Journal of Young Investigators Research

Effect of Rocker Double Lambda Mechanism on Mobile Robot

Abdullah Cihan Ozdemir[1*], Sancar Akbasak[1], Yusufcan Tezel[1], Ecem Sert[1], Cengiz Jamal[1]

Since the end of the 19th century, mobile robots, called autonomous systems, have evolved to satisfy environmental needs. The use of mobile robots has increased with the development of mechanism studies. The suspension mechanism, which allows to satisfy these needs, continues to evolve as part of the mobile robot. The wheel-based suspension mechanism enables the robot to operate in conditions, which plays an important role in the operation of the robots in difficult geographical conditions such as rough terrain. The rocker Bogie on Mars is widely preferred as a mobile robot because it overcomes obstacles that are 1.5 times higher than the diameter of the robot wheel. In this study the mechanisms were combined to improve the efficiency with respect to obstacle. The double lambda mechanisms have been symmetrically and integrated into the rocker bogie mechanism. This study focused on the design stages of rocker double lambda bogie mechanism on a mobile robot, which could be used for search and rescue missions in rough terrain conditions. The effect of the double lambda mechanism on the rocker bogie mechanism was investigated and studied to develop the mechanism. With some iterations in the design, the results show that the rocker double lambda bogie mechanism overcomes the design constraints, environmental and geographical barriers more easily than the rocker bogie mechanism.

INTRODUCTION

Systems that take a movement, transform it into another movement or transmit the movement are called mechanisms. Robots are machines that act intelligently depending on their mechanical systems and associated control and detection systems and computer algorithms. The utility of mobile robots have expanded from entertainment, to toys and military tasks (Volos et al., 2013) to perform search and rescue missions to search mission and rescue protocol applications. Mobile robots are robots that are not fixed to a physical point and can perform a desired function by moving in a defined environment (Tzafestas, 2014). The use of robots in search and rescue operations is necessary for fast intervention. The robots help to identify the location of disaster victims, assess the situation and rescue them (Murphy et al., 2008). The importance of search and rescue mobile robots has been understood after they were tried in space (Barlas, 2004). The first striking example of the use of mobile robots in space research was the Sojourner, which was launched by NASA on December 4, 1996 and landed on Mars on July 4, 1997 (Fiorini, 2000). Rocky 7 was moderated with respect to Sojourner using modern computer system, comparable in mass and size (Volpe et al., 1996). Some of the other robots designed to use on Mars are Micro5 (Kubota et al., 2003) and Mars Exploration Rovers (MER) (Tunstel et al., 2003), produced in Japan and the USA, respectively. For climbing a 150 mm obstacle, a 100 mm wheel diameter is sufficient for the Micro5. Additionally, Micro5 rover is more compact, has a lighter weight and low power consumption (Kubota et al., 2003).

Address correspondance to:
[1]Department of Mechanical Engineering, Izmir Institute of Technology, 35430, Urla İzmir, Turkey
*abdullahcihanozdemir@gmail.com

doi:10.22186/jyi.37.5.51-56

Except where otherwise noted, this work is licensed under *https://creativecommons.org/licenses/by/4.0*

Acceptance date: February 2020
Publication date: May 2020

Different mechanism and control types are used for mobile robots such as the mobile parallel robot (Li et al., 2018), the one-actuator mobile robot (Ito et al., 2019), the flip mechanism (Liu et al., 2018), and the hybrid locomotion mechanism (Tanaka et al., 2017). The mobile robot that is investigated in this study is designed to operate on rough surfaces, resist the challenging conditions, obtain visual data and carry necessary supplies. The primary purpose of creating this robot is to ensure the efficiency of rescue operations in which this robot may be employed. The video and image transmission from machine to receiver is provided by distanced-operation which enables it to reach the mobile robot even in rough terrain to enable its functioning. For these goals, the rocker double lambda bogie mechanism will be tested in Mars exploration rover. Developed in early 1990s, the “rocker bogie” features excellent weight distribution in various positions. The rocker bogie mechanism

© Ozdemir et al., 2020

is more compact, faster and better suited for rough terrain than a leg mechanism. This mechanism is also preferred for different fields of engineering as it can be employed solar energy (Murambikar et al., 2019), in Mars Rover (Nguyen, 2017), and for climbing (Hong et al., 2013). The main reason for working on the rocker double lambda bogie mechanism is that it provides greater stability in comparison with other mechanisms. Besides stability, another advantage advantages of the wheeled machine is its mobility.

The aim of this study is to design a mobile robot and to assess the rocker double lambda bogie mechanism's effect on a mobile robot.

METHODS

The rocker bogie mechanism is a kind of suspension mechanism which has six wheels and six actuators. The right and left sides of the rocker bogie mechanism move independently, which helps the two sides of the apparatus to climb over obstacles of different sizes *s*. The robot can clear the obstacles twice as high as its wheel diameter (Barlas, 2004). Instead of using standard rocker bogie mechanism, rocker double lambda bogie mechanism was utilized. The standard rocker bogie mechanism has an overturn problem that creates a moment due to the obstacle reaction force (Figure 1a). Pivot joint is connection point between rocker linkage and bogie linkage and F_{obs} means obstacle force to climb. To resolve this problem, the linear suspension mechanism is used (Figure 1b).

In order to calculate the rest of the dimensions, the center of mass was assumed as point *O* (Figure 2). The assumption was based on the fact that point *O* is the connection point between the legs and the body with the shaft, and most of the weight should be located on the virtual line drawn between the above parts of the robot. After that, the body was arranged to actualize this assumption.

To be able to find the d_2 and d_1 (Figure 2) values, a momentum equation was taken according to point *O*.

$$\text{Equation 1: } M_o = (F_{rear} + F_{middle}) \cdot d_2 - F_{front} \cdot d_1$$

$$\sum M_o = 0$$

$$(F_{rear} + F_{middle}) \cdot d_2 = F_{front} \cdot d_1$$

However, Equation 1 could not be solved without knowing reaction forces on wheels. In order to solve this equation, $\frac{d_2}{d_1}$ ratio was assumed to be 1. We assumed that symmetric the wheels experienced equal reaction forces. Later, to be able to find the d_2 and d_1 distances, $\left|\frac{CB}{2}\right| = |BA|$ assumption was made. Therefore, the ratio between the reaction forces on the wheels was

$$2F_{rear} = 2F_{middle} = F_{front}$$

After using equation 1, the correlation results were as below.

$$d_1 = 146.1 \text{ mm}$$

$$d_2 = 146.1 \text{ mm}$$

$$d_3 = 146.1 \text{ mm}$$

So the total length of the mechanism was calculated to be $d_1 + d_2 + d_3 = 438.3$ mm.

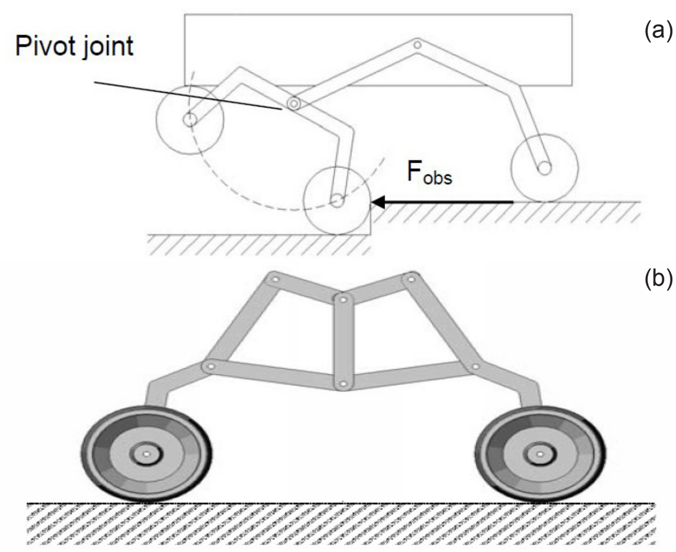

Figure 1. (a) Standard rocker bogie mechanism and overturn problem (b) Rocker double lambda bogie mechanism. A commonly used rocker bogie mechanism is pictured as described in the literature. The rocker bogie mechanism was combined with the double lambda mechanism to observe efficiency of combining.

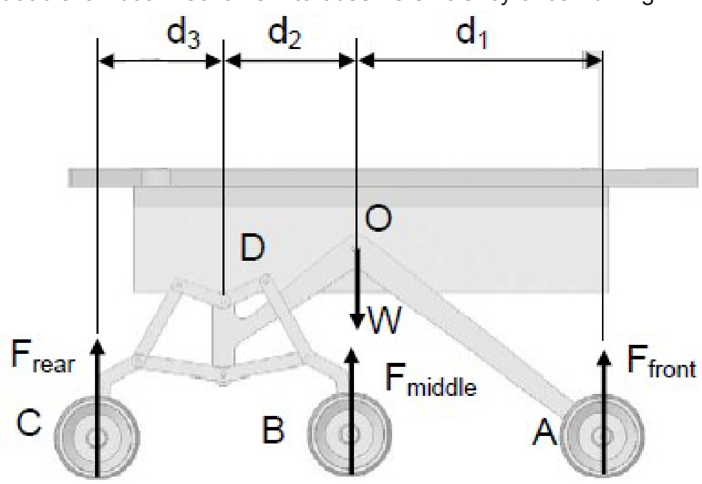

Figure 2. Force Analysis of the Rocker Double Lambda Bogie Mechanism. The locations of the rear and middle wheels can be determined by force analysis of the wheel reactions on the mechanism.

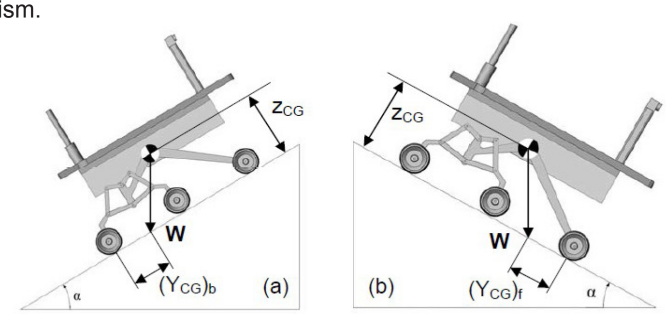

Figure 3. Representation of Downhill Rear and Front Stability Margin. The robot not only moves straight, but also must keep its balance horizontally and vertically. Stability margin is calculated with this free body diagram.

© Ozdemir et al., 2020

Some design criteria were specified for this study; this mechanism should be able to walk on a straight path and turn left/right, go up/down 30° inclined (non-slippery) surfaces, move on rough terrain (with rocks or other obstacles up to 10 cm in height) and be as compact as possible. The mobile robot was designed according to downhill gradeability and cross hill gradeability (Figure 3, Figure 4). The center of gravity distance on the *z* and *x* axis is calculated by using equations 2 and 3, respectively and a safety margin (*SM*) of 0.3 is taken for two cases.

Equation 2: $Y_{CG} \geq Z_{CG} \tan(\alpha)(1 + SM)$

Equation 3: $X_{CG} \geq Z_{CG} \tan(\alpha)(1 + SM)$

By using equations 2 and 3, the width and height of the mechanism were calculated. These results are shown below.

$$Z_{CG} \leq 194.65 \text{ mm}$$
$$X_{CG} \geq 142.6 \text{ mm}$$

The height of the mechanism should be less than 200 mm while the width of the mechanism should be larger than 300 mm (142.6 mm was half of the width).

A critical point was determined by static analysis and fabrication of the mobile robot was started. The thickness of links were calculated by using Von Mises equation (Equation 4). No torsion was observed for the critical point at O (Figure 5) and the total weight of the robot was nearly 4 kg. It was observed that a 2 mm thickness of aluminum would be enough for this study.

Equation 4: $\boldsymbol{\sigma}_{VM} = \sqrt{(\sigma^2 + 3\tau^2)}$

To make it more able to resist axial loads, it was decided to use a double layer of sheet aluminum (Figure 6).

A differential system is arranged in the body using bevel gears, journal bearings and an aluminum plate (Figure 7). Additionally, the differential is located in between the right and left rockers to stabilize the body position. Its working principle is that while the climbs that robot clears the obstacles on one side, the mechanism rotates the main body around the connections of the two sides.

Plexiglass was preferred for the face covering as it provides less weight and the interior of the body can be easily seen. Plexiglass were manufactured with a laser cutter in order to be more accurate. The aluminum profiles were cut at a 45° angle with a miter cutting machine. However, in order to start the assembly of the body, the differential should be assembled first (Figure 8).

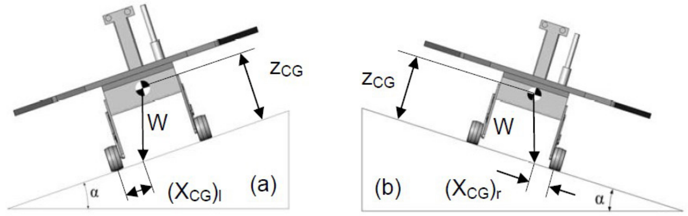

Figure 4. Representation of Cross Hill Stability Margins. The robot was designed to go up and down 30°. Lateral stability margins and dimensions were calculated for maximum slope by this diagram.

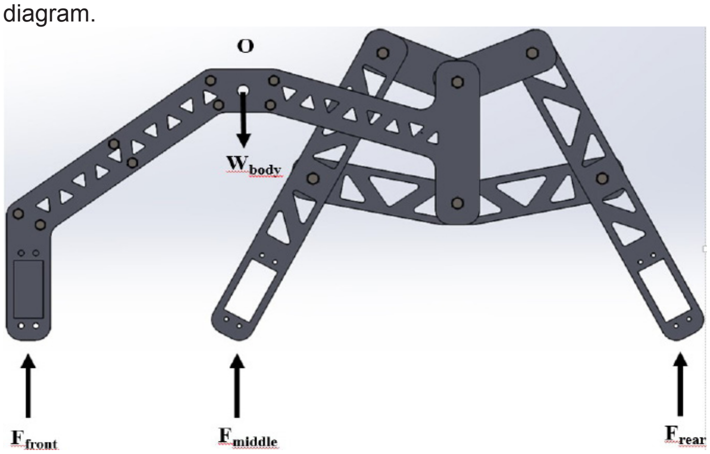

Figure 5. Static Analysis of the Suspension Mechanism. The critical point of the suspension mechanism with Von Mises was found as *O*. It was determined that the robot can carry 4 kg of weight.

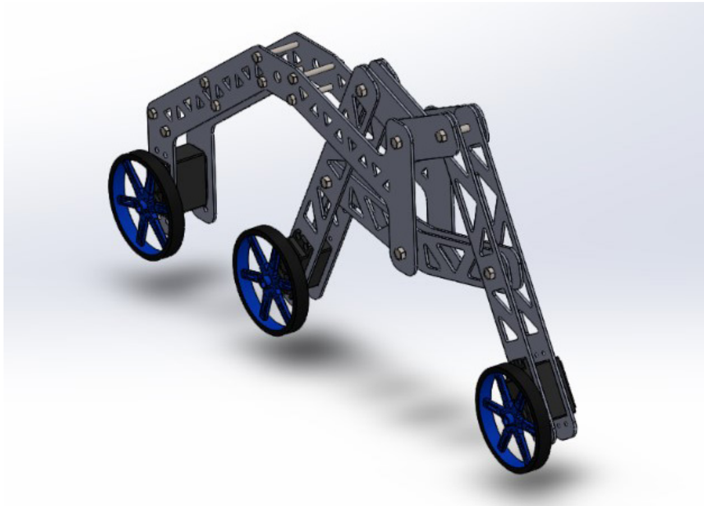

Figure 6. Representation of double layer of sheet aluminum. To make the robot more resist able to axial loads, it was decided to use double layer of sheet aluminum.

RESULTS

A microcontroller that preferred Arduino was used for control of the mobile robot. The progress started by giving the desired command to the mobile robot using the Input device. A command is sent to the Arduino, then the control signal is sent by an Rf data transmitter to the mobile robot. These control signals which are obtained by receiver are processed by Arduino. Then, the commands are sent by the Arduino motor shield to the servos. To obtain information about the ambit of the walking machine, a camera compatible with Arduino will be used. Video will be sent to the LCD using the Rf video transmitter and receiver will be used. The Arduino user will recieve information from the LCD and give commands to the mobile robot. Simply, it is the control system of

© Ozdemir et al., 2020

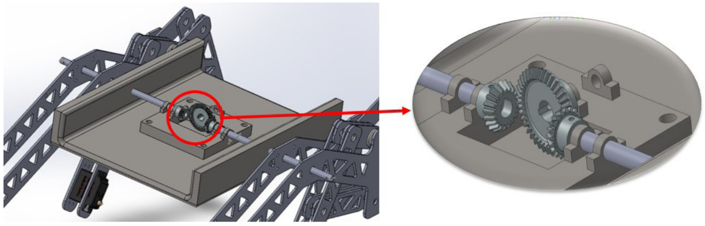

Figure 7. Differential gear mechanism between right and left rockers. One of the two mechanisms designed enables the other mechanism to move in balance while climbing the obstacle.

Figure 8. Assembly of body part. Two rocker double lambda bogie mechanisms and differential system are mounted and connected to a body consisting of plexiglass and aluminum.

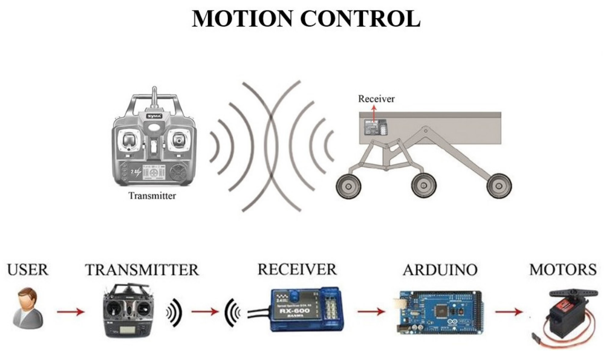

Figure 9. Motion control of mobile robot. For the mechanism to move from pillar to post, the joystick (transmitter) and mobile robot must be in contact.

Table 1. Applied tests and results. Six different tests were applied on mobile robot to obtain stability, over-jump, climbing, movability, road handling and traction. Results show us that rocker double lambda bogie mechanism is similar with other mars rovers. However, as the biggest difference between rocker double lambda bogie mechanism and rocker bogie, the mobile robot can overcome obstacles double diameter of the wheel thanks to the double lambda mechanism.

Tests	Results
Over-jump	Can jump more than 10 cm obstacle
Stability	Can be provided by using differential system
Climbing	Can climb 30°-inclined roads
Movability	Can move in and out - horizontal mobility
Road handling	Limitation of movement cannot be observed
Traction	Limitation of movement can be observed

Figure 10 Obstacle test of suspension mechanism. In mobile robot production, it was determined that the design criterion could exceed 10 cm height. This test shows that mechanism can easily over jump at least 11 cm.

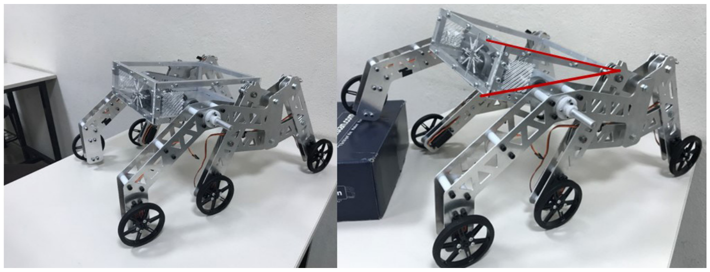

Figure 11. Illustration of Stabilize test for body. This test showed that the assembled robot can balance the leg mechanisms.

Figure 12. Climbing test for the whole system. With this test, it has been seen that the rocker bogie mechanism can climb the 30 degree slope.

the mobile robot. For the mechanism to move from pillar to post, the joystick (transmitter) and mobile robot must be in contact (Figure 9).

Both during production and after installation is completed, the aim of the tests is to monitor the system's operation path and determine the deficiencies. Then, tests were divided by two main parts which are sub-system tests and whole tests (Table 1). One of the important design criteria is that the mobile robot should be able to move on rough terrain. The suspension mechanism can easily jump over obstacles with both the rocker part and bogie part without singularity (Benamar et al., 2010; Alamdari et al., 2013). The significant criteria for the body is that the body should not topple when climbing 30 degree inclined roads or jump over a 10 cm obstacle (Figure 10). The balance of the robot could move forward (Figure 11) and the robot is positioned at a certain angle while it was climbing. To promote stability, a differential system was used on the body.

Load capacity, mobility, climbing, obstacle and stability tests were determined as the whole system tests. The climbing and obstacle tests could also be performed as sub-system tests. The navigation of 30 degree inclined roads is an important criterion for a mobile robot, hence a climbing test was applied. It climbed easily thanks to motor power (Figure 12).

© Ozdemir et al., 2020

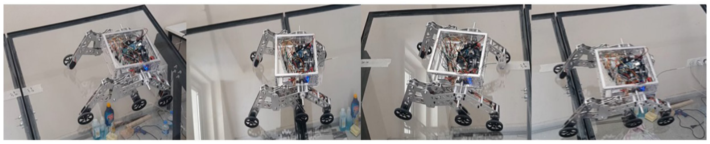

Figure 13. Horizontal motion of mobile robot. It has been tested that rocker bogie mechanism can not only go 30 degrees vertically, but also horizontally, and successful results have been obtained.

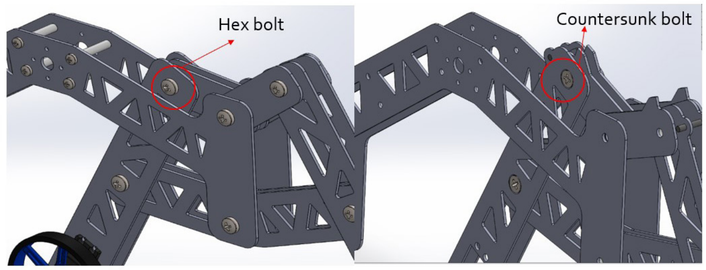

Figure 14. Iteration of stuck problem is solved with using countersunk bolt instead of hex bolt. The design, production and post-production of the project some problems were observed, and these problems caused the iteration in the design. One of the iterations is about stuck problem. In the first design, hex bolts were used on the suspension mechanism. However, the bolt head that is attached to the bogie part rubs against the rocker part restricts the movement. A countersuck bolt could be used instead of hex bolt due to availability and applicability.

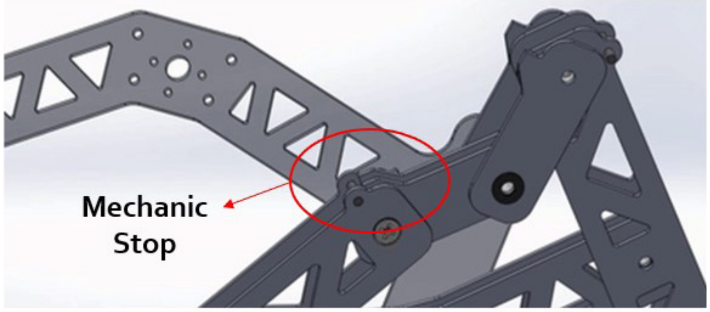

Figure 15. Representation of the mechanic stop to solve the singularity problem. The Double Lambda mechanism can restrict the right and left sides of the bogie and this are called as singularity. We solve this problem with using mechanic stop as stopper.

Gradeability calculations were done for the robot in order to move horizontally on the inclined surface (Figure 13). In other words, this mobile robot should move horizontally, so down-hill and cross-hill gradeability calculations were done and the center of mass of the height should be less than 194 mm, and 65 mm as determined in Materials and Method part.

The design, production and post-production of the project presented some problems, and these problems caused the multiple iterations in the design. One of the iterations was related to the stuck problem. In the first design, hex bolts were used on the suspension mechanism (Figure 14).

After production of suspension mechanism like stuck problem, another problem was observed and it was about singularity. In order to solve singularity part, two solutions can be tried. One of them is that a spring can be used to create reverse force, and the other solution is that a solid link extension can be used to limit the link motion. With respect to manufacturability and workshop opportunity, option two was preferred. and for this issue mechanic stops and two parts which name are shortest and longest links were redesigned (Figure 15). Two double lambda mechanisms are usually preferred to solve the singularity problem instead of the rocker-bogie system (Barlas, 2004). However, the two double lambda mechanisms should be connected symmetrically.

DISCUSSION

The aim of this study was to observe the effect of the rocker double lambda bogie mechanism on a mobile robot. Conceptual design was done after literature review. This mechanism in this study was designed by combining the bogie mechanism and lambda mechanism. Then, the study was evaluated in light of design requirements, and the trajectory of the study determined.

First, the mechanisms were investigated. According to our study, it was observed that the rocker double lambda bogie suspension mechanism is more feasible for this design. The main reason for choosing the rocker double lambda bogie suspension mechanism is to obtain greater stability. Moreover, the suspension mechanism possesses less actuators, and the mobile robot has to be as compact as possible. The suspension mechanism consists of six wheels with a symmetrical structure. Each side possesses three links which are connected to each other via two links, which are the rocker and lambda links. The main linkage is the rocker and the secondary is the double lambda. Another significant advantage of the rocker double lambda bogie mechanism is its ability to climb up to 1.5 times the wheel diameter.

Actuators are devices that provides the motion of the robot. In this study, an electric motor (servo motor) was selected as the actuators. The main reason for using a servo motor was that it allows for greater controllability and position accuracy. The mobile robot can be supplied with a battery.

The obstacle capability, which is 1.5 times the wheel diameter, is doubled with this design. With the double lambda mechanism and iterations used, the mechanism size was reduced compared to other classical mars rovers. Different iterations not only contributed to the size of the mechanism, but also solved singularity and friction problems.

The production of the mechanism and the applicability of the new design are not physically problematic. Production can be achieved by using conventional methods or by laser cutting and does not require processes such as machining after production. Therefore, the production cost can be kept as low as possible.

Nowadays, even though the electronic aspect of robots has become popular, mechanism technique and design have not lost their importance. In this study, a different design has

© Ozdemir et al., 2020

been realized by using a four-bar mechanism which is one of the fundamentals of mechanism technique. In addition, this study aimed to contribute to the literature of mechanism technique.

Future studies should investigate the detailed dynamic analysis of this mechanism. In addition to the tests performed in this study, a number of different tests can be simulated and performed under real conditions.

ACKNOWLEDGEMENTS

This work was supported by Faculty of Engineering, Izmir Institute of Technology. Authors would like to thank Dr. Gokhan Kiper, the advisor of the thesis.

REFERENCES

Alamdari, A., Herin, R., and Krovi, V. N. (2013). Quantitative kinematic performance comparison of reconfigurable leg-wheeled vehicles. *16th International Conference on Climbing and Walking Robots*, Sydney, 585-592. available: doi.org/10.1142/9789814525534_0074.

Barlas, F. (2004). *Design of a Mars Rover Suspension Mechanism*, İzmir: Institute of Technology, İzmir.

Benamar, F., Bidaud, P., and Menn, F. L. (2010). Generic differential kinematic modeling of articulated mobile robots. *Mechanism and Machine Theory,* 45, 997-1012, available: doi.org/10.1016/j.mechmachtheory.2010.02.004.

Fiorini, P. (2000). Ground mobility systems for planetary exploration. *IEEE International Conference on Robotics and Automation*, San Francisco, 908-913. available: 10.1109/ROBOT.2000.844164.

Hong, H. S., Seo, T. W., Kim, D., Kim, S., and Kim, J. (2013). Optimal design of hand-carrying rocker-bogie mechanism for stair climbing. *Journal of Mechanical Science and Technology,* 27(1), 125-132, available: doi.org/10.1007/s12206-012-1212-y.

Ito, S., Sugiura, S., Masuda, Y., Nohara, S., and Morita, R. (2019). Mechanism and control of a one-actuator mobile robot incorporating a torque limiter. *J Intell Robot Syst,* 97, 431–448, available: doi.org/10.1007/s10846-019-01036-8.

Kubota, T., Kuroda, Y., Kunii, Y., and Nakatani, I. (2003). Small, leightourght rover Micro5 for lunar exploration. *Acta Astronautica*, 52, 447-453, available: doi.org/10.1016/S0094-5765(02)00187-X.

Li, Y., Yao, Y., and He, Y. (2018). Design and analysis of a multi-mode mobile robot based on a parallel mechanism with branch variation. *Mechanism and Machine Theory*, 130, 276-300, available: doi.org/10.1016/j.mechmachtheory.2018.07.018.

Liu, P., Wang, J., Wang, X., and Zhao, P. (2018). Optimal design of a stair-climbing mobile robot with flip mechanism. *Advanced Robotics*, 32(6), 325-336, available: doi.org/10.1080/01691864.2018.1448299.

Murambikar, R., Omase, V., Nayak, V., Patil, K., and Mahulkar, Y. (2019). Design and fabrication of rocker bogie mechanism using solar energy. *International Research Journal of Engineering and Technology,* 6(4), 143-147.

Murphy, R. R., Tadokoro, S., Nardi, D., Jacoff, A., Fiorini, P., Choset, H., and Erkmen, A.M. (2008). *Search and Rescue Robotics,* Berlin: Springer.

Nguyen, N. T. R. (2017). *Repairing FPGA configuration memory errors using dynamic partial reconfiguration,* Sydney:The University of New South Wales.

Tanaka, K., Zhang, D., Inoue, S., Kasai, R., Yokoyama, H., Shindo, K., Matsuhiro, K., and Marumoto, S. (2017). A design of a small mobile robot with a hybrid locomotion mechanism of wheels and multi-rotors. *International Conference on Mechatronics and Automation*, Takamatsu, 1503-1508, available: 10.1109/ICMA.2017.8016039.

Tunstel, E., Huntsberger, T., Aghazarian, H., Backes, P., Baumgartner, E., Cheng, Y., Garrett, M., Kennedy, B., Leger, C., Magnone, L., Norris, J., Powell, M., Trebi-Ollennu, A., and Schenker, P. (2003). FIDO rover field trials as rehearsal for the NASA 2003 Mars exploration rovers mission. *Proceedings of the 5th Biannual World Automation Congress,* 14, 320-327.

Tzafestas, S. G. (2013). Introduction to mobile robot control., Elsevier.

Volos, C. K., Doukas, N., Kyprianidis, I. M., Stouboulos, I. N., and Kostis, T. G. (2013). Chaotic Autonomous Mobile Robot for Military Missions. *17th International Conference on Communication*, Greece, 197-202.

Volpe, R., Balaram, J., Ohm, T., and Iyley, R. (1996). The rocky 7 mars rover prototype. *EEERSJ International Conference on Intelligent Robots and Systems*, Osaka, 1558-1564, available: 10.1109/IROS.1996.569020.

© Ozdemir et al., 2020