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Original

Overcoming challenges in patient transportation: A novel stretcher design for uneven terrains

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Abstract: Transporting patients through stretchers and wheelchairs is a critical activity in the emergency management services. When such systems need to be used in uneven terrain, outdoor environments, and stairs, the transportation process imparts severe difficulty and challenges for medical attendants and paramedics. Most of the available transportation systems are designed to function on the plain engineered surface. This paper presents a novel concept of a rocker-bogie mechanism-based stretcher for patient transportation in uneven terrain. The rocker-bogie mechanism is proven to be an effective suspension system for navigating through obstacles and stairs. The design considerations of the rocker-bogie mechanism for inclusion in the stretcher are discussed. Static structural analysis of the system is performed using commercial finite element analysis software. Parameters pertaining to structural safety are analyzed. Based on the results of the structural analysis the feasibility of the proposed design is assessed.

Keywords: Locomotion, stretcher, rocker-bogie, uneven-terrain, emergency-management, stair-climbing.

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1. Introduction

Delivering safe and timely medical care to a patient is one of the main functions of medical service providers. Particularly, emergency medical services often deal with unforeseen situations and face several challenges in providing medical assistance to patients. Patient transportation is one of the critical operations performed during emergency management. Trained paramedics are involved in the patient transportation process. A variety of assistive devices and systems like ambulances, wheelchairs, and stretchers are used as per the transportation requirements. Out of the available options, stretchers are commonly used patient transportation mediums in outdoor as well as indoor environments. A variety of forms of stretchers are available in the market. The primary division of stretcher types can be made based on environment i.e. outdoor and indoor. Outdoor stretchers are often mobile so that they can be taken to the requisite spot. An ambulance stretcher is one example of such a stretcher. Indoor stretchers, often possess a fixed structure with a wheel-based locomotion mechanism. Such stretchers are well-suited for flat surfaces and can easily be maneuvered.

In certain environments, where the maneuvering of the conventional stretcher is not possible, the stretchers are manually lifted by the paramedics. Particularly in outdoor environments, and multistoried infrastructures without the facility of a ramp or a lift, the manual transportation of stretcher becomes cumbersome. In such situations, paramedics often face challenges related to ergonomics, patient safety, and efficiency. Cooper and Ghassemieh (2007) highlight the risk of back injuries sustained by ambulance workers during patient transfers using various stretcher systems. They assessed the risks associated with different systems by employing biomechanical failure criteria. Paramedics are often exposed to physical strain due to the repetitive lifting and maneuvering of patients. The study carried out by Verjans et al. (2018) highlighted the potential risk of musculoskeletal disorders among paramedics due to the demanding postures experienced by them during patient transportation in different situations. The authors emphasize the need for further investigation of different factors to develop interventions that can help reduce postural workload and improve ergonomics within ambulances.

To address the challenges associated with assistive devices like wheelchairs and stretchers, modifications in the mechanisms and designs are common practices used by researchers. Liu et al. (2012) proposed a new stretcher design called the emergency carpet. The stretcher bed is made of a unique polyurethane composite material that hardens after being poured into a specially designed fabric mold shaped like a human body. The developed system potentially reduces the risk of further injury during transport. Lim and Ng (2021) proposed the concept of a foldable wheelchair stretcher. Their proposed model combined the functions of a wheelchair and stretcher into a single system, thus enhancing the utility of the model. Hirudkar et al. (2017) modified the design of a combined wheelchair and stretcher model from an automation perspective. They proposed the use of electric actuators and automatic control for achieving locomotion thus reducing manual efforts involved in operation. The conventional stretcher design consists of a wheeled structure thus making it suitable for the flat surface. In case of uneven surfaces, obstacles, and stairs, the wheel-based systems are not suitable. A stretcher model capable of climbing obstacle and stairs can ensure efficient patient transportation in various environment. In outdoor environment with uneven surfaces and obstacles, it can traverse through obstacles and irregular surfaces effectively with less effort compared to the manual lifting of the stretcher. Moreover, in the multistoried indoor environment with staircases, it can be a viable tool for the emergency management. This work focuses on the problem of manual patient transportation through a stretcher in uneven terrain.

In the field of mechanisms, this problem has been addressed by researchers and different mechanisms for traversing uneven terrain have been proposed. The rocker-bogie mechanism is one such mechanism that has proven to be effective in such situations (Hong et al., 2013; Pandey et al., 2022). The said mechanism has been successfully implemented in the Mars rovers for maneuvering in different terrains. This work focuses on the integration of the rocker-bogie mechanism into a stretcher to enable stair-climbing ability and maneuverability for uneven terrain. The design considerations to include a rocker-bogie mechanism into the stretcher model are analyzed. There are several reasons for inclusion of this mechanism in the proposed design. The primary reason is enhanced stability during the obstacle climbing operation. The rocker-bogie mechanism design ensures the even distribution of the weight thus maintaining stability of the structure during maneuver (Kim et al., 2012; Seo et al., 2023). Versatility in the design and adaptability to different applications are the other parameters that support its suitability. Customization of the mechanism is possible to meet application requirements. These features make rocker-bogie mechanism a suitable choice for selected model.

The rest of the paper is organized as follows. Section 2 deals with the design considerations of the rocker-bogie mechanism in a conventional stretcher model. Section 3 describes the results obtained during the analysis of the proposed model in the simulation environment. Section 4 describes the conclusion of this work.

2. Design of stretcher with rocker-bogie mechanism

The design of the stretcher plays a pivotal role in the safe and efficient transportation of the patients. Conventional stretcher designs mostly rely on the wheeled locomotion, which is well suited for flat and even surfaces. In case of uneven terrains and stairs, manually lifted foldable stretchers are used. The proposed design of the stretcher includes the rocker bogie mechanism for easy maneuvering of the stretcher on uneven terrains and stairs. The inclusion of the rocker-bogie mechanism into the stretcher design allows for independent suspension and articulation of each wheel, ensuring all four wheels maintain constant contact with the ground. This eliminates the risk of tipping or losing balance, providing a secure platform for both the patient and the medical personnel during the movement of the stretcher.

The rocker-bogie mechanism is a popular suspension system used for maneuvering uneven terrains and obstacles. It consists of a set of multiple rocker arms connected to the wheels, which allows for independent movement and articulation (Kim et al., 2012; Wang & Li, 2016). This mechanism is commonly found in Mars rovers and off-road vehicles due to its ability to maintain stability on rough terrain. The development of a stretcher design based on the rocker bogie mechanism takes advantage of this proven technology to improve patient transport in challenging environments. This mechanism has demonstrated adaptability to overcome obstacles while keeping the wheels in contact with the ground (Seo et al., 2023). Figure 1 shows the line diagram of the proposed stretcher model rocker-bogie mechanism.

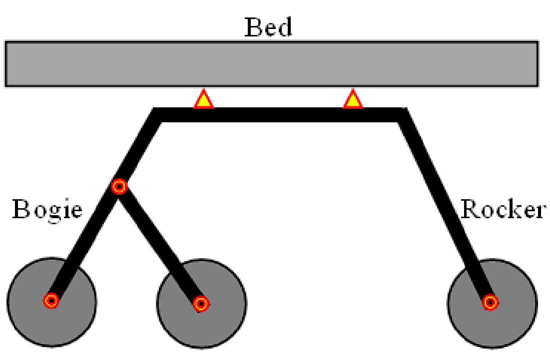


Figure 1. Proposed stretcher model with rocker- bogie mechanism.

The mechanism consists of a pair of rockers on each side of the body. The rockers serve as a connection point between the body and the bogie. The bogie system consists of a set of wheels connected to a common connection point. Every wheel of the mechanism touches the ground while traversing uneven terrain or obstacles as shown in Figure 2. This feature provides good stability to the structure.

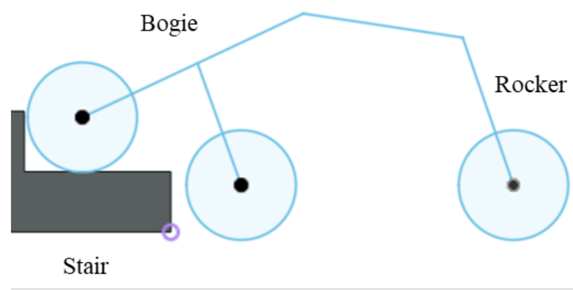


Figure 2. Stair-climbing operation using rocker-bogie mechanism.

To utilize the rocker bogie mechanism in the stretcher, the design and dimensions of the linkages of the mechanisms are modified. These modifications are done based on the study of the commonly available stretcher models. The design considerations of the proposed model are shown in Figure 3.

Two front wheels are attached to the bogie links, while the rear wheel is attached to the rocker. As evident from Figure 3, the angle between the bogie arm is fixed 90° and both rocker arms are inclined at 60° to the horizontal. Let L_1, and L_2 be the lengths of the bogie linkages and L_4 be the center distance between the bogie wheels.

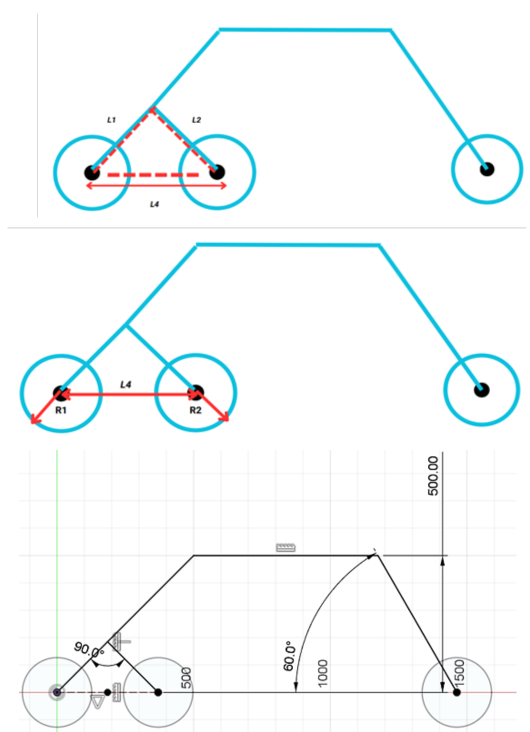


Figure 3. Design considerations of rocker-bogie mechanism.

The links are connected by a passive revolute joint. In the considered design problem, the selection of the appropriate dimensions of the links to support a bed is considered. The rocker-bogie structure supports the bed. A stair structure is considered as an obstacle to the locomotion mechanism. Under the loading condition, the stretcher should be able to climb the obstacle. The geometry of the wheels and linkages imposes constraints on this motion. The primary constraint is maintaining the contact between wheels and the ground. For this purpose, the radius of the wheel is selected greater than the height of the obstacle. The relation between the minimum wheel radius and the height of the obstacle is given by:

$$R_{min} = h/\sin\theta \qquad (1)$$

where R_{min} is the minimum radius of the wheel, h is the height of the obstacle and θ is the maximum angle of the rocker arm during climbing of the obstacle. The second geometric constraint is the formation of the triangular-shaped link of the bogie as shown in Figure 3. This is achieved by maintaining the following relations in the link dimensions:

$$\begin{aligned} L_1 + L_2 &\geq L_4 \\ L_2 + L_4 &\geq L_1 \\ L_4 + L_1 &\geq L_2 \end{aligned} \qquad (2)$$

The third constraint considered in the design is avoiding overlapping between the bogie wheels. This can be expressed by the following condition:

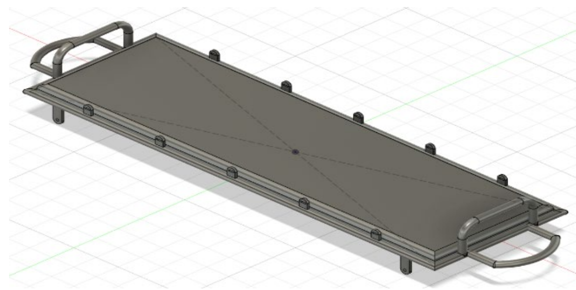
$$L_4 > r_1 + r_2 \qquad (3)$$

where r_1 and r_2 are the radius of the bogie wheels. For the considered case, wheels of the same radius are considered for the model, therefore; the constraint defined above reduces to the following form:

$$L_4 > 2r \qquad (4)$$

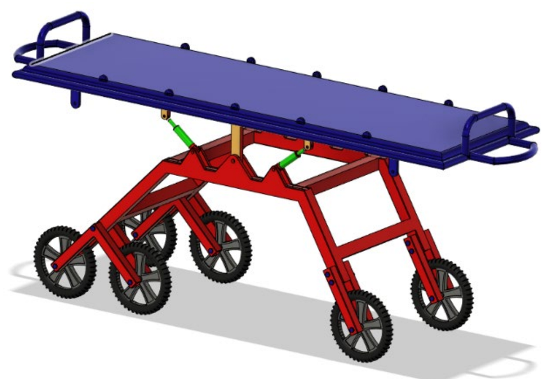
where r denotes the common radius of the wheels. Based on the above considerations the dimensions of the links for the proposed model are finalized.

The proposed stretcher model consists of a bed supported by the rocker-bogie-based locomotion mechanism. The design is based on the manual maneuver of the stretcher for patient transportation. Based on the dimensions of the commercially available stretcher models, the overall dimensions of the stretcher are fixed. The main components of the stretcher are the rocker-bogie-based locomotion mechanism and bed for carrying patients. Three-dimensional modeling of the components is performed using the solid modeling software Fusion 360. The different components of the proposed model along with the assembled model are shown in Figure 4.



(a)

(b)



(c)

Figure 4. (a) Bed, (b) locomotion mechanism, (c) stretcher model with rocker-bogie mechanism.

3. Analysis and simulation results

3.1. Structural analysis of stretcher

Structural analysis is a crucial step of the design process as it reflects the response of the structure under different loading conditions. The robustness of the stretcher is essential for the safe and efficient transport of the patients. Moreover, the proposed design is intended to be used in uneven terrain, in such a case its structural analysis is of paramount importance. To perform the structural analysis of the stretcher model, a CAD model of the stretcher was utilized. Since the frame structure of the stretcher bears the load, the same has been considered for the finite element analysis of the model. The finite element analysis is performed using ANSYS workbench. The CAD model was imported into the ANSYS software and analyzed. The meshed structure of the model is shown in Figure 5.

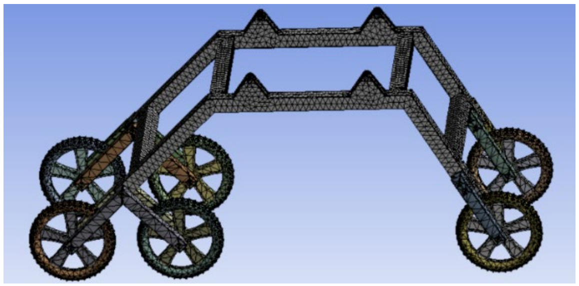


Figure 5. Finite element model of the locomotion-mechanism.

To predict the response of the structure under the application of load, static structural analysis is performed. The static analysis reveals how a structure reacts to a constant force. For this purpose, a static force of 1000 N was applied at the four clamps of the rocker. The force was applied in the downward direction and the wheels were considered grounded during the analysis. Figure 6 shows the results of the static analysis.

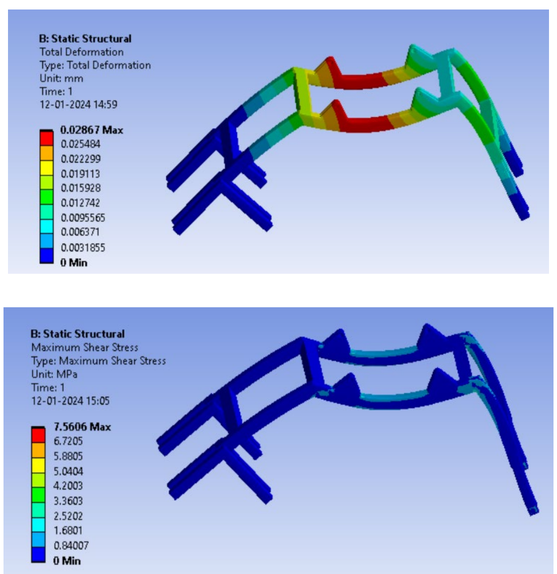


Figure 6. Results of static structural analysis.

It can be seen from Figure 6 that the total deformation of the structure is 0.02867 mm. Maximum deformation is observed near the center of the rocker. The material used to model the structure is aluminum. The observed deflection is small in context to the given load. The shear stress distribution of the structure is also shown in Figure 6.

For the present case, the downward forces acting at the clamps are responsible for the shear of the structure relative to the bottom portion. The maximum shear stress is observed at the top of the structure, where the shear force is the maximum. The maximum shear stress observed in the structure 7.5606 MPa is well below the maximum allowable shear stress of the material, hence the structure is free from failure due to shear stress.

The material used to model the stretcher is aluminum, which is known for its good strength to weight ratio. The considered application relies on the manual maneuvering of the stretcher; therefore, the weight of the structure is an important criterion of design and material selection. As indicated in Fig. 6, the deigned structure possesses sufficient strength to bear the weight of the human body. Moreover, durability, ease of fabrication, and cost efficiency are some other parameters that makes aluminum suitable for the considered model.

3.2. Structural analysis of stretcher

The modal analysis represents fundamental techniques of FEA to identify the dynamic behavior of the model under vibration. While traversing in the uneven terrain and during obstacle climbing operation, the proposed model tends to undergo vibration. The model utilizes aluminum as structure material, the modal analysis is crucial due to its light weight and complex geometry of the locomotion mechanism. The modal analysis is performed to analyze the natural frequencies and corresponding mode shapes of the stretcher model. The natural frequency of the model represents the frequency at which the model tends to vibrate without any external excitation, whereas the mode shapes represent the deflection pattern under the action of natural frequency. For the proposed model, the modal analysis results are shown in Figure 7.

Ten different modes of analysis, their natural frequencies, and corresponding deformation are shown in Figure 7. Among all the ten cases, maximum deflection is observed in mode 7 with a deflection value of 13.92 mm. Under the applied loading condition, the deflection value is within the permissible limit therefore, the structure is safe for the intended use.

3.3. Multibody dynamics simulation

To assess the operation of the stretcher model, multi-body dynamic simulations were performed. One of the main objectives of the developed stretcher model is to traverse uneven terrain. Particularly, stair climbing ability is a challenging task without the use of motorized wheels. During the multibody dynamic simulation, the stair-climbing ability of the model is assessed. Figure 8 shows the motion profile of the stretcher model on a flat surface and during stair climbing operation.

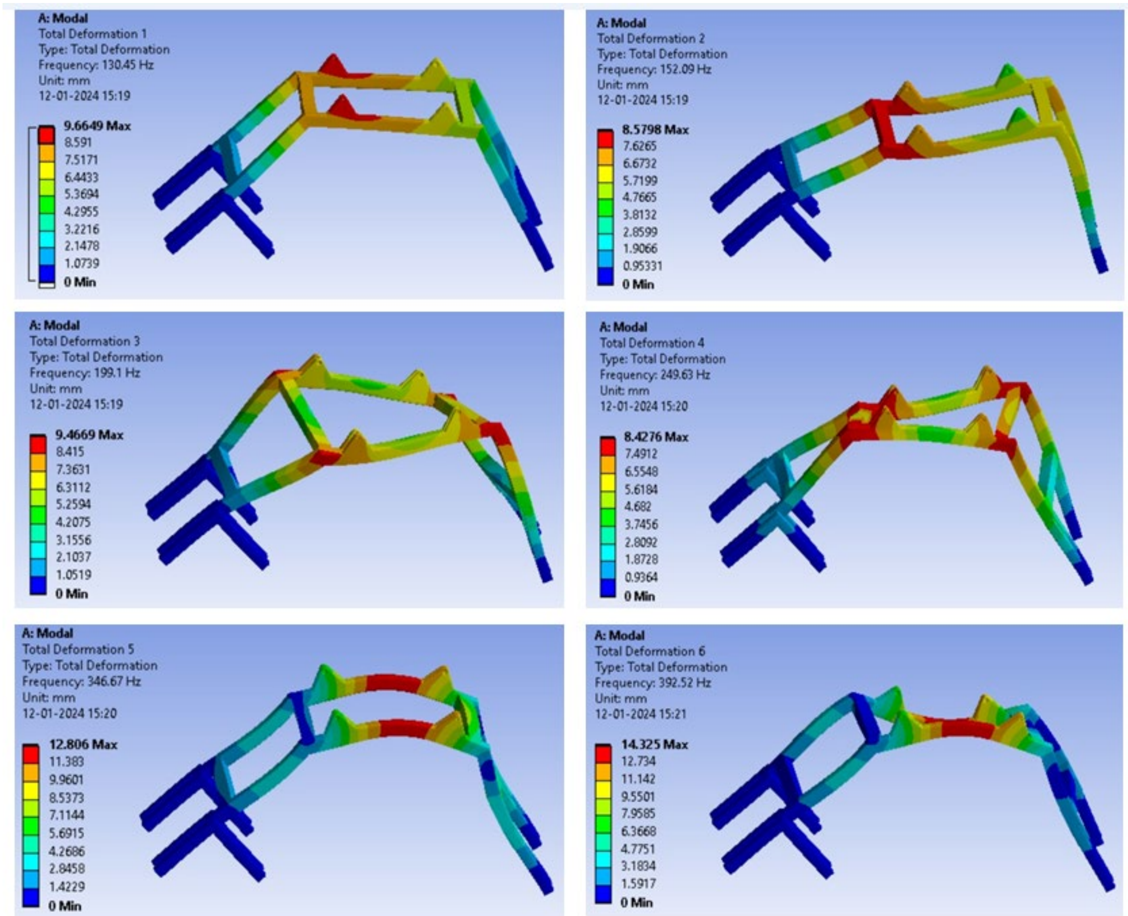
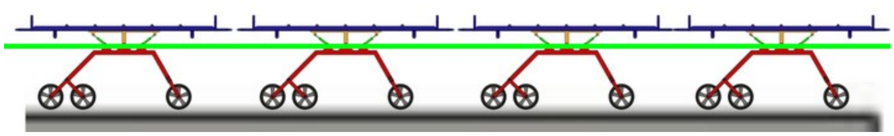
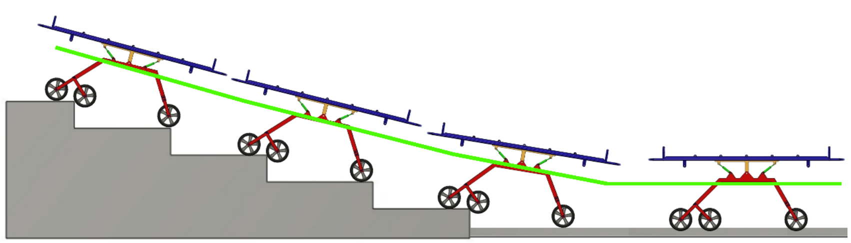


Figure 7. Results of modal analysis for the stretcher model.



(a) Flat Surface



(b) Stair climbing

Figure 8. Motion simulation of the stretcher model.

As evident from Figure 8, the stretcher can locomote in both conditions under the tested condition. In the former case, it is easier to maneuver the stretcher on a flat surface. The path traced by the center of gravity of the model is a straight line. In the latter case, it is necessary to maintain the contact of the wheel with the ground to climb a stair. This requires higher torque to prevent slip due to reduced contact area while ascending. Under the tested condition, the developed model was able to climb the stairs, thus fulfilling the intended purpose.

Motion simulation reflects the suitability of the model for the intended operation. However, the applicability of the proposed model in the actual condition is subject to certain geometrical and environmental constraints. The primary geometrical constraints are the height of the obstacles or stairs, and wheel diameter. Typically, rocker bogie equipped mechanisms can climb height up to 1.5 times of its wheel radius. Therefore, the wheel diameter and height of stairs in case of indoor application of the stretcher needs to checked. It is essential to satisfy this geometric constraint for maneuvering over the obstacle without losing stability of the structure. Another key geometrical constraint is the tilt angle of the rocker-bogie mechanism. This constraint necessitates the center of gravity of the system to remain within the safe range during obstacle climbing. Thus, the dimensions of the mechanism, diameter, and tilt angle becomes important for specific applications. Certain environmental factors like dimensions of the confined spaces, design of the staircases, and turning radius can also affect the indoor operation of the proposed stretcher model. Moreover, patient comfort is a critical issue during transportation, a trained paramedic or medical professional may ensure a suitable way of operating the stretcher.

4. Conclusions

This work presents the design considerations of a stretcher for emergency management. The design constraints of the rocker-bogie mechanism for inclusion into a stretcher model are discussed. The integration of the rocker-bogie mechanism into the stretcher enables it to traverse easily on uneven terrains and stairs. Moreover, the static structural analysis, modal analysis, and multibody dynamic simulation results are presented to justify the suitability of the design. The simulation results reflect the suitability of the model from a structural safety viewpoint. As traditional stretchers have long been challenged by the obstacles presented by stairs and uneven terrain, often relying on manual lifting. The presented model utilizes an adaptable wheel configuration to enable locomotion in uneven terrain, and stairs thus reducing manual efforts.

Conflict of interest

The authors have no conflict of interest to declare.

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References

Cooper, G., & Ghassemieh, E. (2007). Risk assessment of patient handling with ambulance stretcher systems (ramp/(winch), easi-loader, tail-lift) using biomechanical failure criteria. *Medical engineering & physics*, *29*(7), 775-787. https://doi.org/10.1016/j.medengphy.2006.08.008

Hirudkar, A., Bhusari, C., Khedkar, A., Parekar, A., & Daf, S. P. (2017). Automatic stretcher cum wheelchair. *International Research Journal of Engineering and Technology (IRJET)*, *4*(3), 1659-1663.

Hong, H. S., Seo, T., Kim, D., Kim, S., & Kim, J. (2013). Optimal design of hand-carrying rocker-bogie mechanism for stair climbing. *Journal of Mechanical Science and Technology*, *27*, 125-132.
https://doi.org/10.1007/s12206-012-1212-y

Kim, D., Hong, H., Kim, H. S., & Kim, J. (2012). Optimal design and kinetic analysis of a stair-climbing mobile robot with rocker-bogie mechanism. *Mechanism and machine theory*, *50*, 90-108.
https://doi.org/10.1016/j.mechmachtheory.2011.11.01

Liu, Y. S., Feng, Y. P., Xie, J. X., Luo, Z. J., Shen, C. H., Niu, F., ... & Zhu, H. (2012). A novel first aid stretcher for immobilization and transportation of spine injured patients. *PLoS One*, *7*(7), e39544.
https://doi.org/10.1371/journal.pone.0039544

Lim, S. H., & Ng, P. K. (2021). Synthesisation of design features for multifunctional stretcher concepts. *Journal of medical engineering & technology*, *45*(2), 145-157.
https://doi.org/10.1080/03091902.2021.1873442

Pandey, A., Kumar, A., Diwan, T. D., Hasan, M. E., Mohanty, R. L., & Gour, S. S. (2022). New concept-based six-wheels rocker-bogie robot: design and analysis. *Materials Today: Proceedings*, *56*, 726-734.
https://doi.org/10.1016/j.matpr.2022.02.243

Seo, T., Ryu, S., Won, J. H., Kim, Y., & Kim, H. S. (2023). Stair-climbing robots: A review on mechanism, sensing, and performance evaluation. *IEEE Access*, *11*, 60539-60561. https://doi.org/10.1109/ACCESS.2023.3286871

Verjans, M., Schütt, A., Schleer, P., Struck, D., & Radermacher, K. (2018). Postural workloads on paramedics during patient transport. *Current Directions in Biomedical Engineering*, *4*(1), 161-164. https://doi.org/10.1515/cdbme-2018-0040

Wang, S., & Li, Y. (2016). Dynamic Rocker-Bogie: Kinematical Analysis in a High-Speed Traversal Stability Enhancement. *International Journal of Aerospace Engineering*, *2016*(1), 5181097. https://doi.org/10.1155/2016/5181097