An Approach to Developing an Optimal Model of the Mobile Platform of a Collaborative Robot

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***Abstract*— The article presents a methodology for selecting a drive system for a mobile platform of a collaborative mobile robot, taking into account the requirements for it. Optimization of the drive system and its functional capabilities, in accordance with the overall set of criteria, will ensure excellent stability, maneuverability, and energy efficiency of the cobot. The possible mechanisms for driving the platform are examined and an analysis is made of the situations in which they can be implemented, depending on the application of the collaborative mobile robot.** **Keywords—Service Robot, mobile platform, Cobot.**

INTRODUCTION

The rapid advancement of collaborative robots (cobots) has created new opportunities for their integration into dynamic and unstructured environments, where mobility, adaptability and human–robot interaction are becoming critical requirements. Unlike traditional industrial robots, which operate in strictly controlled settings, mobile cobots must navigate complex terrains, share workspaces with humans, and perform a diverse range of tasks with high precision and safety. These emerging conditions demand the development of optimized mobile platforms [1], [3], [7] capable of supporting advanced perception, navigation and interaction functionalities.

Achieving such optimization requires a systematic approach that integrates mechanical design, sensor configuration, motion control, energy management, and environmental constraints into a unified model. The mobile platform becomes the foundation upon which the robot’s cognitive and operational capabilities are built. Therefore, defining an optimal model is essential not only for improving mobility performance, but also for enabling intelligent behaviour, reliable operation, and effective collaboration with human operators.

This report presents an approach for developing an optimal model of the mobile platform of a collaborative robot. The methodology includes the analysis of various mobility mechanisms, the evaluation of sensory and energy subsystems, and the formulation of a structured framework for design optimization. The aim is to achieve a balanced solution that maximizes maneuverability, stability, energy efficiency, and environmental adaptability, while meeting the specific functional requirements of collaborative applications.

Through this approach, the study contributes to the broader effort of enhancing the autonomy, safety and functional versatility of next-generation mobile cobots, enabling their deployment across industrial, service, medical, and field environments.

I. FUNCTIONAL CAPABILITIES OF THE MOBILE PLATFORM

Mobility and navigation

Drive: The platform is equipped with four wheels (or alternatively with omnidirectional wheels/track modules), ensuring movement in all directions.

Navigation: Uses Lidar, IMU, ultrasonic/infrared sensors, and cameras for mapping the environment (SLAM) and autonomous movement.

Automatic obstacle avoidance: Analyzes the environment in real time and changes the trajectory to avoid collisions. Precise positioning: GPS or visual localization to determine the position indoors or outdoors.

II. METHODOLOGY

The proposed approach for developing an optimal model (Fig.1) of the mobile platform of a collaborative robot [2], [4] follows a structured methodology that integrates mechanical design, sensory system optimization, mobility analysis, and energy management.

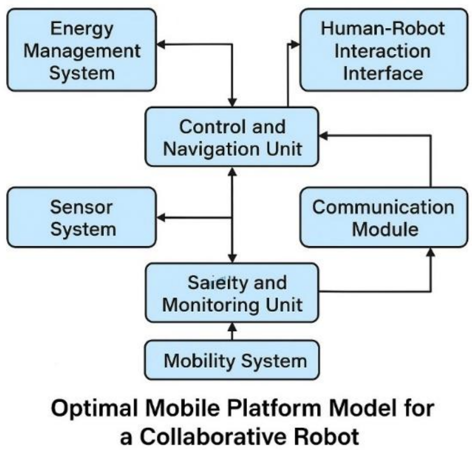

Fig.1 The mobile system.

The methodology is organized into several key stages, each addressing critical aspects of performance, safety, and operational efficiency.

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1. Requirements Definition

The process begins with identifying the functional, operational, and environmental requirements of the collaborative robot. These include:

- ✓ intended tasks and interaction scenarios,
- ✓ required load capacity and workspace,
- ✓ expected terrain conditions and mobility constraints,
- ✓ safety standards for human–robot interaction,
- ✓ endurance, autonomy, and energy efficiency criteria.

A detailed requirements matrix is formulated to guide subsequent design decisions.

2. Selection and Evaluation of Mobility Mechanisms

Several mobility configurations are analysed to determine the most suitable mechanism for the application. These may include:

- ✓ Mecanum wheels for omnidirectional motion,
- ✓ differential drive systems for simplified control,
- ✓ Ackermann steering for higher-speed maneuvering,
- ✓ tracked or triangular chain-track modules for off-road capability.

Each mobility type is assessed using performance indicators such as maneuverability, obstacle negotiation, stability, traction, and energy consumption. Simulation models or empirical tests support the comparative evaluation.

3. Modeling of Mechanical Structure

A geometric and dynamic model of the mobile platform is developed, incorporating:

- ✓ chassis geometry and center of mass estimation,
- ✓ suspension or stabilization systems (if applicable),
- ✓ kinematic and dynamic equations of motion,
- ✓ load distribution and structural rigidity considerations.

This model enables verification of stability margins, turning behaviour, and motion smoothness under different operating conditions.

4. Sensor System Integration

The next step focuses on designing and integrating the sensory subsystem responsible for perception and navigation. The methodology includes:

- ✓ selection of appropriate sensors (IMU, LiDAR, encoders, camera modules, ultrasonic sensors, etc.),
- ✓ definition of sensor placement for optimal field of view and minimal interference,
- ✓ calibration procedures for accurate data acquisition,
- ✓ fusion of sensory information to support localization, mapping, and obstacle avoidance.

Sensor performance is evaluated through controlled tests or simulation data.

5. Energy Subsystem Design and Optimization

To ensure continuous operation, the energy subsystem is modelled and optimized. The process includes:

- ✓ evaluation of power consumption of motors, electronics, and sensors,
- ✓ selection of power sources (Li-ion battery pack, supercapacitors, hybrid fuel cell systems),
- ✓ development of an energy management strategy to balance peak loads, regenerative braking, and continuous supply,
- ✓ estimation of autonomy based on operating profiles.

This stage integrates numerical analyses to optimize energy density and operational duration.

6. System-Level Integration and Functional Architecture

A unified functional architecture is created to connect mobility, perception, control, and energy modules. This includes:

- ✓ development of a block diagram representing data and control flows,
- ✓ definition of communication protocols and subsystem interfaces,
- ✓ integration of motion control algorithms with sensory inputs,
- ✓ implementation of safety mechanisms for human–robot interaction.

The full system model ensures seamless cooperation between hardware and software components.

7. Simulation, Verification, and Optimization

- ✓ The integrated model is tested through:
- ✓ physics-based simulations,
- ✓ kinematic/dynamic testing,
- ✓ sensor simulation scenarios,
- ✓ energy profile validation.

Optimization algorithms (multi-criteria optimization, Pareto analysis, or heuristic methods) are applied to refine the design based on predefined criteria such as maneuverability, stability, energy efficiency, and operational robustness.

8. Prototype Development and Experimental Validation

A prototype of the mobile platform is constructed to validate the theoretical model. Experimental tests include:

- ✓ motion and navigation trials,
- ✓ sensor accuracy and robustness evaluation,
- ✓ energy consumption and autonomy measurements,
- ✓ performance assessment under realistic collaborative scenarios.

Collected data is compared to simulation results to refine the final model.

III. The Approach For Optimizing The Robot Structure

The intelligent mobile system integrates perception, control, and motor capabilities to enable autonomous and adaptive operation of a mobile platform. The sensor subsystem collects environmental data, which is processed by AI control (Fig.2), perception, and localization modules to recognize objects and spatial structures [6].

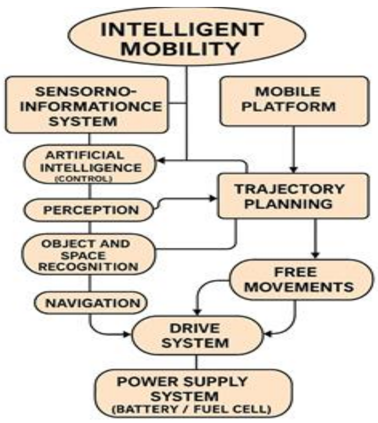

Fig.2 The intelligent mobile system.

The system enables autonomous, safe, and adaptive mobility—it can orient itself, plan, avoid obstacles, and perform tasks such as docking and navigation without human intervention.

The approach to optimizing the robot structure includes the following steps (Fig.3) :

1. Defining the objective function: This can be a combination of parameters such as the scope of the workspace, the length of the manipulator, the constraints of the motors, etc. The

goal is to create an objective function that needs to be optimized.
2. Defining the constraints: This includes the constraints on the dimensions of the robot, the workspace, the maximum and minimum lengths of each part of the manipulator, and other constraints that may affect the design of the robot.
3. Using optimization methods: In order to find the optimal values of the parameters of the robot structure, various optimization methods can be used, such as genetic algorithms, simulated cooling, gradient methods, etc.
4. Design and analysis of the results: Once the optimal parameter values are obtained, a detailed design of the robot structure can be carried out, and then the results of simulations or experiments can be analyzed.

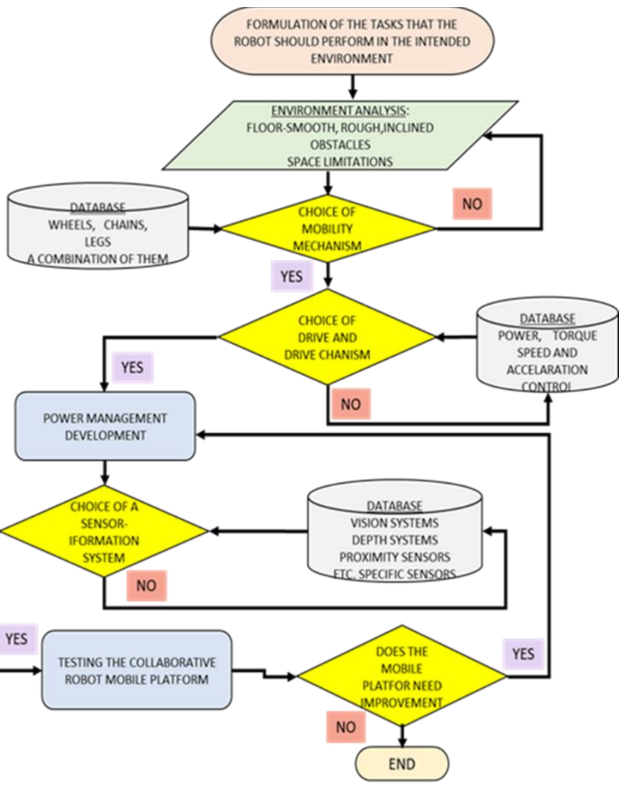

Fig.3 Block diagram of an approach for developing an optimal model of a mobile platform for a cobot.

This approach can help create robots with better performance and efficiency in various applications, such as healthcare, education, etc. Using this method and upgrading it by using parametric identification and calibration of a robot manipulation system leads to the synthesis of a model operator by studying the service coefficient.

III. Differential Wheeled Mobility

Differential wheeled locomotion is among the most widely adopted mobility solutions in service, industrial, and medical robotics due to its high mechanical efficiency, simplicity, and straightforward control structure. Wheeled platforms are especially suitable for structured indoor environments where low rolling resistance and high locomotion speed offer substantial operational advantages.

A. Advantages of Wheeled Locomotion

1) High Energy Efficiency

Wheels exhibit minimal rolling resistance, resulting in reduced energy consumption, lower heat generation in actuators, and extended operational autonomy. This makes wheeled platforms well-suited for applications requiring long-duration missions or continuous mobility.

2) High Maximum Speed

Compared to tracked and legged systems, wheeled robots can achieve significantly higher translational velocities. This characteristic is valuable in logistics, fast indoor delivery, and surveillance applications that require rapid and efficient point-to-point movement.

Fig.4 3D image of a differential wheel variant Mobility.

3) Mechanical Simplicity

Wheeled platforms feature a simple mechanical architecture with few moving components. They lack high-stress joints and complex suspension mechanisms, typically requiring only motors, gearboxes, and wheel assemblies. As a result, they are easy to manufacture, maintain, and scale.

4) Simplified Control and Kinematics

Differential drive robots provide mathematically tractable kinematics. Two-wheel differential platforms, four-wheel variants, and robots employing Ackermann steering all enable predictable motion control with low computational requirements.

5) High Performance on Flat Surfaces

Wheeled systems operate optimally on smooth, hard terrain such as laboratory floors, concrete, tile, and industrial surfaces. This makes them ideal for most indoor service and medical environments.

6) Low Maintenance Requirements

Typical maintenance tasks—such as tire replacement, bearing lubrication, and gearbox servicing—are minimal compared to those of tracked or legged systems, reinforcing wheels as a cost-effective mobility choice.

B. Limitations of Wheeled Locomotion

1) Limited Obstacle-Crossing Capability

Wheeled robots encounter challenges when negotiating steps, curbs, rubble, or highly uneven terrain, restricting their applicability in disaster-response and off-road environments.

2) Reduced Off-Road Performance

Due to their small contact area, wheels provide less traction and are more prone to slippage on deformable surfaces such as soil, sand, and mud.

3) Performance Issues on Wet or Slippery Terrain

Slick or wet surfaces significantly reduce wheel traction. Specialized tire patterns or compliant rubber materials are required to mitigate this effect.

4) Limited Payload Capacity

Load distribution across discrete wheel contact points restricts the maximum payload capacity of small to mid-sized wheeled robots, when compared to tracked platforms.

5) Poor Mobility on Soft Terrain

Soft substrates such as grass, snow, mud, and sand may cause wheel sinkage and reduced stability, negatively affecting mobility and control accuracy.

C. Application Domains of Differential Wheeled Robots

1) Laboratory and Educational Robotics

Low cost, intuitive control, and inherent safety make wheeled platforms highly suitable for research, prototyping, and STEM education.

2) Industrial Logistics and Warehousing

Automated Guided Vehicles (AGVs) and Autonomous Mobile Robots (AMRs) commonly employ wheels to enable reliable operation in large industrial facilities with smooth floors.

3) Medical and Service Robotics

Wheeled platforms are frequently used for autonomous delivery of medical supplies, logistics support in clinical environments, and service tasks in hospitals and laboratories.

4) Inspection and Security

Wheeled systems support long-duration patrols, infrastructure surveillance, and indoor/outdoor monitoring tasks where low energy consumption is advantageous.

5) Domestic and Office Robotics

Robotic vacuum cleaners, indoor delivery robots, and office service robots predominantly rely on wheels due to low noise, simplicity, and smooth indoor terrain.

6) Agricultural Robotics

Although less suitable for highly uneven terrain, wheeled robots can be deployed for precision farming, crop monitoring, and spraying on firm ground or moderately irregular surfaces.

D. Summary

Differential wheeled mobility provides a highly efficient and mechanically simple solution for structured environments. While limited in obstacle negotiation and off-road performance, wheeled platforms remain the dominant choice for logistics, industrial automation, medical service robotics, and indoor autonomous systems due to their cost-effectiveness, high speed, and low maintenance requirements.

Fig. 4 3D image of a 3D Omni/Mecanum

Two other alternative options for driving the mobile platform of a collaborative service robot are Omni wheels (Fig.4) [5], [8], and triangular chain modules. The Mecanum drive provides holonomic motion in the plane, enabling independent control of the longitudinal and lateral velocities, as well as of the yaw rate around the vertical axis. As a result, the platform can perform omnidirectional motions and achieve precise docking in confined and structured environments such as the interior of a field medical unit or a hospital corridor.

Triangular chain-track modules (Fig.5), in turn, represent a more complex mechanical structure, in which each running unit consists of three sprockets connected by a continuous track. The triangular geometry and the placement of the modules with respect to the robot body allow the instantaneous centre of rotation to be shifted to the contact point between the track and the obstacle, thus enabling the platform to roll over curbs, rocks and stairs. This configuration offers superior terrain-traversal capability and stability on soft, rough or debris-covered surfaces, which is critical for search-and-rescue operations and field medical deployments in harsh outdoor conditions.

Fig. 5 3D image of a mechanism for mobility with triangular sprockets for a cobot.

The comparative analysis indicates that the Mecanum drive is more suitable when manoeuvrability and high-precision positioning in constrained indoor spaces are the primary design criteria, whereas the triangular chain-track solution is preferable when off-road mobility and robustness are dominant requirements. In the following sections, the Mecanum configuration is therefore adopted as the baseline mobility system for the medical service robot, while the chain-track variant is treated as an alternative option for extreme-terrain scenarios.

Table 1.

Comparison of Mobility Systems for Mobile Robots

Criteria	Standard Wheels	Mecanum Wheels	Tracked (Chain-Track) Drive
Mobility DOF	2 (V_x, ω)	3 (V_x, V_y, ω)	2 (V_x, ω)
Energy Efficiency	★★★★★	★★★★	★★★
Speed	★★★★★	★★★★★	★★★
Maneuverability in Tight Spaces	★★★	★★★★	★★★
Sideways (Lateral) Motion	X	✓	★★★★★
Terrain Adaptability	★★	★	★★★★★
Obstacle Crossing	Poor	Poor	Excellent
Slip Resistance	Moderate	Low	Very good
Control Complexity	Low	Moderate	Moderate
Maintenance Cost	Low	Moderate	High
Production Cost	Indoor, industrial floors	Indoor, logistics	Off-road, rescue, military

Where each type is most suitable

✓ Standard wheels - Logistics, Hospitals, Laboratories, Autonomous deliveries, Industrial AGV/AMR

✓ Mecanum wheels - narrow spaces, service robots, warehouses with limited aisles, robot manipulators that need to move sideways

✓ Track drive - military applications, rescue operations, uneven and rough terrain, inspection of external infrastructure.

Comparison of triangular chain modules, classic chain drive and extended chain drive

The triangular chain module design is implemented by a chain that moves around three gears forming a triangular geometry. The front gear is raised, serving as an element for overcoming obstacles. The central gear often acts as a drive wheel.

Fig.6 3D image of a variant of a mobility mechanism with a chain for a cobot.

Fig. 7 3D image of a variant of a mobility mechanism with extended chain for a cobot.

The advantages of this design are that it has the best ability to overcome obstacles - stairs, rocks, curbs, as well as the ability of the moment center of rotation (ICR) at the point of contact of the robot to "overcome" obstacles instead of crashing into them.

The triangular chain module design is ideal for rescue missions and very uneven terrain and is very stable on slopes. Torsion suspension can be included for improved dynamics.

Disadvantages of triangular track modules are more complex mechanics (three sprockets, longer chain), higher production and maintenance costs and a smaller contact area with the ground, which leads to less traction in mud/sand compared to long chains.

Applications: Search and rescue robots, robotic platforms for field/defense operations, work in collapsed buildings, reconnaissance and inspection

Classic track drives (fig.6 compact standard tracks) are characterized by a construction of two parallel tracks, each of which is supported by several rollers.

Their advantages are that they have good mobility on any terrain on uneven terrain, simpler and more affordable than triangular track modules. They are compact, which makes them with good maneuverability in confined spaces. A special quality is the balanced performance between speed, traction and stability.

The disadvantages of the classic track drive are the lower performance in overcoming obstacles compared to triangular tracks. It can "jump" when climbing sharp edges or curbs, which makes them less stable on very steep slopes.

They find applications in industrial service robots, telepresence or manipulation robots, small unmanned vehicles (UGVs), medical mobile platforms.

Extended (long-track) drives (fig.7 - long, multi-roller track system) are characterized by a structure covering almost the entire length of the chassis, multiple support rollers, which results in a very large contact area with the ground, as well as improved traction for soft or slippery terrain.

Advantages of the long-track drive are the best traction among the three systems (mud, snow, sand), high stability for transporting heavy payloads, low vibrations on rocky terrain due to the many support rollers. This makes them an excellent choice for heavy, field medical robotic systems.

Disadvantages include a large contact area, which results in lower top speed. Higher power requirements during cornering, and increased weight and energy consumption.

Used in heavy field medical robots, logistics and transport UGVs, snow/mud platforms, high stability applications.

Comparison Table 2

Criterion	Triangular Tracks	Classic Tracks	Extended Tracks
Obstacle crossing	☆☆☆☆☆	☆☆☆	☆☆☆☆
Traction in mud/sand	☆☆☆☆	☆☆☆	☆☆☆☆☆
Slope stability	☆☆☆☆	☆☆☆	☆☆☆☆☆
Speed	☆☆☆	☆☆☆☆	☆☆
Maneuverability	☆☆☆	☆☆☆☆	☆☆
Manufacturing complexity	High	Medium	High
Maintenance	Medium	Low	High
Shock/mud resistance	Medium	High	Very High
Optimal terrain	Rubble, rescue	Indoors/medium terrain	Heavy off-road

From the analysis (Table 2), the following conclusion can be drawn:

✓ To overcome high obstacles, it is desirable to use triangular modules.

✓ Classic tracks are the optimal option for balanced mobility, speed and compactness.

✓ For maximum traction and stability in difficult terrain, extended systems with long tracks are the best choice.

Fig. 8 3D image of a variant of a mechanism for mobility with a combined chain, the first with triangular sprockets and the second with two wheels, for a cobot.

Considering a mixed (hybrid) wheel-in-chain drive type – a platform with two short chain modules, each consisting of several support wheels around which a rubber chain is stretched (Fig.8). This combines the characteristics of wheel and chain drives.

The hybrid variant shown is characterized by the fact that the tracks remain at the front (for better traction and overcoming obstacles), and at the back: only one large wheel, which helps stability and maneuverability. This is a variant (Fig. 9) between a tracked and wheeled robot - often used in platforms for uneven terrain.

The kinematic and structural idea of this hybrid variant is that on the side there are two independent track modules (left and right), with each module consisting of several wheels (rollers) that distribute the weight along the length of the track and can be driving or supporting.

Fig. 9 3D image of a hybrid (mixed) version of a mobility mechanism for a cobot.

Externally, the system behaves like a classic tracked robot (differential control: left/right track), but internally we have a wheeled chassis, which provides better load distribution, less local deformation of the track, more uniform overcoming of irregularities.

2. Advantages of mixed drive

✔ Lower ground pressure due to the large contact area of the track and the distribution of the weight over several support wheels, which leads to less sinking in soft terrain (mud, sand, snow) compared to wheel drive.

✔ Good cross-country ability and smooth movement, which is due to

the many support wheels smoothing out shocks, and hence less vibration of the platform and manipulator - important for medical and service tasks.

✔ Stability on slopes due to the length of the support base (the distance between the front and rear contact wheels) provides good longitudinal stability.

Low center of gravity → lower risk of overturning when moving on a slope.

✔ Mobility in difficult conditions is realized through the combination of "wheels + tracks" and is optimal for destroyed buildings, uneven terrain around field hospitals, mud and wet grass.

3. Disadvantages include:

✓ Higher complexity and cost - more wheels, bearings and axles → more maintenance components. The chain wears out and requires periodic tensioning and replacement.

✓ Higher energy consumption - the friction between the chain and the rollers is greater than that of a purely wheeled platform, which leads to higher energy consumption at the same speed.

✓ Lower maximum speed due to mass and friction, the maximum linear speed is usually lower than that of omni-wheels or standard wheels.

4. Such a mixed chain drive is very suitable for field medical and rescue robots - reaching victims through rubble, mud, snow. Logistic tasks in difficult terrain - transporting consumables, oxygen cylinders, hydrogen cylinders, etc. around a field hospital.

In conclusion, the mixed wheel plus chain drive in the shown configuration gives a more even load distribution on the support wheels and provides a stable and reliable mobile platform for a collaborative robot.

III. LEGGED MOBILITY CONCEPT

Legged mobility represents a fundamentally different approach to ground locomotion compared to wheeled and tracked platforms. Instead of relying on continuous surface contact, legged systems generate motion through discrete footholds, enabling a robot to traverse complex, discontinuous, or highly unstructured environments. In the context of collaborative service robotics and field medical deployment, legged locomotion provides a significant strategic advantage by allowing the robot to operate effectively where conventional mobility mechanisms become ineffective.

A legged mobile platform (Fig.10) typically consists of multiple articulated limbs, each comprising several degrees of freedom (DoF) that enable lifting, swinging, placement, and load-bearing actions. The resulting kinematic structure allows the robot to dynamically adapt its posture and center of mass to maintain stability during locomotion. Depending on the gait pattern—tripod, quadrupedal crawl, trot, or dynamic bounding—the system may operate in statically stable or dynamically stable regimes. This versatility enables robust locomotion over rubble, debris, collapsed structures, steep inclines, and soft deformable terrain, all of which are common in disaster-response and field medical scenarios.

Compared to wheeled and tracked mobility, legged systems offer several critical advantages. First, individual foot placement allows precise selection of stable contact points, enabling traversal of obstacles that cannot be rolled over. Second, the ability to control body height, pitch, and roll allows the robot to maintain a stable operating platform for a mounted collaborative manipulator, even when the surrounding terrain is uneven. Third, legged locomotion reduces the need for large continuous contact areas, minimizing ground disturbance and allowing the robot to move through narrow passages, rubble voids, and staircases.

Fig.10 3D image of a legged mobility concept

However, these benefits come with significant engineering challenges. Legged platforms require sophisticated control architectures that integrate inverse kinematics, gait planning, whole-body control, and real-time balance stabilization. The energy consumption of legged systems is typically higher than that of wheeled or tracked robots due to the active lifting of limbs and the continuous torque demand of multi-joint actuators. Safety in human-robot interaction is also more complex, as the robot must ensure compliant behavior despite having many rapidly moving limbs.

In field medical contexts, the legged mobility concept is particularly promising. A quadrupedal collaborative robot can access confined or obstructed areas to deliver medical supplies, perform teleoperated manipulation, support patient assessment, or carry diagnostic sensors. The platform's ability to adapt posture enables stable manipulation even on irregular terrain, while its mobility allows deployment in environments that are inaccessible to conventional mobile medical robots. As a result, legged mobility forms a strong foundation for next-generation collaborative systems capable of assisting medical personnel under extreme operational conditions.

IV. COLLABORATIVE SERVICE ROBOT DESIGNED FOR PEDIATRIC HOSPITALS.

Based on an analysis of the activities of healthcare workers: doctors, nurses, laboratory technicians, physiotherapists, and orderlies, it is proposed to create a collaborative mobile robot that can perform some of the activities of hospital workers, thereby not only facilitating their work in processes that can be robotized, but also creating conditions for reducing the risk of infection among staff.

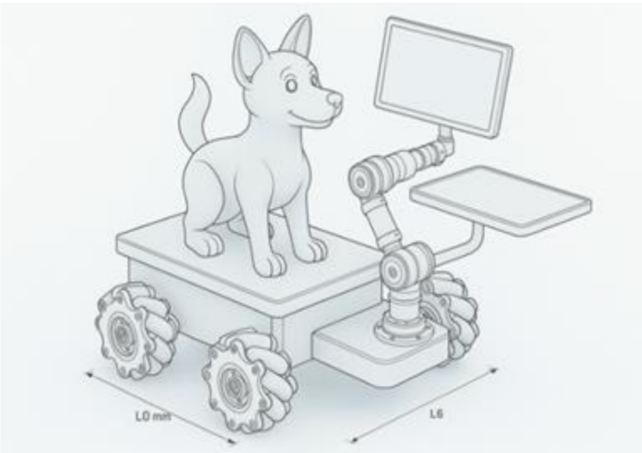

Fig.11 Collaborative service robot designed for pediatric hospitals.

A cobot model (Fig..11) has been proposed that can be implemented in pediatric clinics.
The model is a mobile platform with omni-wheels of a Collaborative Service Robot (Fig. 50). Its design resembles a children's toy and is expected to be well received by young patients. The mobile platform is built with four omnidirectional wheels, which provide high maneuverability in confined spaces, and the arm is a manipulator with a degree of redundancy allowing for increased manipulability. A tray is provided for picking up and handing over manipulated objects (medicines, cups, utensils, etc.) to ensure greater reliability and safe use of the cobot.

6. CONCLUSION

Any requirement for the robot's mobile platform ultimately boils down to imposing certain restrictions on the choice of drive system.
The optimal drive configuration will ensure excellent stability, manoeuvrability and energy efficiency.
The methodology presented is the basis for conducting research aimed at optimizing the selected drive system and its functional capabilities in accordance with the overall set of criteria.
The resulting assessment enables the collaborative robot to function reliably.
A well-chosen platform is a stable basis for its implementation in intelligent collaborative robotic systems.

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