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Design and Analysis for Mobile Robot

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Abstract: This paper presents a detailed study on the conceptual design and analysis for Mobile Robot (MR). It provides an overview of MR, explaining its significance in the current world. It reviews various design and analysis models employed in existing works for evaluating its performance. The paper further presents a conceptual design and analysis of MR based on motorized wheels. It contains a steering wheel in the rear and front portion and two wheels on a cart on each side. The wheel at the front portion possesses a spring suspension for ensuring ground contact of wheels. The vehicle's steering is realized through controlling the steering at the rear and front wheels and also the speed difference of cart wheels. It then presents the kinematic study of the conceptual design for investigating the MR's performance so as to support future advancements and applications.

Keywords: Conceptual design, Mobile Robot, Performance evaluation

I. INTRODUCTION

Recently, huge developments have occurred in the robotics domain. MR is an advanced version of conventional robot which comprises improved features and is employed in tasks where the conventional robots fail to function or achieve the expected performance. As a crucial wing of service robot, MR has been widely utilized in dangerous and hazardous environments [1], [2] where operators cannot reach or find it difficult to fulfill the desired goal such as in military reconnaissance, emergency rescue operations, underground detection, aerospace exploration, etc. High mobility in distinct environments is the significant necessity of a MR [3], [4], [5]. Human inspection in complex environments is expensive and time consuming. Moreover, in some instances it is highly sophisticated. By using MRs the human inspection tasks can be simplified and expected targets can be met easily. Motion optimization in wheeled vehicles is mainly related to slip minimization. Various studies pertaining to analysis and development of wheeled MRs have been carried out in [6], [7], [8], [9], [10], [11]. Reducing wheel slip minimizes the total energy consumption and also enhances the MR's climbing performance. The design of MR highly influences its performance. Thus, through better design and analysis the operating performance of MR can be improved.

The organization of the conceptual paper is as follows: Section I provides a concise introduction of MR, explaining its necessity and significance. Section II reviews the works on design, analysis and performance assessment of MR. Section III discusses the significance of the current research. Section IV provides the conceptual design and analysis of MR. Section V concludes the proposed work, in addition to presenting the main findings of the work and future developments to be considered for supporting further applications.

II. LITERATURE SURVEY

An optimal design of a stair-climbing MR and its kinetic analysis was presented in [12]. In this work, Taguchi scheme was adopted owing to its cost-effectiveness and simplicity in satisfying desired multiple constraints and in objective function formulation simultaneously. The parameters of employed rocker-bogie (RB) mechanism were optimized using the Taguchi technique for enhancing the MR's adaptability and climbing potential for distinct kinds of stairs. For ensuring the stable performance of proposed RB mechanism while stair climbing the area between the trajectory of its centre of mass (CM) and the straight line was minimized under the kinematic bounds for preventing the interferences between the ground and MR. Furthermore, the climbing behavior of RB mechanism was assessed using the friction metric. The locomotive strategy derived from kinematic study of a stair-ascent motion for RB mechanism minimized the slip at the stair-ascent phase and enabled efficient stair-climbing. In [13], design and realization of a modifiable wheel-legged MR was presented. It integrated the obstacle climbing potential of legged robot and maneuverability and stability of wheeled robot through a wheel-legged transformable mechanism. The movements of MR under legged and wheeled modes were analyzed and results indicated that these modes could be easily switched for distinct terrains. In [14], analysis and design of a soft MR comprising multiple, separate thermally activated joints driven using a single actuator was presented. A solder-dependent locking system was developed for controlling the proposed under-actuated mechanism so as to trigger individual joints without any additional actuators. The proposed MR achieved steering and translational motion through thermally excited joints and a central motor actuator. It achieved a translational speed of 7.5 mm/s and steering speed of 0.9 deg/s. In [15], hardware design and mechanical structure of all-environment MR was provided. In this study,

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sealing mechanism, cylindrical mechanism and coaxial eight-rotor mechanism were coupled effectively for operating MR in three distinct environments. In [16], an omni-directional MR with 4-mecanum wheels was discussed. The two-level control system and three-layered mechanical design ensured flexible applications. The rotational motions were validated for detecting the slippage. The robot rotated at an angular velocity and linear velocity of 0.25 rad/s and 0.25 m/s simultaneously and slipped 70~80 mm owing to the slippery surface and faster rotation of outer wheels than the inner wheels. In [17], kinematic analysis of two-wheeled MR was presented. The system architecture comprised two co-axial wheeled structure powered using DC motors. The robot dimensions and right/left wheel velocities were considered for deriving the relation for angular and linear velocity of MR. In [18], an omnidirectional MR was designed. The MR's mechanical system involved four mecanum wheels with a damping suspension mechanism. The robot's control mechanism and mechanical system were developed with modular and multilayer structure which enabled robot to be easily upgraded and transformed. In [19], an omnidirectional non-holonomic MR design was presented. The MR was designed using an integrated application of CAM/CAE/CAD for fulfilling the essential design requirements like assimilability, modularity and manufacturability. In [20], design of MR with passively hinged driving tracks was presented. The MR was designed with two rocker links, four pitch-roll two-degrees-of-freedom passive joints and four driving tracks. Results showed that proposed MR design reduced maneuverability and high terrain ability by approximately 44.51% and 25.48%. In [21], design of a MR was presented. The MR operated in three distinct locomotion modes namely roll-over mode, tracked mode and wheeled mode. Mechanical design of MR with kinetic and static analysis was presented. The torque/force properties, transformation function, geometric constraints and MR performance were illustrated and characterized. In [22], mechanical design of wheel-leg MR was presented. The fundamental features of proposed module and robot motions using the module were confirmed through basic motion experiments. In [23], a tethered MR design was presented for analyzing the turnover and slip. The tethered tension for preventing turnover and slippage on a slope was calculated initially from the mechanical analysis of the developed MR. Stability study of MR indicated that it failed to move downwards on extreme slopes. Results illustrated that the MR's traversability was improved by aligning the altitude of center of gravity (COG) to the tether setting point. Moreover, through adaptive tether tension control, the MR successfully traversed extreme slopes without turnover and slippage. In [24], a passively-actively convertible MR design was presented. The proposed MR could passively adjust to distinct terrains with a balance-rocker (BR) mechanism. In this study, a novel adaptable side frame was designed for controlling the MR's roll axle. This side frame was employed as a suspension for changing the COG position so as to boost the necessary traction. The BR mechanism provided pitch averaging and guaranteed that all the wheels made contact with the ground surface. In [25], an omnidirectional MR design and its mobility assessment was discussed. The experimental assessment of robot's mobility behavior indicated that it possessed a velocity-independent and configuration invariant omnidirectional mobility. Furthermore, it indicated that for achieving high agility and better adaptation to omnidirectional motion, suspension properties of MR should be optimized.

III. RESEARCH SIGNIFICANCE

The conventional MRs are found to exhibit only a single motion mode such as foot, wheel, peristalsis, flight, etc. indicating the adaptability of such robots to be poor in the distinct environments. Moreover, the uncertainty of dynamic frameworks, robot structure complexity, and weak adaptability have resulted in performance deterioration of MRs. Additionally, conventional MRs are developed to perform only a specific task and are not flexible to operate in diverse environments. This is mainly owing to the design architecture and constraints. Thus, the design factor plays a crucial role in the MR performance. Efficient and robust design greatly helps in achieving the desired targets. Therefore, this research work intends to propose a conceptual design and analysis for all-terrain MR. It intends to explore the existing design-analysis models for MRs so as to learn the design factors, design constraints for enhancing the MR's performance.

IV. DESIGN AND ANALYSIS OF MOBILE ROBOT

4.1 Mechanical Design

The conceptual MR designed in this work is a mobile vehicle with six independently powered wheels as depicted in Figure 1. In the front portion, the wheel is placed in the identical plane and its position is controlled through a spring. The forward motion of MR is guided using the front wheel which serves as the steering and the lateral stability is offered on both the sides using two wheeled carts or bogies. The rear wheel is attached rigidly to the body and it also serves as steering for supporting and guiding the motion of MR. The lateral view of MR is depicted in Figure 2.

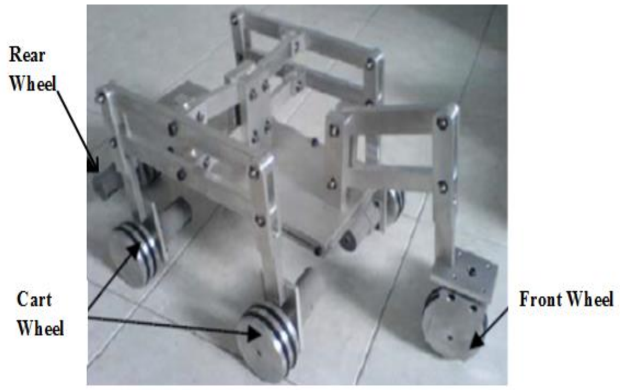

Figure 1. The mechanical design of MR

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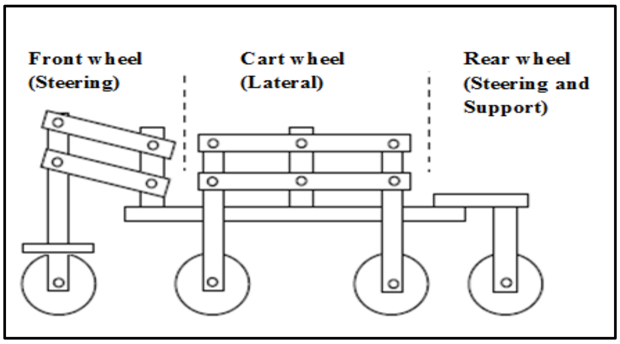

Figure 2. The lateral view of MR

For the six motorized wheels, a non-hyperstatic arrangement is provided using the parallel structure of carts and the spring dangling fork for maintaining a better ground clearance, and ensuring maximum adaptability, stability and superior climbing abilities. Furthermore, the robot is designed to maintain all its wheels in contact with the ground as depicted in Figure 3.

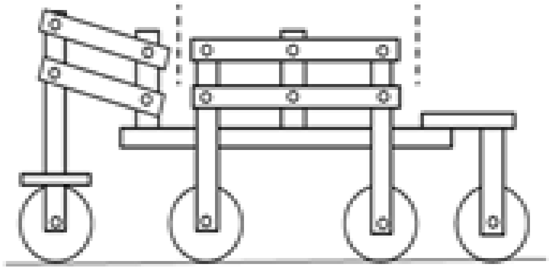

Figure 3. Wheels of robot maintained in contact with ground

The MR's base plate, wheel holder and front wheel holder are made up of aluminum (Al) alloy 6061. The MR's base plate is designed to hold the controller and battery onto it. The wheel holder is designed to attach the lateral bar with the lateral wheel while the front wheel holder is designed to attach the frontal bar with the frontal wheel as depicted in Figure 4.

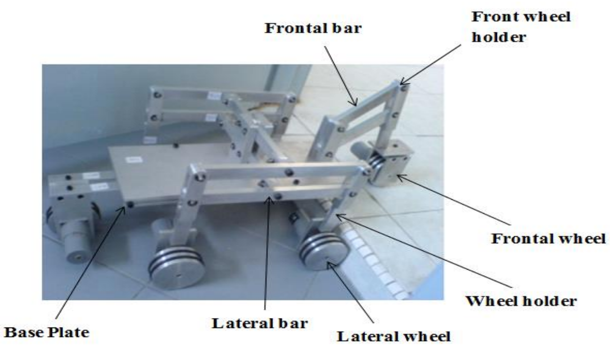

Figure 4. Critical parts of MR

All six separate DC-motors consolidated with the wheels possess a power of 0.68 W each and are controlled individually. The total mass of the MR base is 6 kg and the weight of the robot battery (2 Ah, 12 V) is 600g. The rotation per minute (rpm) is 60 and torque is 125 Nm. From the speed and torque of motor, the force and velocity on every wheel of rover is estimated using equation (1) as

$$V = \pi N d / 60 \qquad (1)$$

where, V represents velocity (m/s), N represents the rotation per minute (rpm) and d represents the wheel diameter.

Substitution of N =60 rpm and d = 80 × 10^{-3} values in equation (1) velocity is estimated.

$$V = \pi(60)\,(80 \times 10^{-3}) / 60$$

$$V = 0.25132 \text{ m/s}$$

The force F is estimated using equation (2) as

$$F = P/V \qquad (2)$$

where, P represents the DC-motor power (W), F represents force (N) and V represents the velocity (m/s)

$$F = 0.68 / 0.25132$$

$$F = 3.1035 \text{ N}$$

4.2 Design Analysis

Performance of proposed MR is evaluated using kinematic motion analysis. The proposed MR is designed to traverse at distinct terrain, where step-ascent motion is regarded as one of the impediments that this robot is able enough to overcome. Figure 4 depicts the capability of MR for a step-ascent motion. The kinematic movement of MR is analyzed through Autodesk Mechanical Desktop Software.

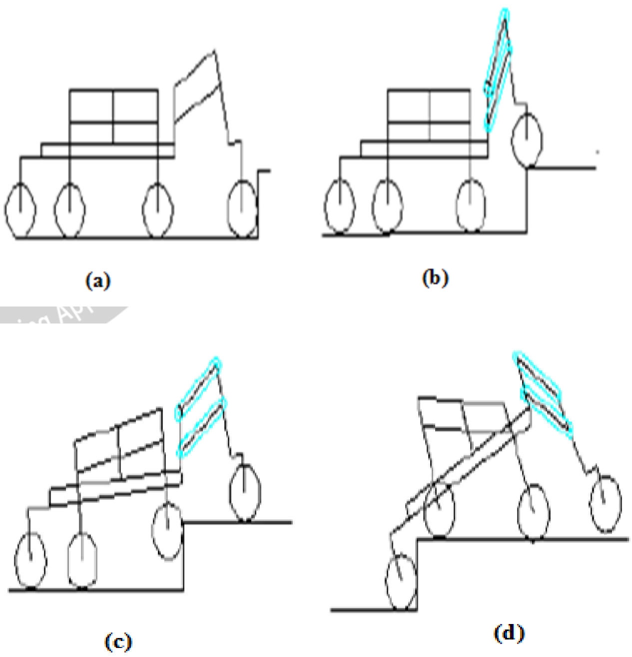

Figure 5. Sequences depicting the mobile rover climbing the step

The robot's motion sequence in climbing the step is depicted in Figure 5 and 6. The prime intention of rover is to overcome a step having same height as its wheel diameter. Initially, the front fork is made to climb the step (as depicted in Figure 5b and 6a), thereby relieving the load on cart/lateral wheels and allowing the cart wheel to climb easily (as

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depicted in Figure 5c and 6b). When the next cart wheel comes in contact with the wall, the cart turns around the step's upper corner. At this period, the COG almost reaches its ultimate height (as depicted in Figure 5d and 6d). Ultimately, the final wheel can get on the step easily, dragged by the remaining wheels. Since the carts are independent from one another, it is also possible to ascend the step even if

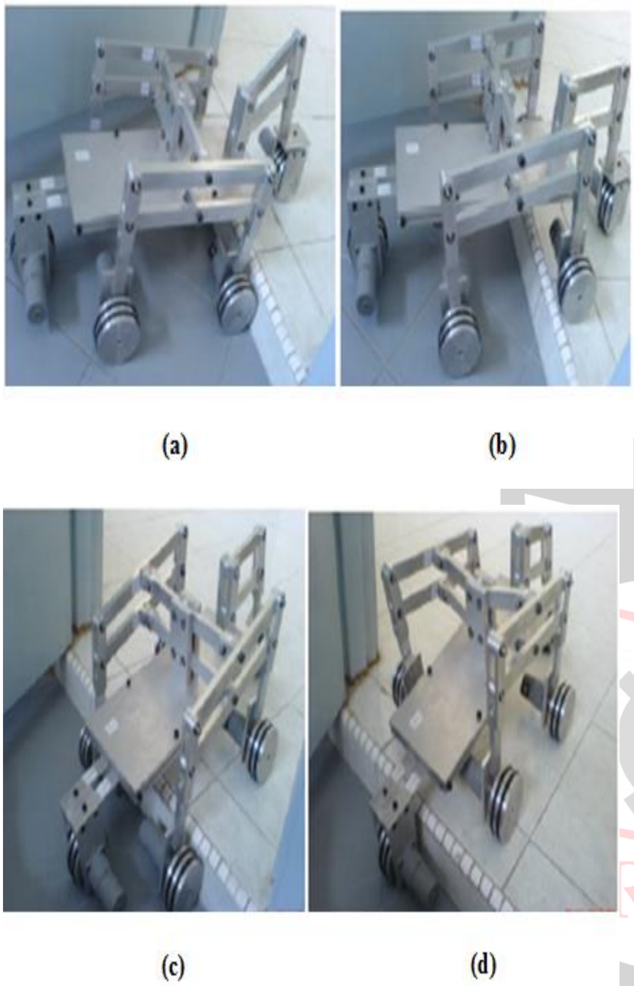

Figure 6. Climbing sequences of rover for the step having same height as its wheel diameter

This conceptual MR design is capable of climbing the stairs easily for steps possessing the same altitude as the wheel diameter of the robot. However, the performance of this design needs to be further investigated for diverse wheel diameters and their step-ascending capability.

V. CONCLUSION AND FUTURE SCOPE

The conceptual paper presented a brief overview of MR and its significance in the modern era. It explored various design-analysis frameworks used in existing literary studies for assessing the MRs performance. Analyzing the design, performance evaluation models of MRs in existing studies indicated that despite substantial developments in MRs design, still a huge room for improvement persists. The paper presented a conceptual design of MR dependent on motorized wheels. The kinematic evaluation of proposed conceptual design indicated that it was capable of overcoming the impediments of same altitude as MR's wheel diameter and could also climb stairs easily. The future development for MR would be design optimization for slip reduction. This could be accomplished through optimizing the tension forces. Additionally, optimization of wheel design for distinct wheel diameters and its kinematic analysis would aid in MR's performance enhancement. Additionally, wheels integrated with sensors would greatly assist in transforming the passive framework to active one capable of functioning without human guidance.

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