TIJER || ISSN 2349-9249 || © January 2024, Volume 11, Issue 1 || www.tijer.org

Design of a customizable robotic platform for undulated terrain exploration

Bharath Kumar Dandu
Mitra Robotics
Bengaluru, India

Nithyaashree Gridharan
Dazarus
Bengaluru, India

P Anand Reddy
Dazarus
Bengaluru, India

***Abstract*— This paper proposes a novel customizable robotic platform that can be used in any terrain for several purposes. The design emphasizes adaptability, with the ability to switch between autonomous and manual control, making it suitable for applications in healthcare, military, and research sectors. The paper delves into the detailed design of the rover base, encompassing steering mechanisms, suspension systems, dynamic center of mass adjustment, and electrical, electronics, and control systems.**

The Robotic Avatar stands out with its structural efficiency, omnidirectional movement, and the capability to navigate varied terrains, including inclined surfaces of up to 45 degrees. The communication system integrates secure wireless protocols for remote control, while the computation system employs an industrial-grade embedded system, potentially interfacing with Robotics Operating System (ROS). The paper also elaborates on the robotic arm's selection, kinematics, actuation, material selection, and end-effector customization. The modular design allows for interchangeable end effectors, contributing to the platform's adaptability and multifunctional capabilities.

It is of prime importance to have such a platform at the frontier of these industries, so as to improve the efficiency, efficacy and safety.

Keywords—Robotic Platform, Robotic Arms, Dynamic Center of Mass, Control Systems, Healthcare

I. INTRODUCTION

The dawn of computing heralded an era of unparalleled computational prowess, with machines demonstrating an exceptional aptitude for executing repetitive tasks with unwavering accuracy. The emergence of robotics has since extended these capabilities into the tangible realm, marrying computational exactitude with physical precision. In this evolution, AI-augmented robots have emerged as a pinnacle, skillfully undertaking tasks once the sole domain of human dexterity and excelling in high-stress, high-risk environments.

The Robotic Avatar is a direct response to this technological advancement. Equipped with two robotic arms and a four-wheeled base, is engineered for specialized tasks like sample collection, intricate operations etc., in challenging conditions. Its design enables precise operation in environments where traditional robotics may falter. With the ability to switch between autonomous and manual control, it finds its niche in healthcare, military, and research sectors, adeptly handling complex operations where precision and adaptability are crucial and human safety is a concern.

Initial trade-offs had been performed with a quadruped and wheeled robot, from the research of Marco Hutter et al. [1] has shown that there are significant advantages to quadruped (ANYmal) with increased flexibility, but lacks on the payload capacity and efficiency, for a high number of controls needed.

Hence, the next process was to delve into the four-wheeled robot with some existing research done by C Cariou et al. [2] with important work done in its control systems for capabilities to operate on all terrain.

Figure 1 Robotic Avatar (Simulated Image)

II. METHODOLOGY

A. Design & Specifications

1) Design Aspects

Robotic Avatar is a composite of multiple components, each contributing to its total weight. An accurate estimation of this weight is crucial for designing the power and structural requirements. Given Components and Assumptions:

- Two robotic arms, each approximately 20 kg.
- Four 17-inch motorcycle (EV) wheels, 12 kg each.
- Three 2 kWh lithium-ion batteries, each 13 kg, for swappable functionality.
- Estimated weight of the base structure, assumed at 75 kg for required structural integrity

Figure 2 Robotic Avatar with peripherals (Simulated image)

- Calculations:

Total weight of robotic arms = 2 × 20 kg = 40 kg (1)

Total weight of wheels = 4 × 12 kg = 48 kg (2)

Total weight of batteries = 3 × 13 kg = 39 kg (3)

Estimated weight of the base ≈ 75 kg (4)

Total estimated weight = 40 kg + 48 kg + 39 kg + 75 kg = 202 kg (5)

2) *Power Requirement for Incline Movement*

Considering the Robotic Avatar's operation on inclined surfaces, we calculate the power requirements taking into account its total weight, the incline angle, and the traverse velocity. Given parameters:

- Self-weight of Robotic Avatar: 202 kg
- Incline angle: 45 degrees
- Traverse velocity: 2 m/s

P = W × g × v × sin(Incline angle) (6)

P = 202 kg × 9.81 m/s2 × 2 m/s × sin(45◦) (7)

P ≈ 202 kg × 9.81 m/s2 × 2 m/s × √ 2 2 (8)

P ≈ 2823.1 W or 2.8231 kW (9)
(continuous power requirement)

3) *Battery Capacity Estimation*

Adequate battery capacity is pivotal for ensuring the Robotic Avatar's operational endurance. Here, the capacity is calculated based on the desired operational time.
Desired operational time (T) = 2 hours

C = P × T/1000 (10)

C = 2.8231 kW × 2 h/1 (11)

C ≈ 5.6462 kWh (12)

4) *Wheel Motor Power Capacity*

Each wheel's motor power capacity is determined by the total power requirement divided by the number of wheels.

$$P_w = \frac{P}{\text{Number of wheels}} \qquad (13)$$

$$P_w = \frac{2.8231\ \text{kW}}{4} \qquad (14)$$

$P_w \approx 0.7058$ kW or 705.8 W per wheel (continuous power rating) (15)

Given the potential for peak power to be 2 to 3 times the continuous rating for intermittent operation:

Peak power per wheel ≈ 2 kW (16)

With these specifications, the Robotic Avatar is expected to function efficiently on a 45-degree incline, supported by a battery capacity of approximately 6 kWh and wheel motors capable of handling the necessary power requirements. This section outlines the essential design and engineering aspects of the Robotic Avatar, highlighting its structural dimensions, functional dynamics, and communication systems, which are crucial for its versatile operation across various environments and tasks.

5) *Structural Design & Modular Dimensions*

Figure 3: Size comparison with a human (Simulated image)

The Robotic Avatar is designed with a focus on structural efficiency and adaptability. It stands at an impressive height of approximately 2.1 meters (7 feet) when fully extended, which enhances its operational reach. The weight of the robot varies between 180 and 220 kg, depending on the materials and components used, allowing for a balance between durability and agility. The arms of the robot have a manipulator reach of about 850 mm and are capable of handling payloads up to 5 kg, enabling diverse operational capabilities.

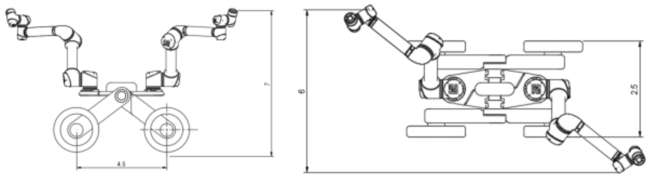

Figure 4: Side and Top View of the Robotic Avatar

6) *Functional Dynamics*

The Robotic Avatar incorporates advanced functional dynamics for enhanced versatility. Its holonomic base allows for omnidirectional movement, ensuring maneuverability in a variety of operational settings. It is capable of handling diverse terrains including flat, rocky, and inclined surfaces of up to 25 degrees. While the standard maximum speed is set at 2 m/s in laboratory conditions for safety, the design supports increased speeds up to 25 km/h, subject to further testing and development.

7) Computation & Communication

The computation and communication systems of the Robotic Avatar are central to its functionality, featuring an industrial-grade embedded system for local control. This setup potentially integrates with Robotics Operating System (ROS) for accurate task execution. Remote control capabilities are ensured via secure wireless protocols like WiFi or LTE/5G. The manipulators are controlled through protocols such as EtherCAT or CAN bus (as researched by Jung Yup-Kim et al. [3]), highlighting the system's precision and responsiveness in varied operational contexts.

B. Rover: The Robotic Avatar's Base

In this paper, the term 'Rover' refers to the robust base platform designed to support the operational functionalities of the Robotic Avatar's arms. The concept sketches provided serve as a visualization of our intentions, showcasing the potential functionality and design aesthetic of the Rover. While indicative of our innovative approach, these images represent a starting point; the final product is expected to evolve with larger arms and modular end effectors for a wide array of tasks. The Rover will be constructed with a focus on durability and versatility. It will feature robust wheels designed to withstand harsh terrain, and each wheel will be powered by an in-wheel hub motor, offering high torque capabilities of 8Nm per wheel. This design ensures that the Rover has the power and grip needed to navigate challenging environments.

1) Steering

The Robotic Avatar's rover base incorporates a comprehensive array of steering mechanisms, optimized for diverse operational needs. The design includes Differential Steering, suitable for a range of terrains with its reliable control through variable wheel speeds. Ackermann Steering, which optimizes turning radius and efficiency on more consistent surfaces. Skid-Steering, enabling pivot turns for heightened agility in confined spaces. Lastly, Articulated Steering provides superior stability and control, particularly effective on uneven terrains. Steering mechanisms as discussed by Rustamov et al. [4] are a critical decision that hinges on the rover's intended use case scenarios, encompassing factors like the complexity of the terrain and the desired level of maneuverability. For the initial prototype, differential and Ackermann steering mechanisms present an optimal combination of simplicity and precision, making them suitable for a wide array of operational conditions. As development progresses, the rover's design maintains the flexibility to incorporate more specialized steering systems to meet specific environmental challenges.

Figure 5 Robotic Avatar Base (Simulated Image)

2) Suspension

The suspension design of the Robotic Avatar is critical to its ability to navigate and operate across a multitude of terrains. Our design incorporates a blend of systems that offer distinct advantages:

2.1 Rocker-Bogie Suspension Known for its deployment on Martian terrain, the rocker-bogie system is designed to maintain all wheels in contact with the ground, affording the rover enhanced stability and obstacle negotiation capabilities without traditional shock absorption. The use of Rocker-Bogie suspension has been investigated by A. Singh et al [5] for a difficult terrain traversed by a rover.

2.2 Independent Suspension This system allows for each wheel to move independently, enabling the rover to adapt to various terrain profiles, maintain a balanced weight distribution, and ensure smooth navigation across uneven landscapes.

2.3 Active Suspension Systems As an enhancement to either the rocker-bogie or independent suspension, an active suspension system provides the rover with the ability to dynamically adjust its suspension. Using sensors and actuators, this system reacts in real-time to terrain changes, which is particularly beneficial for height adjustment and optimal ground clearance. In line with our design requirements and field test outcomes, we are inclined towards adopting a hybrid suspension approach. This would combine the rugged performance of the rocker-bogie or independent suspension with the cutting-edge functionality of an active system. The choice will ultimately be informed by extensive testing to determine the best fit for the rover's operational needs.

3) Dynamic Center of Mass

The rover's stability and adaptability are bolstered by a key design feature: the dynamic Centre of Mass (CoM) adjustment. This system utilizes linear actuators within the active suspension to modify the rover's height, optimizing stability for speed on smooth surfaces and maximizing ground clearance for rough terrain. The CoM adjustment is essential when the rover is equipped with various end effectors and is performing complex tasks. Through real-time data from sensors, the rover's onboard algorithms calculate the optimal CoM and direct the linear actuators to adjust the base height accordingly. This ability to shift the CoM is visually represented in Figure 4.2. This mechanism enhances the rover's operational efficiency across different terrains by ensuring it remains balanced and agile, ready to execute a wide range of tasks effectively.

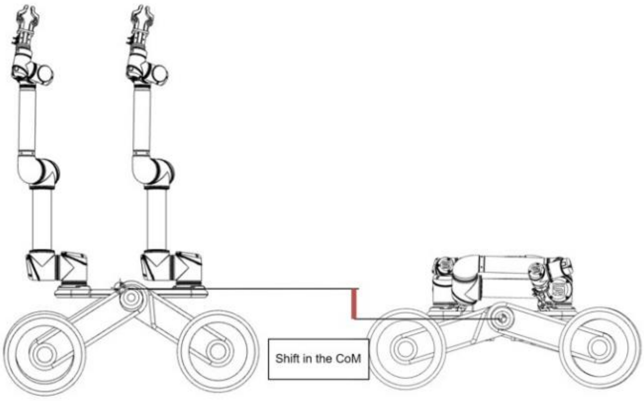

Figure 6 Change in centre of mass

4) *Electrical, Electronics & Control Systems*

The Avatar's EECS is an intricate assembly designed to empower the rover with precision and adaptability. For the selection of the components, reference to the paper by Ibna Rouf et al.[6] has been done. Key components include:

4.1 Wheel Motors and Drivers Brushless DC motors embedded within each wheel hub provide the rover with the necessary torque for varied terrains. Paired with motor drivers with feedback, they enable precise speed and direction control, crucial for differential and Ackermann steering methods.

4.2 Suspension Actuators Actuators in the suspension system adjust the rover's clearance and damping in response to terrain conditions. These active components are vital for maintaining stability and handling, contributing to the rover's ability to shift its Centre of Mass (CoM) dynamically.

4.3 Steering Actuators For articulated steering capabilities, actuators are employed to pivot the rover's segments, enhancing maneuverability. These are especially important when navigating tight spaces or complex terrains.

4.4 Inertial Measurement Units (IMUs) By measuring linear and angular motion, IMUs inform the rover's control system about its orientation and movement, which is essential for navigation and CoM adjustments.

4.5 Force/Torque Sensors Embedded in the rover's arms, these sensors provide feedback on the interaction with the environment, informing the control system to adjust for balance and stability.

4.6 Joint Encoders They deliver precise positioning of the rover's joints, feeding data to the control system for accurate movement and posture adjustment.

4.7 Depth Sensors and LiDAR These create 3D environmental maps, identifying potential obstacles and aiding in autonomous navigation.

4.8 Load Cells When manipulating objects, load cells measure the forces exerted, allowing for real-time CoM adjustment to maintain stability.

4.9 Vision Systems/Cameras Critical for object detection and navigation, these systems work in conjunction with onboard algorithms to predict and adapt to environmental changes.

4.10 Power Supply and Management Li-ion batteries provide the energy, supported by a Battery Management System (BMS) for efficiency and longevity. The power supply is chosen to match the rover's demand, ensuring endurance for extended missions.

4.11 Communication Systems The rover's communication capabilities are equipped with Bluetooth for short-range interactions, Wi-Fi for local network connectivity, and mobile GSM for broader communication requirements, enabling comprehensive data transmission and control.

4.12 Onboard Computing A high-performance computing unit processes sensor data and executes control algorithms, enabling real-time decision-making for communications and autonomous operations.

4.13 Diagnostics and Health Monitoring Continuous monitoring systems assess the rover's functional health, enabling predictive maintenance and immediate anomaly detection.

4.14 Auxiliary Energy Sources A secondary battery with reduced capacity is incorporated to provide backup power. This ensures that essential systems remain operational and basic navigation is possible in the event of primary battery failure.

C. *Robotic Arm*

The selection of the robotic arm for the Robotic Avatar will be from high-precision arms available in the market, ensuring alignment with our specific design and functional requirements. The chosen arm will be complemented with custom-designed end effectors to cater to our diverse applications.

1) *Kinematics & Actuation*

1.1 Kinematics and Actuation The configuration of the robotic arm will be defined using the Denavit-Hartenberg (D-H) parameters, essential for establishing the arm's kinematic model.

Forward Kinematics: The forward kinematics of the arm are described using transformation matrices. The equations has been referred to from the paper by Mueller et al.[7]:

$$T_{i-1}^{i} = \mathrm{Rot}_{z,\theta_i} \cdot \mathrm{Trans}_{z,d_i} \cdot \mathrm{Trans}_{x,a_i} \cdot \mathrm{Rot}_{x,\Omega_i} \tag{17}$$

Inverse Kinematics: Inverse kinematics are crucial for planning and control, calculating joint angles (θ_i) for desired end effector positions and orientations. This is accomplished using a function f^{-1}. Dynamic Behavior: Modeled using the Euler-Lagrange equation, the dynamics consider the difference between kinetic and potential energies and the applied joint torques.

Control Strategies: Control is achieved via a PID (controls equation referred from the paper by Borase et al. [8]) control loop for each motor, adjusting motor torque based on the error:

$$\tau(t) = K_p e(t) + K_i \int e(t)dt + K_d \frac{de(t)}{dt} \tag{18}$$

2) *Material Selection*

Material selection for the robotic arm, including aluminum, plastic, and steel, will ensure structural integrity and weight balance. Slewing bearings will be integrated to accommodate axial, radial, and moment loads, crucial for the arm's range of motion.

3) *End-Effector Customization*

Custom-designed end effectors will be developed to meet the specific requirements of our use cases, enhancing the arm's adaptability and efficiency. Mitra Robot Experience: Our team's experience with developing the Mitra Robot, featuring cost-effective and efficient solutions with precise finger movements, will inform the design and functionality of the Robotic Avatar's arm. Compatibility and Adaptability: The robotic arm will be designed to be highly adaptable and compatible with the rover’s base, ensuring its effectiveness across various scenarios and tasks

D. Onboard Systems

The architecture of the Robotic Avatar is designed with a range of integrated on-board systems, essential for its versatile and efficient operation. These systems, encompassing everything from mobility and energy management to sensory perception and communication, are detailed in the following table. Each system’s components and their functionalities are outlined to provide a comprehensive understanding of the Avatar’s operational mechanics.

The architecture of the Robotic Avatar is designed with a range of integrated onboard systems, essential for its versatile and efficient operation. These systems, encompassing everything from mobility and energy management to sensory perception and communication, are detailed in the following table. Each system’s components and their functionalities are outlined to provide a comprehensive understanding of the Avatar’s operational mechanics.

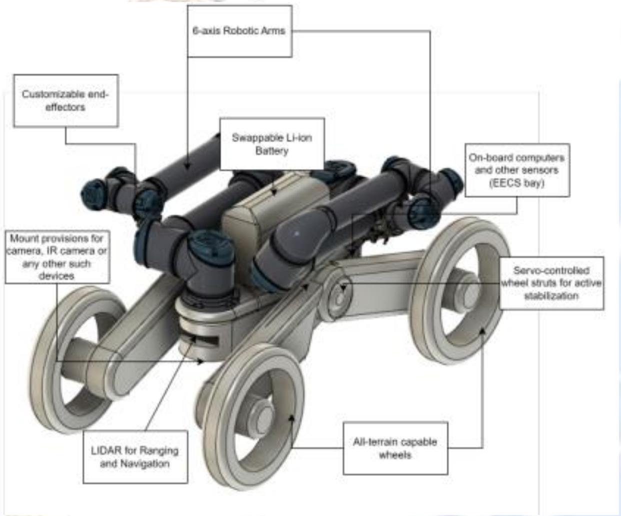

Figure 7 Components on the Robotic Avatar

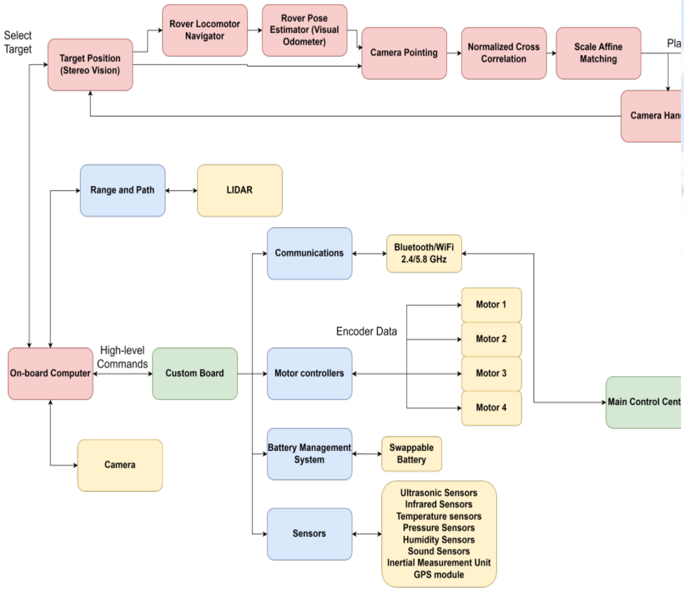

Figure 8 System Architecture

III. APPLICATIONS

The development of the Robotic Avatar represents a significant leap in the field of robotics, not merely as an isolated product but as a versatile platform capable of multiple applications. Central to its functionality is the advanced integration of AI and machine learning algorithms, which are crucial for enhancing the control systems. These algorithms enable the Avatar to perform complex tasks autonomously, which would be challenging or impractical to manage manually. The sophistication of these AI systems allows for their potential extrapolation and application in controlling other machines, marking a significant advancement in robotic automation. A key feature of this platform is its modular design, particularly evident in the interchangeability of its end effectors. This modularity allows for a wide range of applications, extending the Avatar’s utility across various industries and tasks. By simply changing the grippers or tools, the Avatar can transition between roles, from precise laboratory operations to handling hazardous materials, showcasing its adaptability and multi-functional capabilities. This flexibility underlines the platform’s potential as a transformative tool in various technological and industrial applications.

A. Laboratory and Hazardous Material Handling

Application: The Robotic Avatar, equipped with grippers or modifiers such as drill bits and screwdrivers, can be extensively used in laboratory environments and for hazardous material handling.
Functionality: By altering its end effectors, the Avatar can perform diverse tasks ranging from manipulating medical equipment to conducting research involving radioactive materials. Its design will ensure precision and safety in handling dangerous substances.
Benefit: This adaptation can significantly reduce human exposure to hazardous conditions, improving safety and efficiency in operations. The Avatar’s capability to handle materials safely will negate the need for personnel to don protective hazmat suits.

B. Survey and Exploration in Unsafe Locations

Application: With attachments like cameras, sensors, and probes, the Robotic Avatar can be a vital tool for surveying and exploration in unsafe and inaccessible locations.
Functionality: The Avatar can navigate challenging terrains, collecting essential data, capturing images, and performing detailed environmental analyses, particularly in post-disaster or contaminated areas.
Benefit: Utilizing the Avatar for these tasks can significantly reduce the risks to human surveyors. This is especially crucial in environments where immediate human intervention is risky or unfeasible.

C. Telemedicine in Isolation Wards

Application: Outfitted with cameras, screens, health monitoring devices, and sensors, the Robotic Avatar can become an indispensable asset in telemedicine, especially in isolation wards for contagious diseases.
Functionality: It can enable healthcare professionals to remotely examine and interact with patients in isolation, facilitating real-time transmission of patient data and visual feedback.
Benefit: This application can minimize the risk of disease transmission to healthcare workers and ensure continuous, effective patient care. The Avatar’s ability to operate in

isolation wards can provide timely medical attention to patients while ensuring the safety of healthcare staff.

ACKNOWLEDGMENT

The authors of the paper thank their families and the organization for constant support and encouragement.

REFERENCES

[1] "ANYmal - a highly mobile and dynamic quadrupedal robot | IEEE Conference Publication | IEEE Xplore," ieeexplore.ieee.org. Available: https://ieeexplore.ieee.org/abstract/document/7758092 . [Accessed: Jan. 12, 2024]

[2] C. Cariou, R. Lenain, B. Thuilot, and M. Berducat, "Automatic guidance of a four-wheel-steering mobile robot for accurate field operations," Journal of Field Robotics, vol. 26, no. 6–7, pp. 504–518, Apr. 2009, doi: https://doi.org/10.1002/rob.20282

[3] J.-Y. Kim, I.-W. Park, J.-H. Lee, M. Kim, B. Cho, and J.-H. Oh, "System Design and Dynamic Walking of Humanoid Robot KHR-2," CiteSeer X (The Pennsylvania State University), Jan. 2006, doi: https://doi.org/10.1109/robot.2005.1570316

[4] K. J. Rustamov and L. O. Tojiev, "Types of Steering and Their Design Aspects," Indonesian Journal of Innovation Studies, vol. 20, Oct. 2022, doi: https://doi.org/10.21070/ijins.v20i.746

[5] A. Singh and P. Jain, "Design and Concept of Rocker-Bogie Suspension for a Planetary Rover Prototype," SSRN Electronic Journal, 2020, doi: https://doi.org/10.2139/ssrn.3647078

[6] T. Ibna Rouf Uday et al., "Design and Implementation of the Next Generation Mars Rover," IEEE Xplore, Dec. 01, 2018. doi: https://doi.org/10.1109/ICCITECHN.2018.8631928. Available: https://ieeexplore.ieee.org/abstract/document/8631928?casa_token=lKtSYReqJDAAAAAA:rn2a7NVMKHIdAfQIC6ZpO4n5ts9XngKkzBq6kCH8WffdaGFz9wgkZMWf6lzWv-inAVPKZkMsZQ . [Accessed: May 01, 2023]

[7] A. Mueller, "Modern Robotics: Mechanics, Planning, and Control [Bookshelf]," IEEE Control Systems, vol. 39, no. 6, pp. 100–102, Dec. 2019, doi: https://doi.org/10.1109/mcs.2019.2937265

[8] R. P. Borase, D. K. Maghade, S. Y. Sondkar, and S. N. Pawar, "A review of PID control, tuning methods and applications," International Journal of Dynamics and Control, vol. 9, no. 2, pp. 818–827, Jul. 2020, doi: https://doi.org/10.1007/s40435-020-00665-4