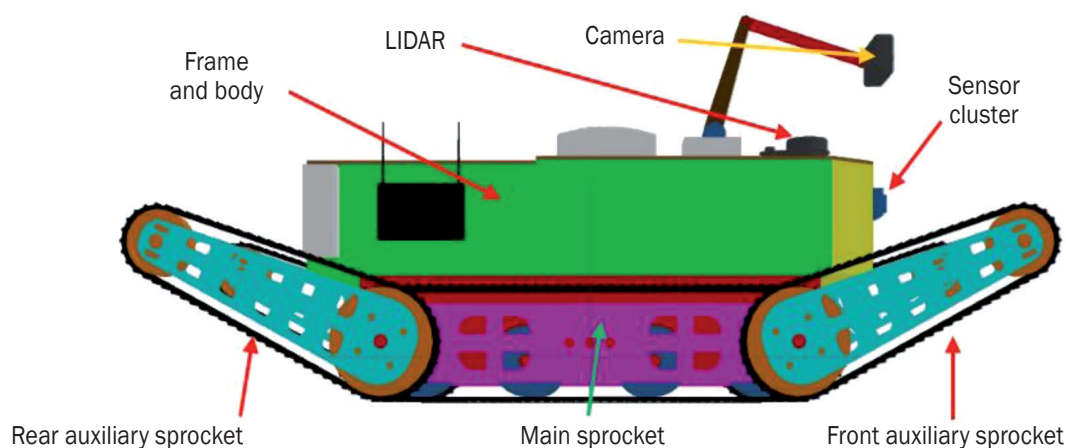


Fig. 1. Simulation of the proposed design idea of the RoSafe robot model

Рис. 1. Имитация предложенной конструктивной идеи модели робота RoSafe

⁶Figure – available from: electronics. Available from: https://www.researchgate.net/figure/Design-of-an-all-terrain-mobile-manipulator-ATMM-consisting-of-an-all-terrain-mobile_fig2_357754425 [Accessed 1st March 2025] / Режим доступа: https://www.researchgate.net/figure/Design-of-an-all-terrain-mobile-manipulator-ATMM-consisting-of-an-all-terrain-mobile_fig2_357754425 (дата обращения: 01.03.2025).

⁷Robot-jaguar-v6. Available from: www.robotshop.com/products/dr-robot-jaguar-v6-tracked-mobile-platform-arm [Accessed 1st March 2025] / Робот-ягуар-v6.. Режим доступа: www.robotshop.com/products/dr-robot-jaguar-v6-tracked-mobile-platform-arm (дата обращения: 01.03.2025).

⁸Jaguar-v4. Available from: <https://www.robotshop.com/products/jaguar-v4-w-manipulator-arm-mobile-robotic> [Accessed 1st March 2025] / Ягуар-v4.. Режим доступа: <https://www.robotshop.com/products/jaguar-v4-w-manipulator-arm-mobile-robotic> (дата обращения: 01.03.2025).

and human behavior observation [20]. These works are consistent with the research direction of the proposed topic, such as mobility in movement, so the authors chose a hybrid track mechanism, specifically two main tracks, combined with four auxiliary track legs to conduct research and design this robot model. This research aims to propose a domestically localized robot model, as a foundation for the application of robots in the field of monitoring and protecting workers in high-risk, toxic environments, and monitoring work processes and rescuing in emergency situations.

Modularize the structure and propose a list of equipment. Modularization of the robot's structure is one of the key factors to ensure the scientific and comprehensive nature of the system, each module will undertake a certain function, high adaptability when changing and upgrading technology. Therefore, in this study, the authors built three modules for the RoSafe version of the mobile robot, corresponding to each group of modules are the accompanying equipment lists to meet the criteria of the technical requirements set out in the research direction (Table 1–3):

Movement module (M1-RoSafe): ensures the mobility of the robot on many types of terrain.

Control module (M2-RoSafe): processes signals, coordinates activities, ensures safe and accurate operation.

Observation and positioning module (M3-RoSafe): provides the ability to sense the environment, support control and monitoring.

DESIGN PROCESS AND PROPOSAL OF ROBOT MODEL ROSAFE

Choosing Solidworks software as a simulation design tool. The choice of design and simulation software plays a decisive role in the accuracy and ability to analyze the motion and optimize the structure of the robot. Popular software such as CATIA, NX or Creo, however, in this study SolidWorks (Fig. 2, 3) was chosen because of its ability to visualize 3D parametric modeling, dynamic analysis, collision testing and effective load simulation. Compared to other software, SolidWorks has a friendly interface, fast processing speed, easy installation, low cost, and can be used for a free version with a suitable term for re-

Table 1. Moving module block (M1-RoSafe)

Таблица 1. Подвижный модульный блок (M1-RoSafe)

No.	Equipment Name	Proposed Specifications	Characteristics
1	Main motor	400 W, CANbus, integrated driver	Main drive for both crawler sides
2	Main motor gearbox	$i = 1/30$, shaft D17	Speed reduction, torque increase
3	Auxiliary climbing motor	400 W, CANbus	Supports stair climbing
4	Auxiliary wheel gearbox	$i = 1/100$, shaft D17	Increases torque, reduces speed
5	Sprocket	40	
6	Lithium-ion battery	24–48 V, 25–50 AH	Main power source

Table 2. Control module block (M2-RoSafe)

Таблица 2. Блок модуля управления (M2-RoSafe)

No.	Equipment Name	Main Specifications	Description / Characteristics
1	LiDAR data processing computer	Intel i7, 16 GB RAM, 120 GB SSD	Map processing, SLAM
2	MacBook M4 laptop	16 GB RAM	Monitoring station
3	Android 13 tablet	Snapdragon 8 Gen 2, 5G/4G	Remote control interface
4	Phoenix switch	5 ports, 24 V	Local network connection
5	USB–RS485 converter	FT232RL	Communication interface conversion
6	RF module: Lora 433MHz RS232/RS485 8000m EBYTE E90-DTU(433L30)-V8	24 V	Short-distance data transmission
7	Antenna booster	12 V	Signal amplification
8	SIM7600G-H DTU	LTE/4G, RS232/485	Remote data transmission
9	LoRa DTU A100- L400M30	RS485	Long-distance data transmission

Table 3. Observation and positioning module block (M3-RoSafe)**Таблица 3.** Блок модуля наблюдения и позиционирования (M3-RoSafe)

No.	Equipment Name	Main Specifications	Description / Characteristics
1	2D LiDAR	25 m, 0.225°, Ethernet	Mapping and precise localization
2	Thermal camera	1024 pixels, $\pm 0.3^\circ\text{C}$ accuracy	Temperature monitoring and hotspot detection
3	Hikvision IP camera 2MP	IR 10 m	Night vision and video recording
4	Two-way communication camera	960p HD	Enables communication between operator and robot
5	Gas sensor	O ₂ , CO, CO ₂ , CH ₄ , H ₂ S	Toxic gas concentration monitoring and environmental safety
6	Smoke sensor	10–30 V DC, RS485	Early fire detection
7	LED lighting	24 W, IP66	Illumination for night or dark environments
8	Warning siren	12–24 VDC, 80 dB	Safety alert for surrounding personnel

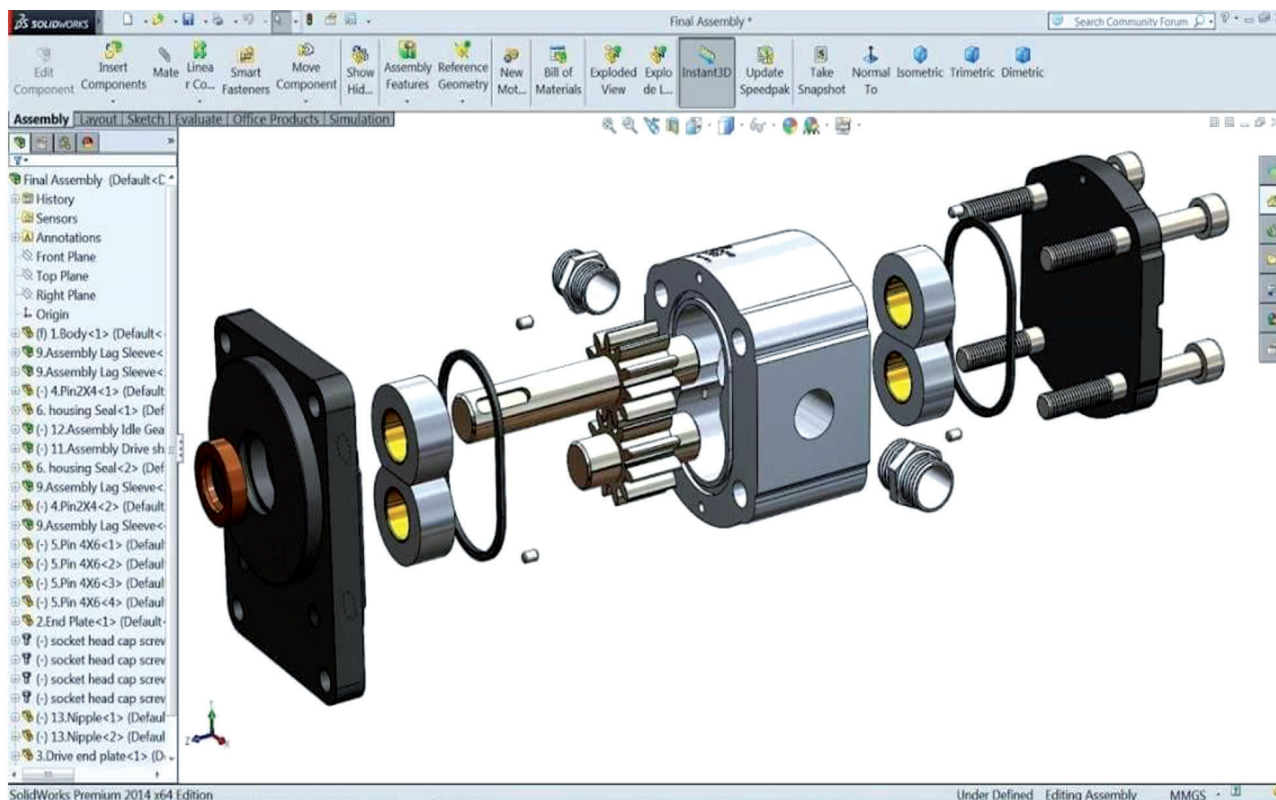
search and training. In addition, the SolidWorks Motion module supports dynamic analysis of track and suspension mechanisms, helping to evaluate early performance before proceeding with manufacturing [21–23].

PROPOSED ROBOT MODEL

The figure 2 demonstrates SolidWorks software interface with a 3D simulation module.

CALCULATION AND SELECTION OF BASIC PARAMETERS

Kinematic equation. RoSafe robot can be described as including: 2 main tracks (left - right) responsible for forward, backward and rotational movements; 4 auxiliary tracks (2 front - 2 rear) can rotate around the joint, helping to climb slopes or overcome obstacles; The main body is the block that mounts the motor, controller, sensors and load-bearing frame.

**Fig. 2.** SolidWorks software interface with 3D simulation module**Рис. 2.** Программный интерфейс SolidWorks с модулем 3D-моделирования

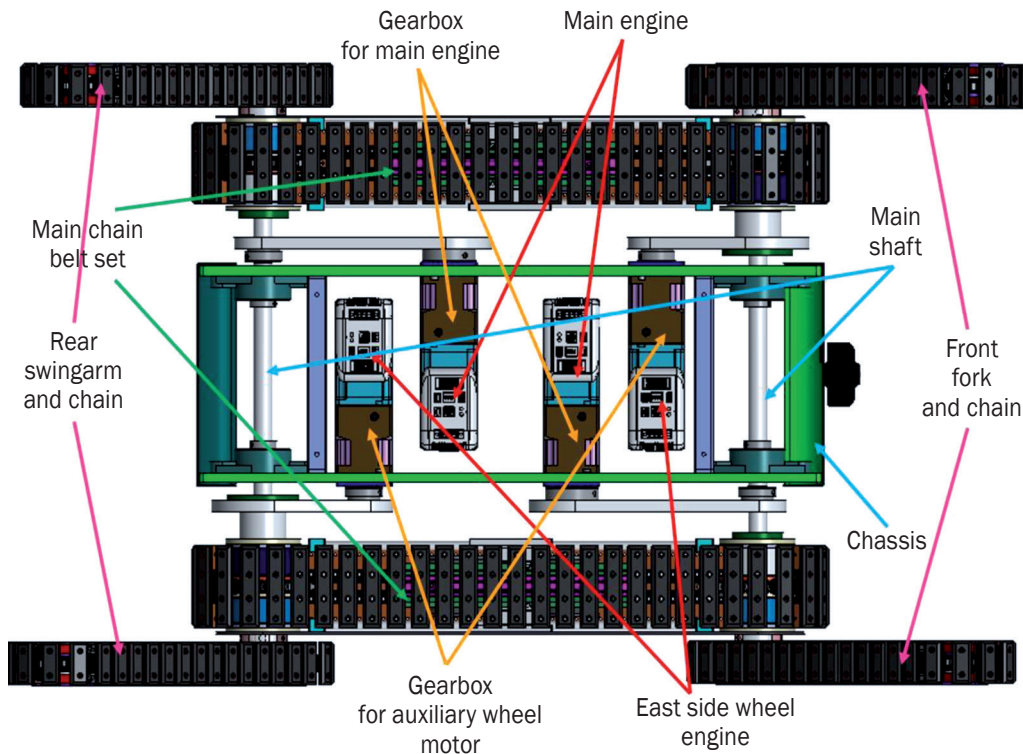


Рис. 3. Описание распределения механических и электрических систем робота RoSafe

Let us first consider the robot as a differential-drive tracked robot, ignoring the independent motion of the auxiliary forks. Where r_l and r_r are the radii of the left and right crawlers, respectively; L is the distance between the two wheels, $u(t)$ and $w(t)$ are the linear and angular velocity of the robot, respectively. The kinematic equation of the robot is as follows [23]:

$$\begin{bmatrix} \dot{x}(t) \\ \dot{y}(t) \\ \dot{\phi}(t) \end{bmatrix} = \begin{bmatrix} \cos(\varphi(t)) & 0 \\ \sin(\varphi(t)) & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v(t) \\ w(t) \end{bmatrix}.$$

Analysis of the force acting when climbing stairs. The case considered for calculation is when the robot moves up the stairs with the largest incline angle. This is the most severe operating condition, requiring the motor to generate the largest traction force. The input parameters for the analysis problem are determined as follows:

- estimated total mass of the robot: $M_r = 130$ (kg);
- maximum slope angle: $\alpha = 45^\circ$;
- rolling friction coefficient: For rubber chains moving on surfaces such as concrete, bricks and stones, the rolling friction coefficient: $k_f = 0.15$;

- gravitational acceleration: $g \approx 9.81 \text{ m/s}^2$.

Fig. 4 illustrates the diagram of the analysis of the external forces acting on the robot when it is moving up the stairs. Ignoring the air resistance caused by the robot moving at low speed, the main forces include:

Gravity (P): Is the total weight of the robot, has a vertical direction and is calculated by the formula:

Traction force (F_r): Is the total force that the transmission system must create at the point of contact between the chain and the slope so that the robot can move up.

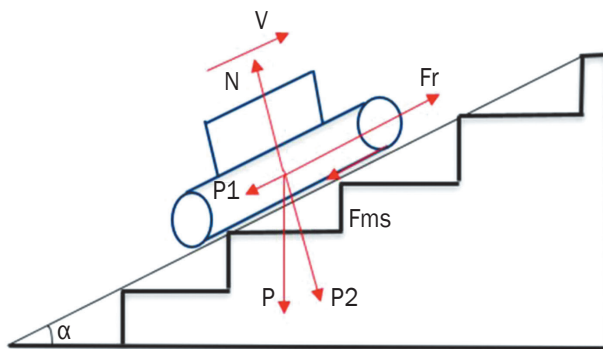


Fig. 4. Diagram of external forces acting on the robot when moving up a steep staircase

Рис. 4. Схема внешних сил, действующих на робота при подъеме по крутой лестнице

Normal reaction force (N): Is the force that the slope acts perpendicular to the robot.

Rolling friction force (F_{ms}): Is the resistance force generated by the deformation of the chain and the surface, always opposite to the direction of movement.

NUMERICAL SIMULATION RESULTS PROPOSED ROBOT MODEL ROSAFE

The figures 5–12 show the results of numerical simulation of the proposed RoSafe robot model.

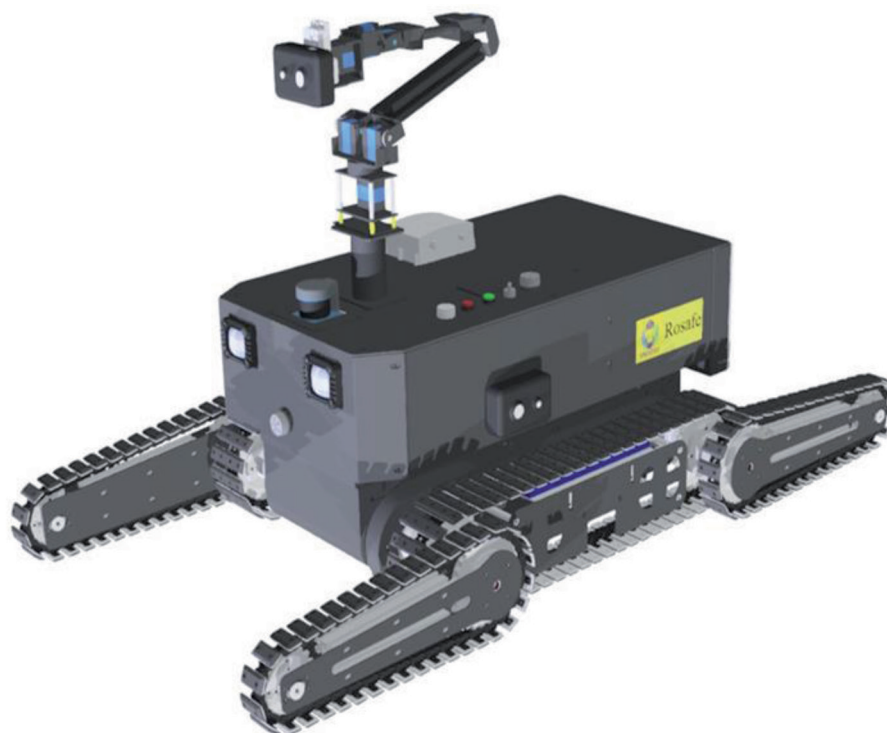


Fig. 5. Completed design of 3D model of RoSafe robot

Рис. 5. Завершенный дизайн 3D-модели робота RoSafe

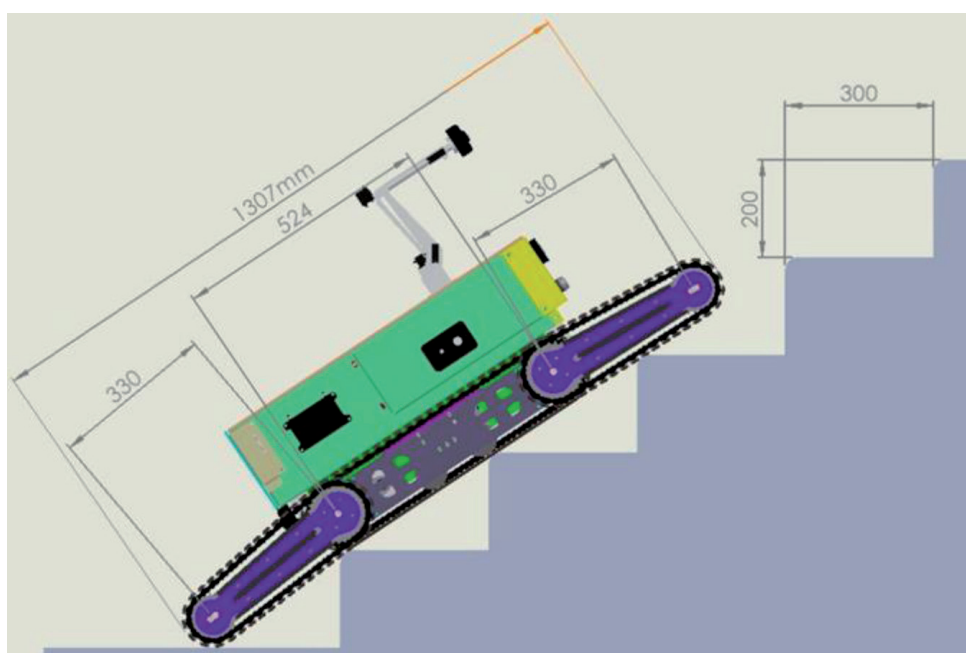


Fig. 6. Simulation with the case of a robot climbing stairs with a maximum step height of 200 mm

Рис. 6. Моделирование на примере робота, поднимающегося по лестнице с максимальной высотой ступени 200 мм

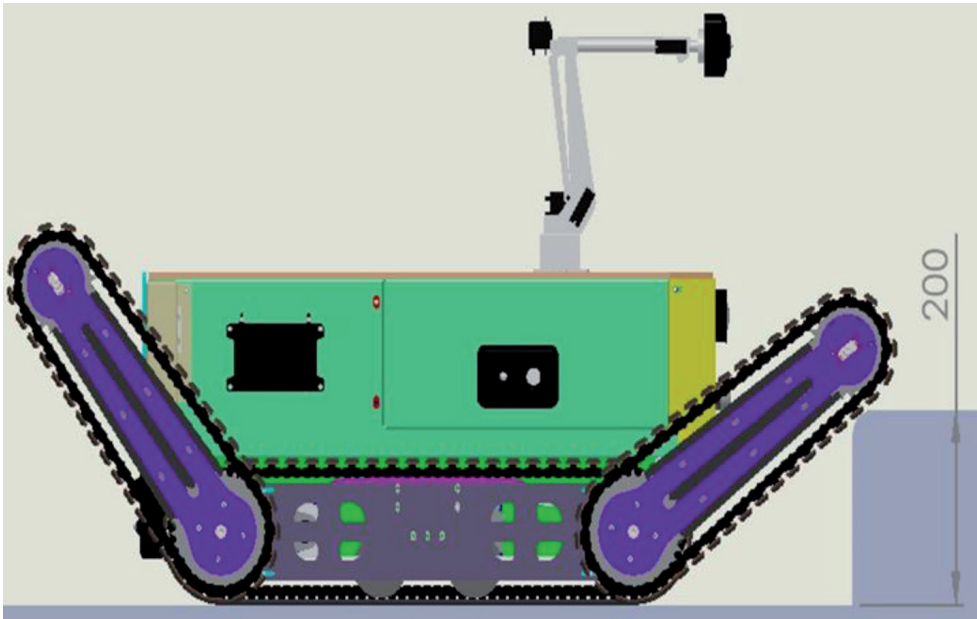


Fig. 7. Simulation with vertical wall climbing robot case, rubble piles with maximum height of 200 mm
Рис. 7. Моделирование с использованием робота для вертикального подъема по стене, насыпи из щебня максимальной высотой 200 мм

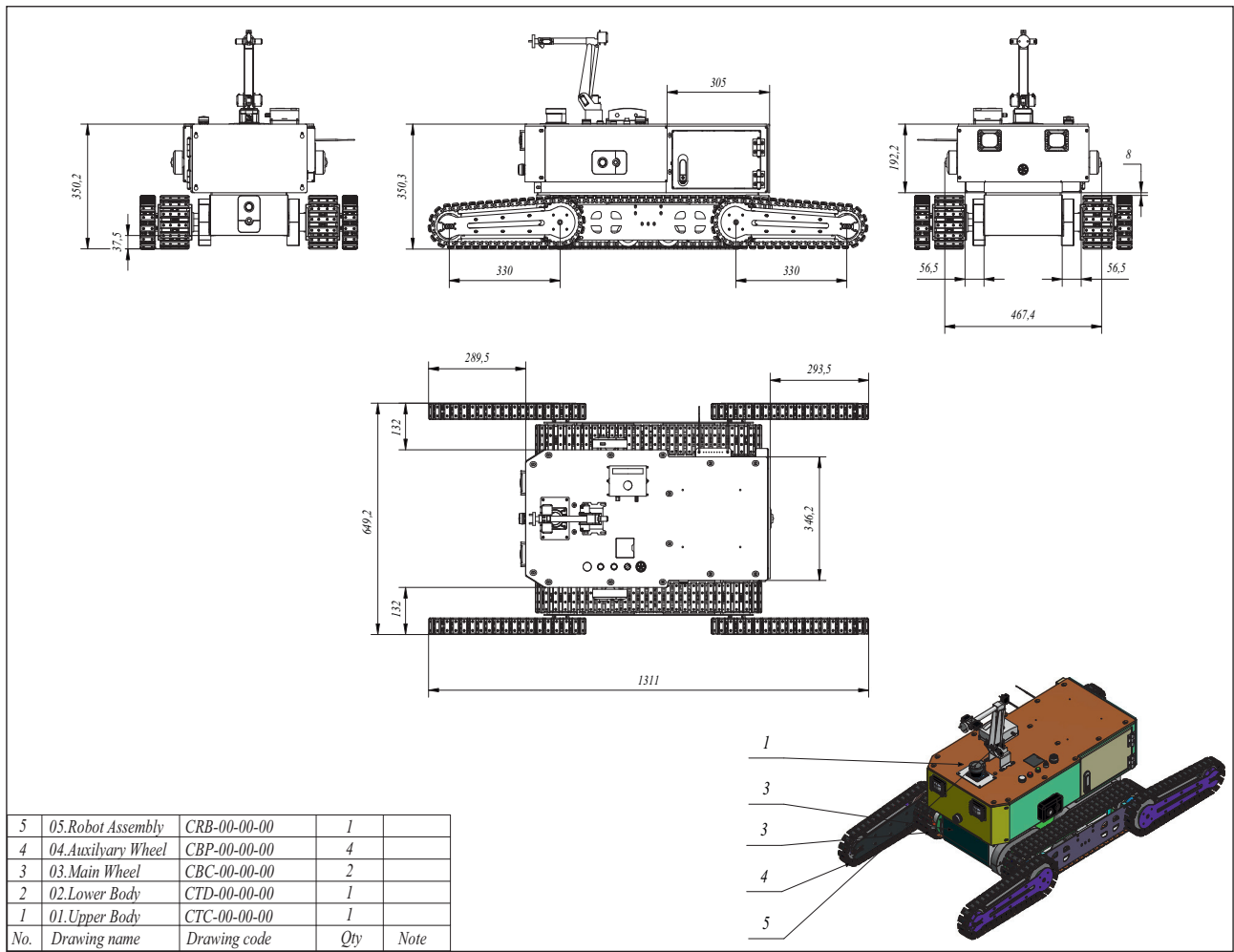


Fig. 8. Overall detailed drawing of the RoSafe robot model
Рис. 8. Общий детальный чертеж модели робота RoSafe

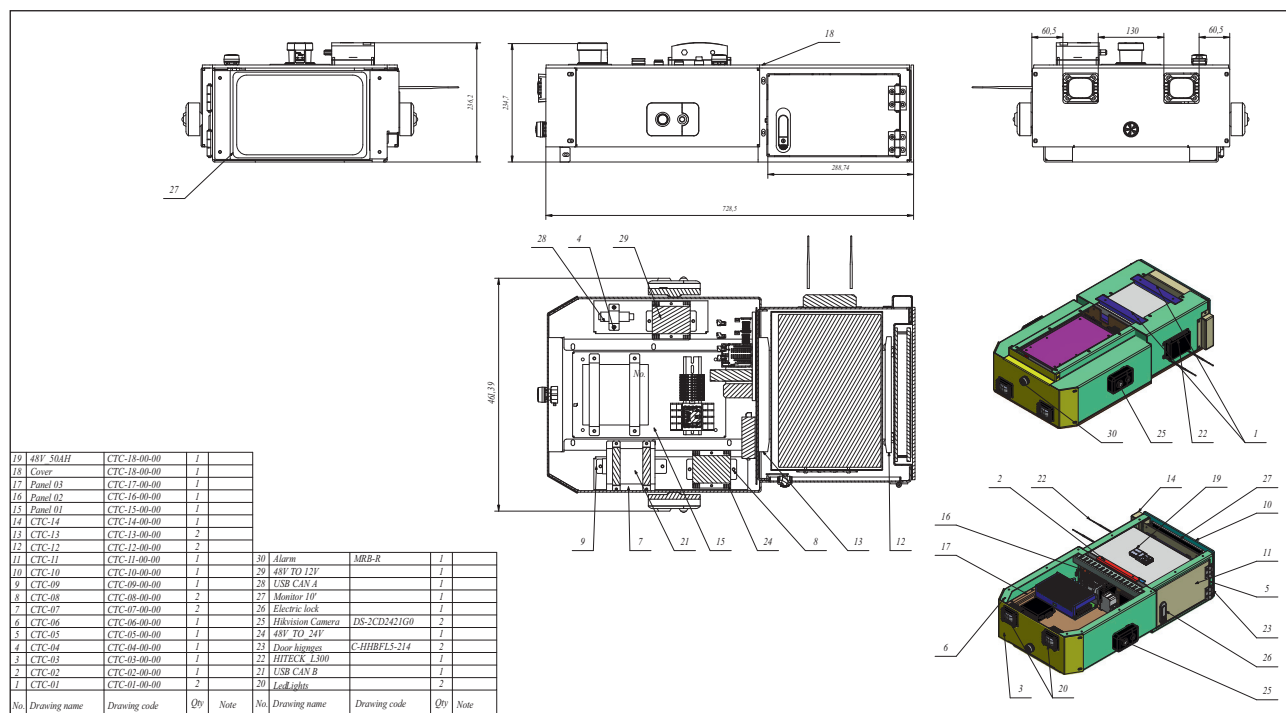


Fig. 9. Design drawing and simulation of the lower body assembly of the RoSafe robot

Рис. 9. Конструктивный чертеж и моделирование нижней части корпуса робота RoSafe

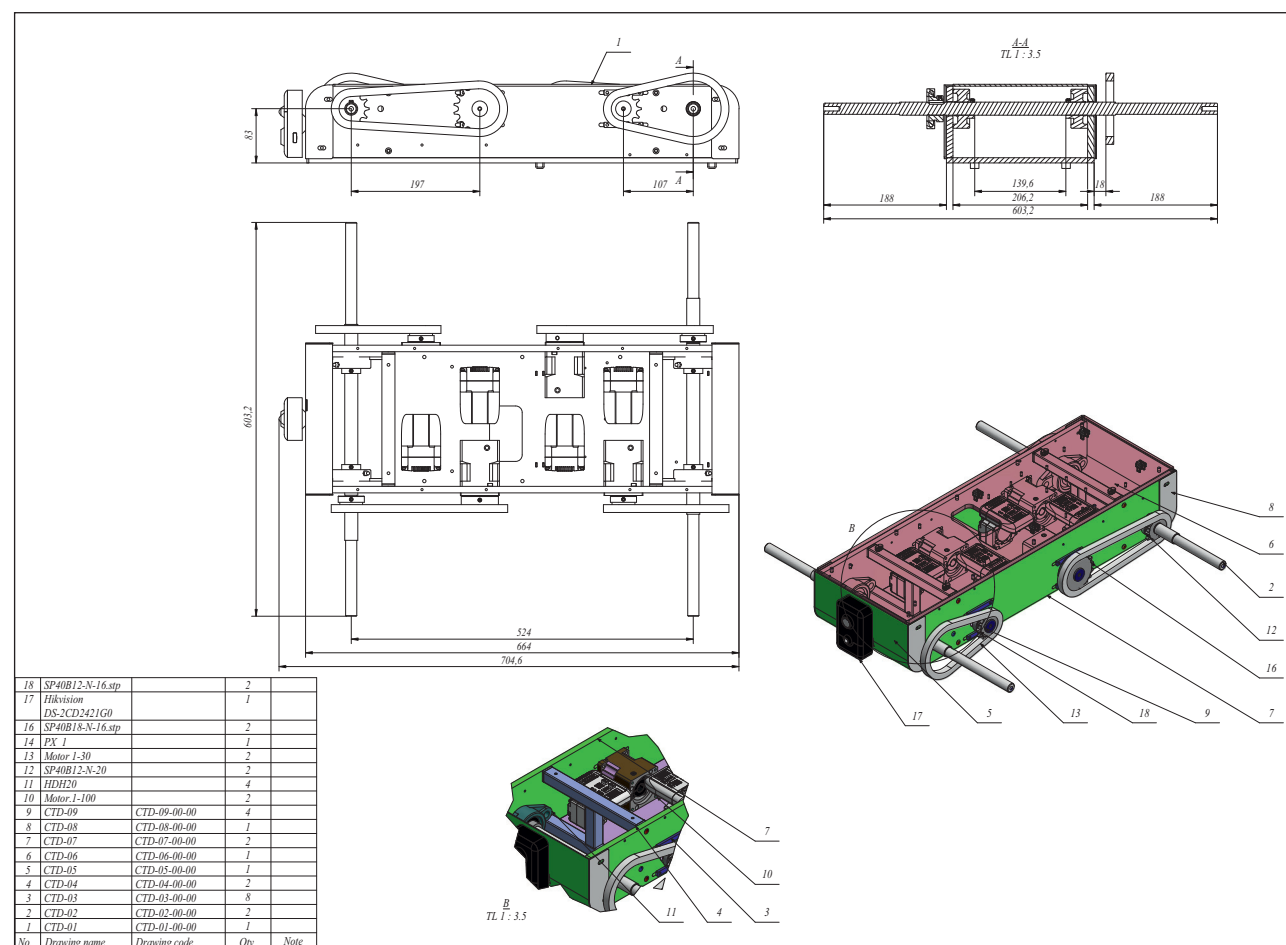


Fig. 10. Design drawing and simulation of the upper body assembly of the RoSafe robot

Рис. 10. Конструктивный чертеж и моделирование верхней части корпуса робота RoSafe

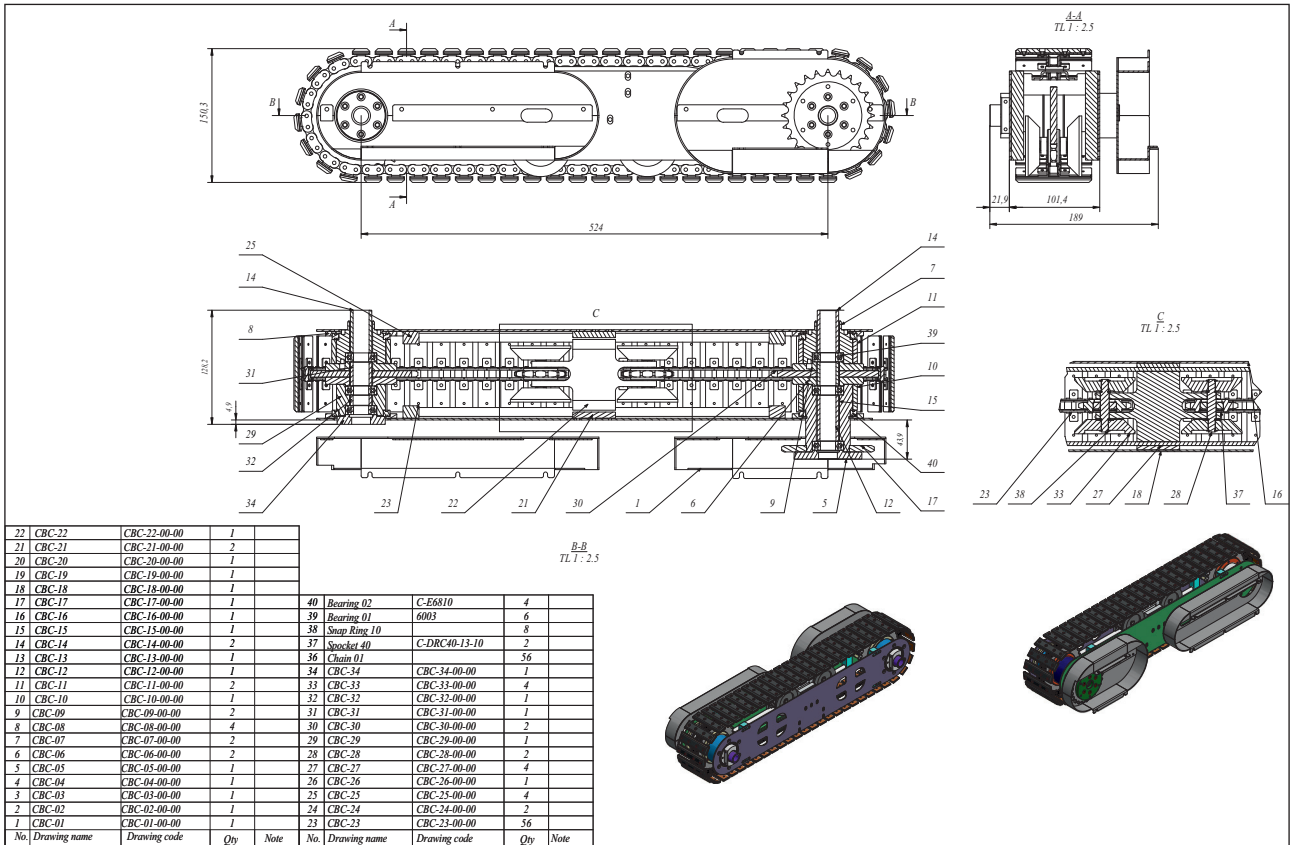


Fig. 11. Design drawing and simulation of the main track assembly of the RoSafe robot
 Рис. 11. Конструктивный чертёж и моделирование узла основной гусеницы робота RoSafe

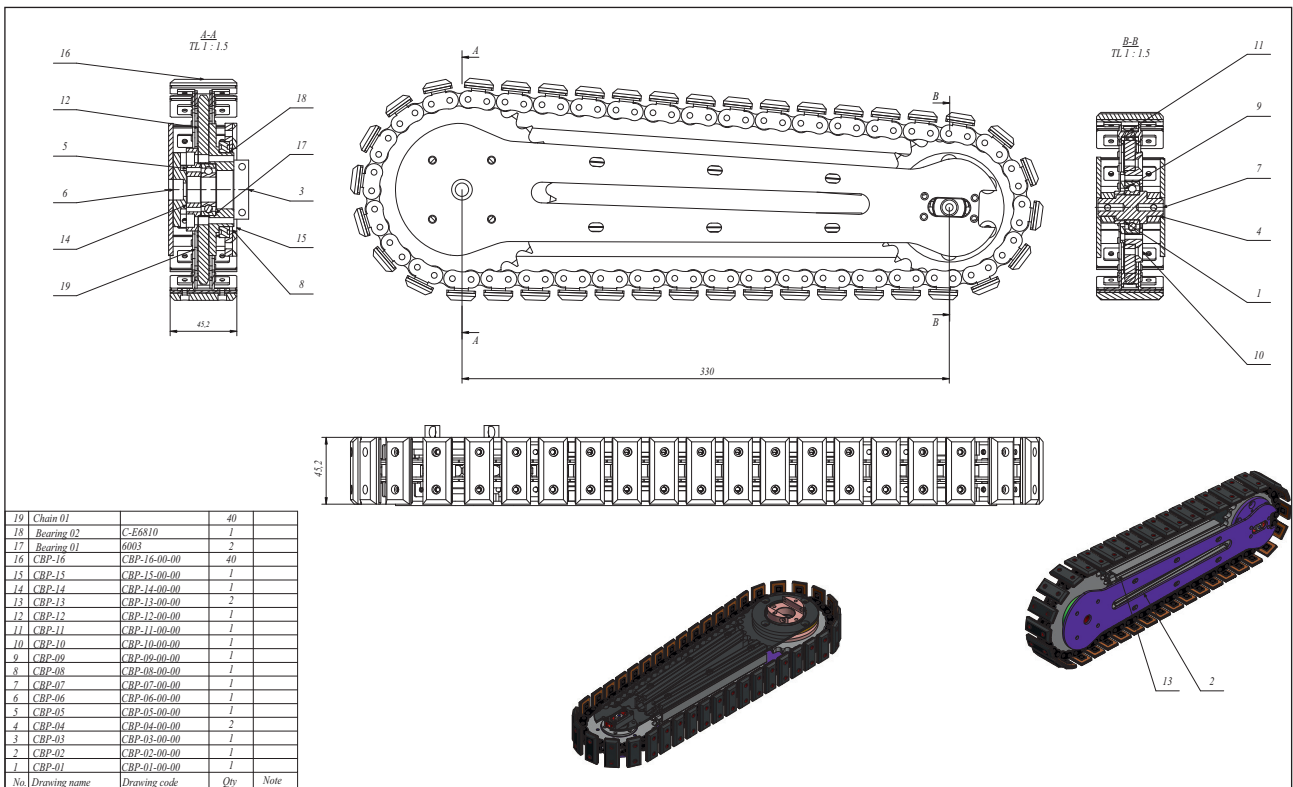


Fig. 12. Design drawing and simulation of the auxiliary track assembly of the RoSafe robot
 Рис. 12. Конструктивный чертёж и моделирование вспомогательного гусеничного узла робота RoSafe

Above, we presented a study on developing a mobile robot model to support workers in high-risk environments. And now, let's derive some conclusions.

CONCLUSION

In this article, the authors analyzed the urgency of applying robots to support workers working in potentially high-risk working environments, thereby researching, proposing and designing a complete RoSafe robot model, and at the same time proposing a comprehensive set of accompanying equipment and components to fully meet the requirements set for robots. The proposed robot model can perform tasks such as:

- moving in narrow spaces of factories, areas with limited access when moving, uneven rubble areas, climbing stairs of buildings;
- the robot performs the task of automatically sending out fire, chemical, and gas warn-

ings through equipped sensors when parameters exceed safety thresholds;

- the robot directly communicates with humans through wireless control, automatically scans the scene map via Lidar to the control center, and is also equipped with a heat sensor to detect and monitor humans.

One of the highlights of this proposal is the integration of a long-reaching arm on the robot to increase the optimization of the robot's operating range in observation and monitoring operations, and is also the basis for the design team to boldly improve the algorithm, build a controller when the robot performs many different tasks at the same time. The proposed RoSafe robot model was calculated, scientifically designed, verified and simulated on SolidWorks software, which is considered an important basis for continuing to complete manufacturing in the next stage.

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