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VIBRATION STEERING OF A VIBRATION-DRIVEN MOBILE ROBOT [1]

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Abstract: *This paper presents a method and control devices aimed at vibration steering of a vibration-driven mobile robot, previously designed, developed, tested and reported. To achieve a proper steering of the robot its control system is properly modified and fitted out with a two-way control unit. The proposed steering method is based upon a specially arranged transmission of the generated vibrations by the robot's propulsion mechanism to the chassis through the stationary wheel's shaft. There is no steering mechanism involved as it is in the modern motor vehicles, but pulsing turning moments are generated and applied to the robot chassis through the wheel's shaft in a diagonal manner. The approach appears to be applicable but requires more powerful turning moments, because when turning the lateral sliding of the wheels has to be overcome. After testing, it seems that the turning moments are not enough. To improve and verify this idea a new vibration-driven robot with independent elastic suspensions of the wheels, having novel internal vibration transmission to the wheels and more powerful propulsion mechanism is designed built and tested. The proposed idea is found to work very well and the turning effect of the robot is greater than in the previously developed robot version. Moreover, to increase the vibration steering effect it is also proposed to change the position of the mass centre of the robot propulsion mechanism combined together with the new steering method. This means that the mass centre of the propulsion mechanism at which the inertial force acts, has to be moved perpendicular to the direction of oscillations to the left or right as desired, generating additional turning moments, and as a result improving the turn-off abilities of the robot is expected.*

Keywords: *vibration steering, pulsing turning moments, independent elastic suspension, propulsion mechanism, vibration-driven mobile robot, steering control unit.*

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INTRODUCTION

There are many attempts in the world to invent and criate a propulsion mechanism using the driving effect of the inertial forces. Some of them which are not utilizing friction forces to propel themselves, known as inezoids (Dean N., 1959), and others using friction forces in combination with inertial forces known as inertial propulsion engines (Chernousko, F. et al 2005). Some researches applied mathematical modelling to study and predict the behaviour of such robots as in the works of Jatsun, S. N. et al 2007, Jatsun, S. V., et al 2009, while others investigate real prototypes (Bolotnik, N., et al, 2011; Provatidies G. 2014; Loukanov I.A. 2015; Loukanov I. A., Vitliemov V. G., Ivanov, V, I. 2016).

In another study, a mathematical model was criated based upon a real prototype of a vibration-driven mobile robot and its dynamics was carefully studied (Loukanov I, A. et al. 2016b). The last study concerning the progress made in the design of vibration-driven mobile robots and the advantages and disadvantages of their performances, reveiled that considerable changes have to be made in orther to allow improved control and an effective steering without using any classical stearing mechanism (Loukanov I.A., et al., 2017).

In this study, the method of steering of a vibration-driven mobile robot is proposed and considered applied to two different prototype robots having semi-independent and fully independent elastic suspensions of the wheels, respectively.

EXPOSITION

Investigating the propulsion method and steering abilities of two wheeled robots

Two different prototypes of vibration-driven wheeled robots are considered, the method of forward or backward motion and the steering to the left or to the right are discussed, and thoroully analized. The steering method is similar to the type of steering of track catapilar tractors, but applied to the wheels of the robots by means of small control DC motors driving either gear or power screw mechanisms. The effect of forward or backward motion and the steering is achieved by using one-way bearings (clutches) meshing them electro-mechanically to the robot's wheels externally or internally. The one-way bearings are mounted into friction rollers connected to linear bearings - carriers. Fig. 1 shows the sixth prototype of a vibration-driven and steering robot where the friction rollers with the one-way bearings are arranged to achieve external friction contact with the robot's wheels.

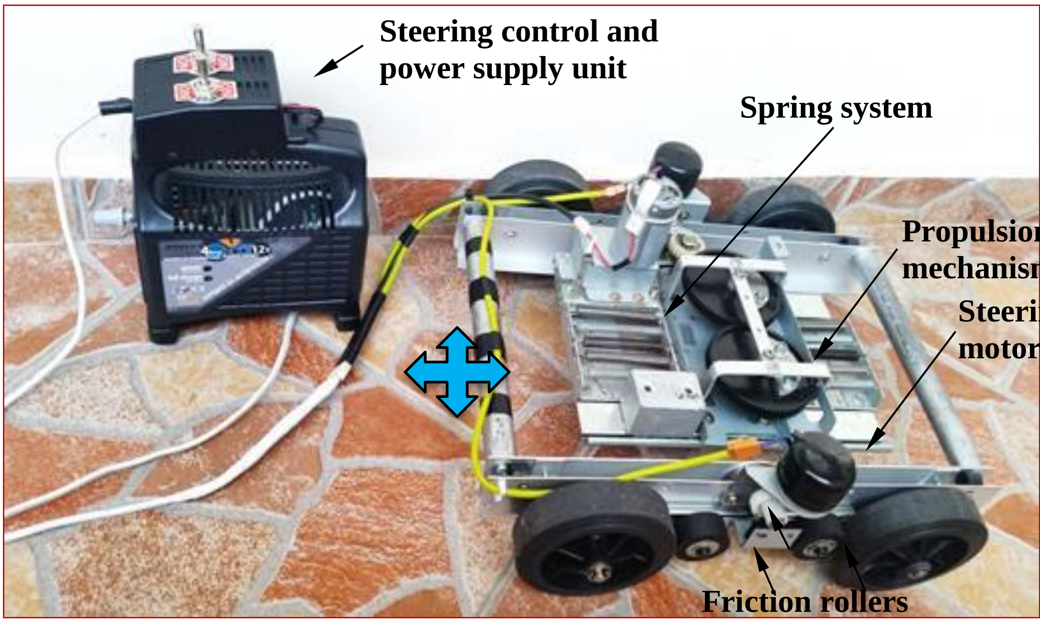

Fig. 1 displays the VI-th version of vibration-driven robot having semi-independent elastic suspension of the wheels and external coupling of friction rollers to the robot's wheels. The robot is capable of moving forward, backward and turning left or right.

Fig. 2 shows the lateral view of the above robot giving details of the control and steering mechanism as well as friction rollers. The picture shows that both rear friction rollers are coupled externally to the rear wheels, which means that the robot will be moving backward.

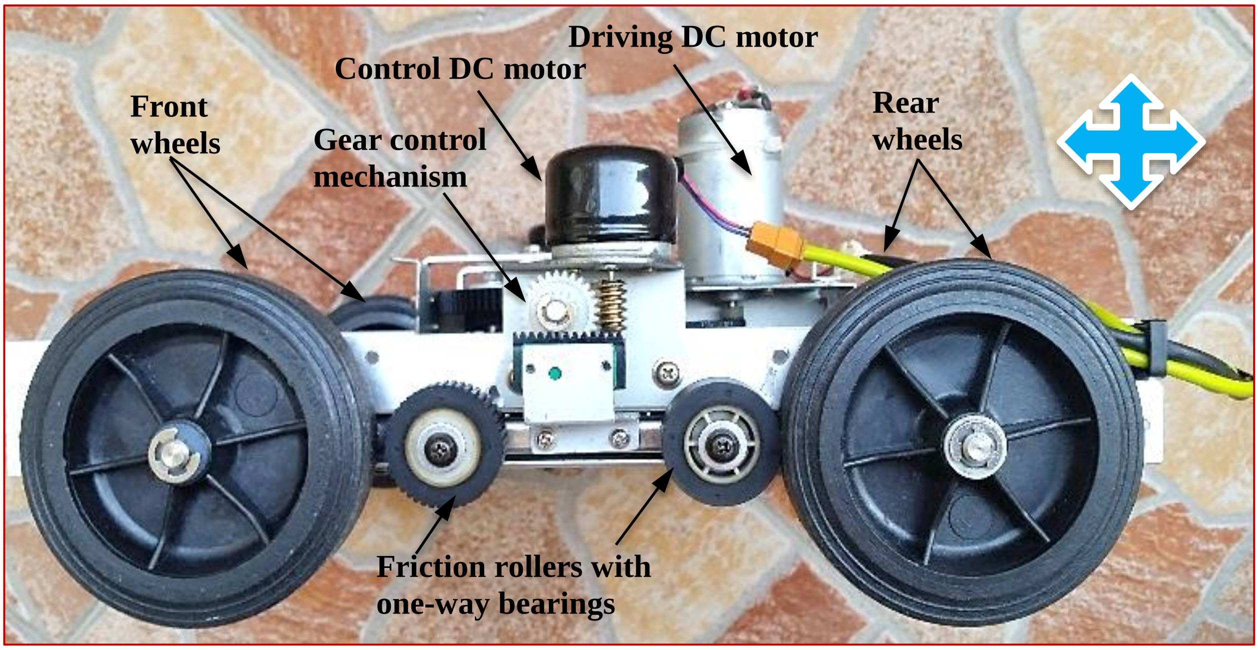

Fig. 2 gives details of the lateral view of the VI-th version of the vibration-driven and vibration-steered wheeled robot.

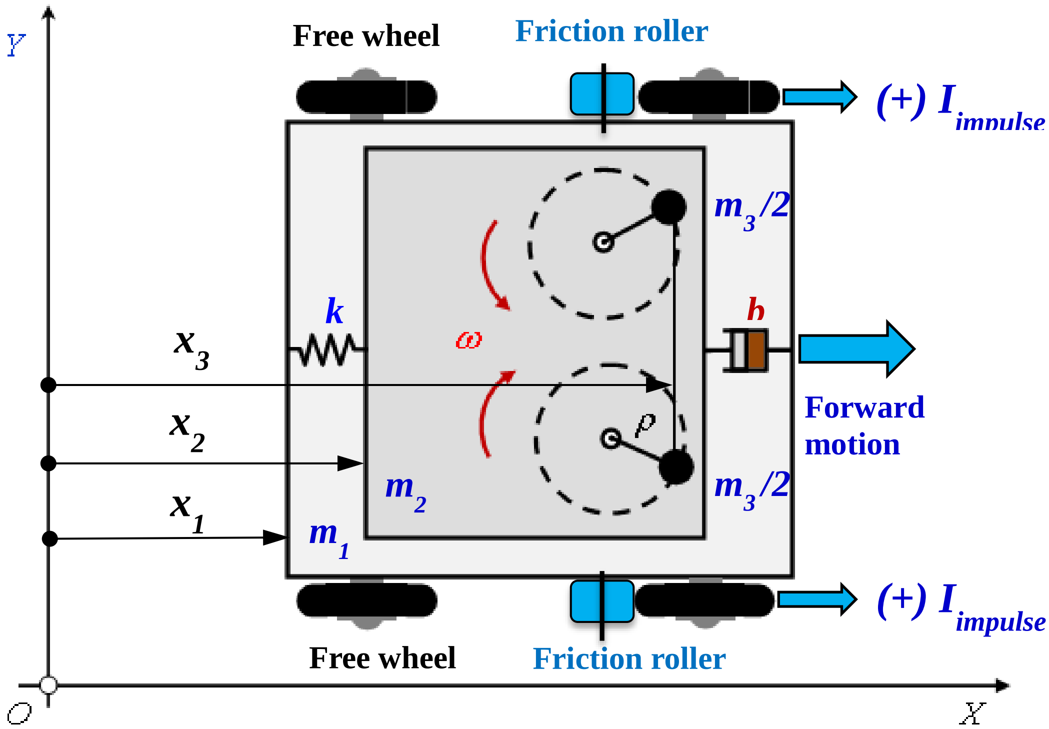

Fig. 3 displays schematically how the forward motion of the robot is achieved.

This is arranged as seen in Fig. 3, by coupling both front friction rollers through the steering mechanisms with the front left and right robot's wheels respectively. This means that only the front wheels are providing ground friction support in order to utilize the positive impulses of the inertial force. On the other hand, the friction forces between the front wheels and the ground will absorb the negative impulses of the inertial force. This may criate some problems due to the nature of the ground surface making a situation when only one of the two front wheels provides a contact with the ground and hence the propulsion effect may suffer noticeably reducing the forward motion of the robot.

To achive a reversing motion, the steering system is arranged to couple both rear friction rollers to the rear wheels respectively. Then the propulsion effect of the negative impulses of the inertial force will be utilized and backward motion of the robot will be achieved. The arrangement of the steering method is illustrated in Fig. 4 bellow.

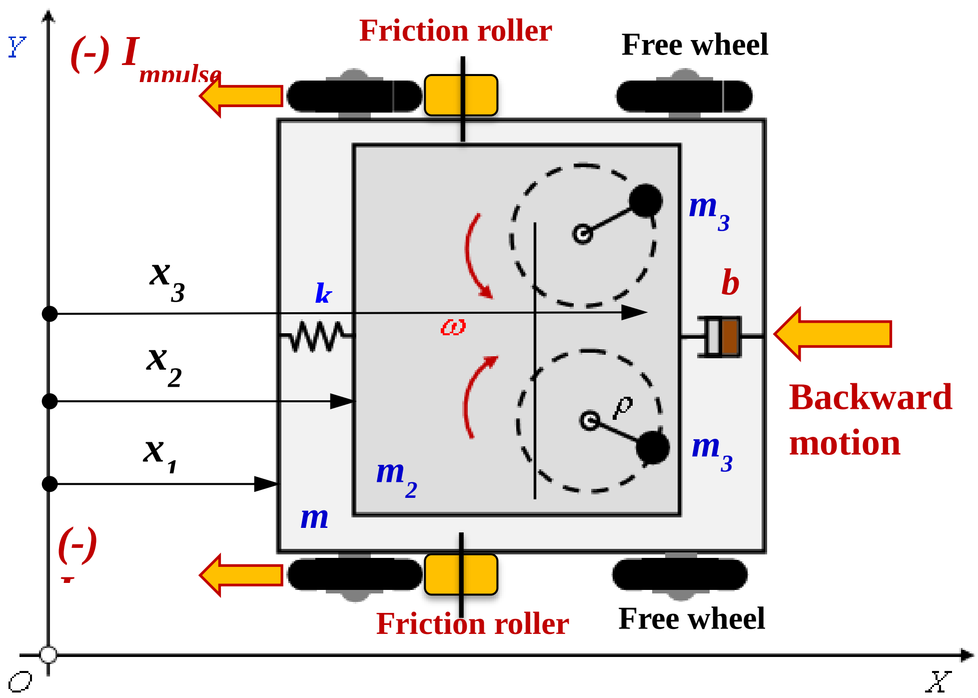

Fig. 4 shows schematically how the backward motion of the robot is realized.

The design organisation of the 6-th vertion of the vibration-driven wheeled robot allows the friction rollers to be coupled in a diagonal manner for example: left-front friction roller to couple the front left wheel and the right rear-back friction rollesr to couple the right back wheel. Under this arrangement, viewing from above a pulsing turning moment is generated in clockwise (CW) direction and the robot will be turning to the right in a pulsing manner.

Fig. 5 illustrates schematically the steering approach for turning to the right illustrating the vibration steering method incorporated in this robot. It is important to be noticed that the generated turning moment has a pulsing nature because it is generated by the moments of two consequtive inertial forces acting one after another with a time difference half of the period of oscillations of the propulsion mechanism. The forces creäting the pulsing turning moment correspond to the positive and the negative impulses of the inertial force respectively.

Contrary to the illustrations shown in Fig. 5, when the front-right friction roller get connected frictionally to the front right wheel and the rear-left friction roller get ingaged to the left rear wheel then a pulsing turning moment in CCW direction is be generated and the robot is turning to the left. This is illustrated in Fig. 6 as seen bellow.

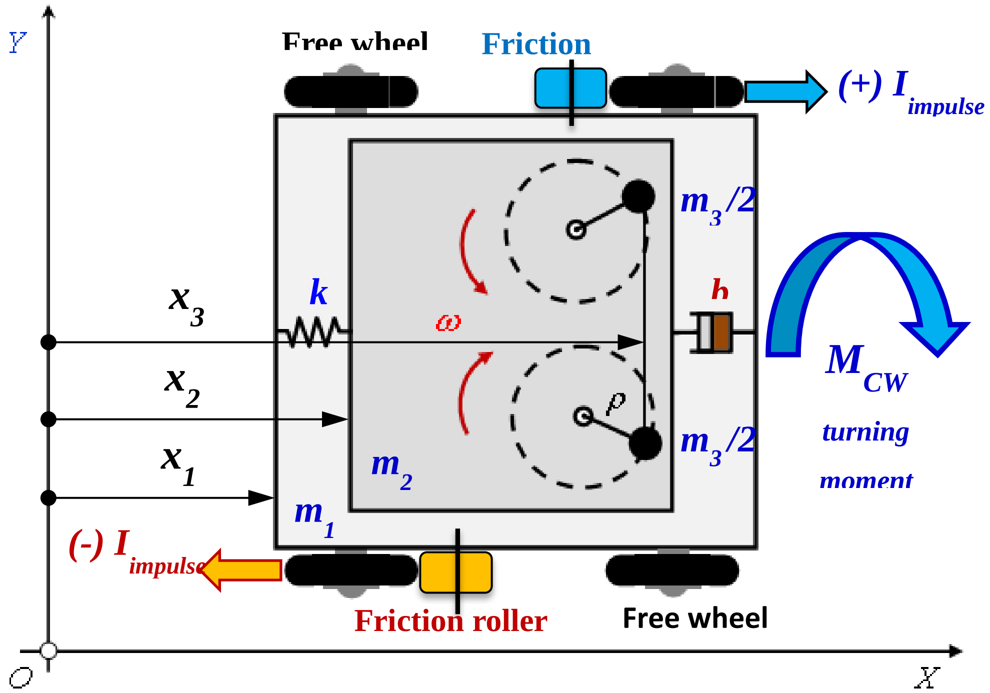

Fig. 5 exhibits the principle of turning the robot to the right.

Analyzing the mechanical performances of the sixth vertion of vibration-driven robot, the following disadvantages may be listed and commented:

- Only two out of four wheels participate in the propultion and steering process of the robot through the friction contact with the ground,
- Under specific conditions, only one wheel may provide driving effect, which weekens the propulsion and steering, this is due to the surface variation of the ground.

The contact forces between the friction rollers and the outher surfaces of the wheels are

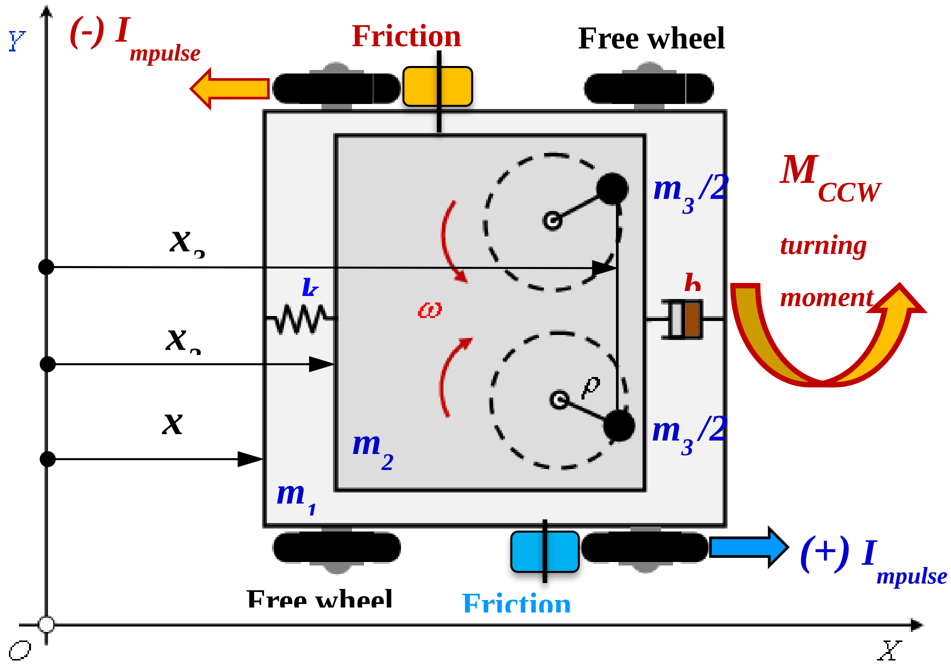

Fig. 6 illustrates the principle of turning the robot to the left.

- not enough for good propultion and steering of the robot,
- The sliding between the wheels involved in the propultion and steering processes and the ground is substantial, therefore reducing the diving effect of the negative impulsis when reversing or steering,

Considering the problems encountered with the sixth version of the vibration-driven robot it is decided to design and manufacture a completely new robot, which will be avoiding all the disadvantages observed in the sixth version. Fig. 7 presents the new robot design and illustrates the independent individual elastic suspensions of the wheels.

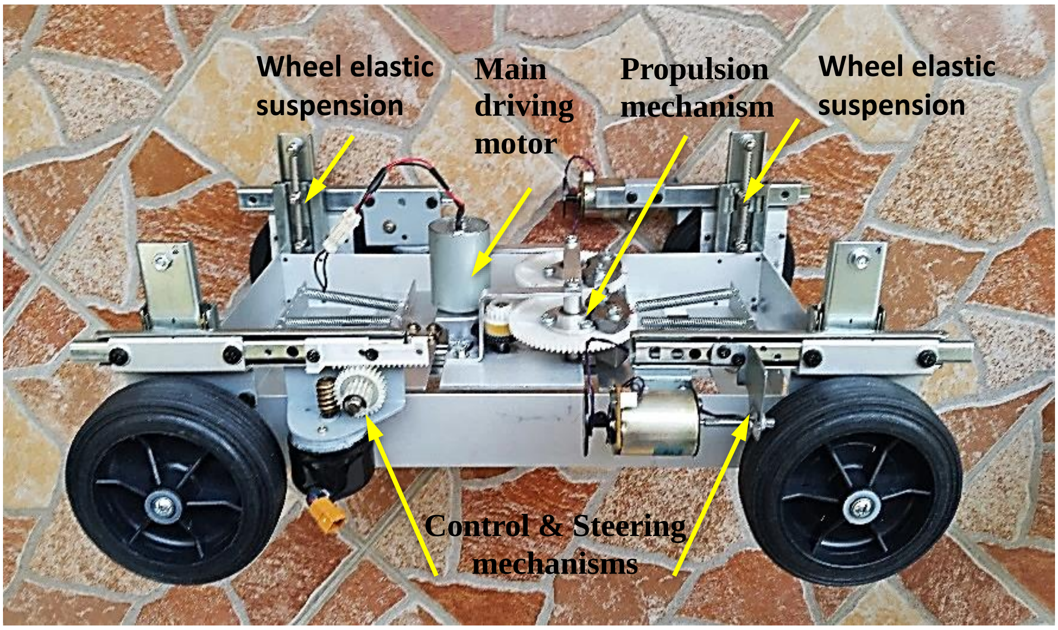

Fig. 7 presents the new seventh version of vibration-driven robot

The new version of the vibration-driven robot consisted of a low frequency propulsion mechanism attached to the chasis via a system of springs and oscillating along two linear bearings. All the springs are connected in series however some of them a connected in a non-linear fasion. The number of springs and their stiffness may vary in order to achieve a close to resonance conditions. The latter is also done by two extra masses added to the oscillation system. The resonance condition enshues strong propulsion and a large propulsion speed of the robot, Apart of the fact tht each wheel has an independent elastic suspension each of them has incorporated within their design two-friction rollers each of them having Vee-shape rubber outher surface. Similarly, the internal cylindrical surface of the wheels has the same Vee-shape to match the vee-shape of the friction rollers. It should be noted that each friction roller has integrated one-way bearing equipped with two needle bearings. The needle bearings are designed to carry the radial load acting on the friction rollers when meshing with the wheels and allow the one-way bearing to operate properly. The fricsion rollers are ingaged in friction contact with the wheels internally by means of a special steering mechanism activated electro-mechanically. For the front wheels the mechanism includes a power screw and a nut, whiles for the rear wheels it contains worm and worm gear meshing a spur rack. Both the nut for the front wheels and the rack for the rear ones are attached to corresponding linear bearings and a carrier of the friction rollers connected to the first. By activating the small DC motors of the steering mechanisms, the Vee -type of friction rollers get ingaged to the Vee-shape internal surface of the wheels. This activates the one-way bearings and achieves either forward, backward or turning motion.

Fig. 8 and Fig. 9 illustrates the steering arrangement for the forward and the backward motion of the robot accordingly, from where one can understand that all the four wheels are involved in a friction contact with the ground and utilize the positive and the negative impulses of the inertial force in achieving the forward or backward motion. As compared to the arrangement for the sixth vertsion of the robot, it is obvious that all the wheels will absorb the negative impulses of the inertial force and thus the velocity and the traction force of the robot will be doubled.

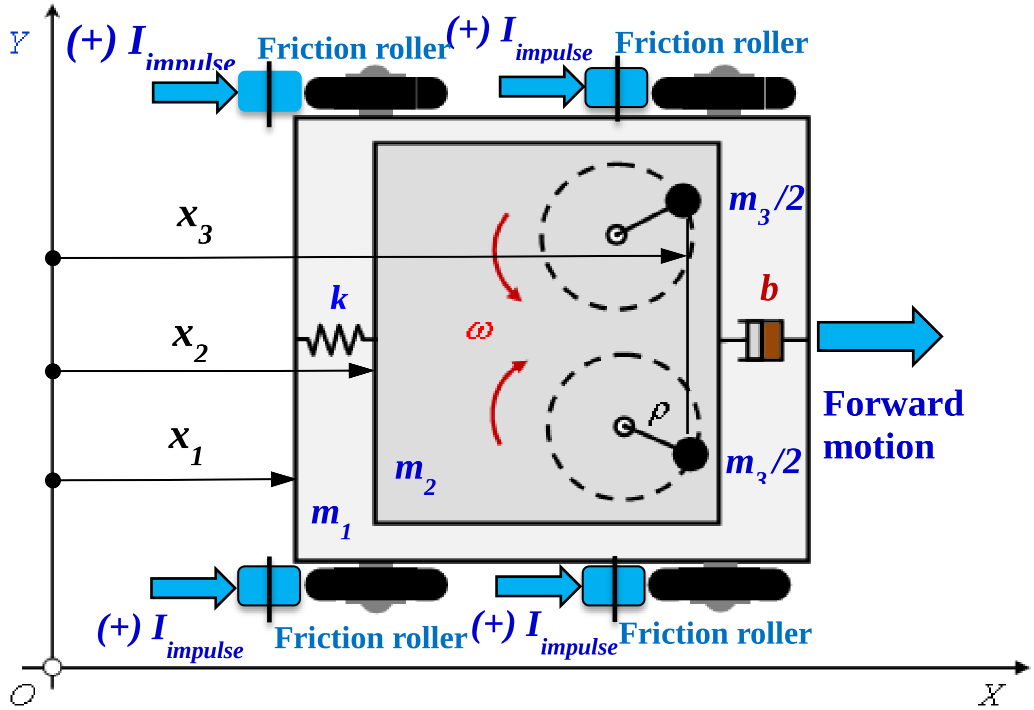

Fig. 8 demonstrates the way the forward motion of the robot is arranged.

Once again, all the wheels participate in utilizing the positive impulses of the inertial force as well as absorbing the negative impulses through friction forces of the wheels and the ground.

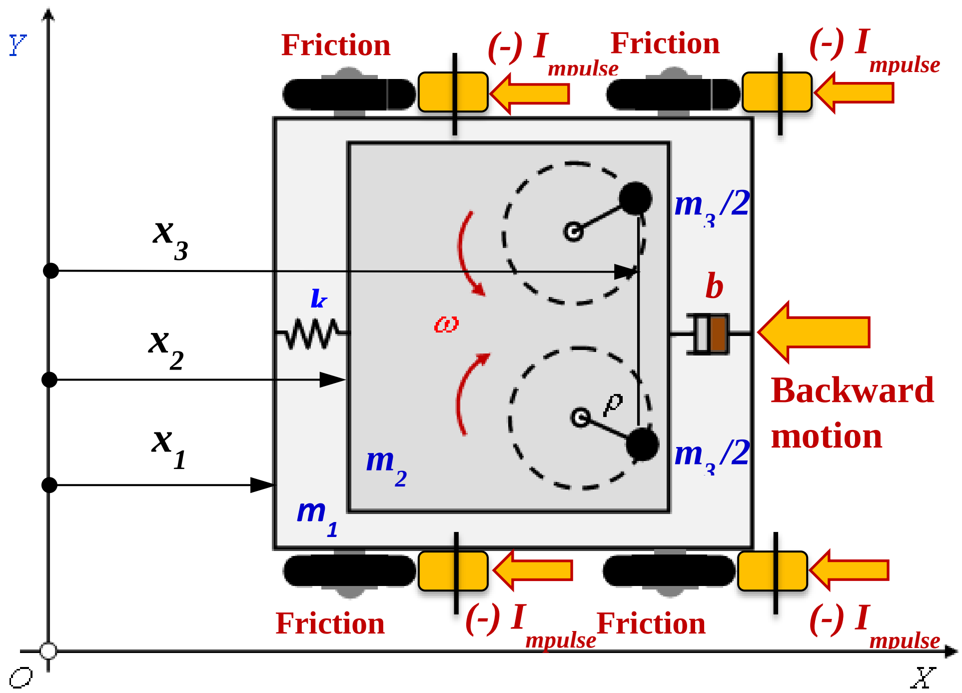

Fig.9 exemplifies the steering arrangement for backward motion of the robot

Clearly, the schematics in Fig. 10 and Fig. 11 indicate that the turning moments in these arrangements are doubled and therefore the robot will turn more efficiently and swiftly.

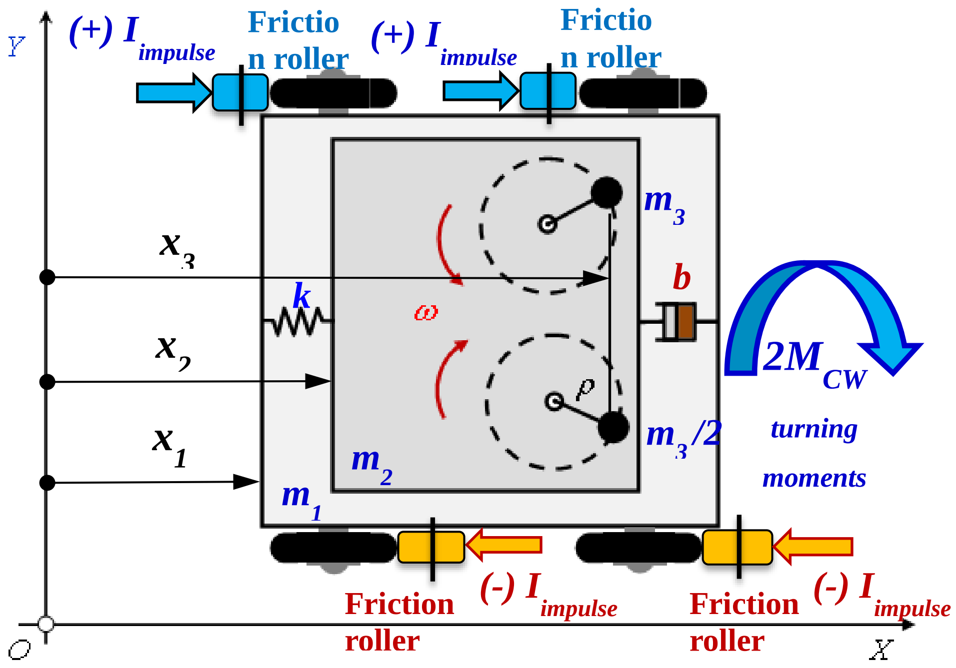

Fig. 10 illustrates the method employed for turning the robot to the right (CW)

This is because half of the wheels move forward and the other half-backward achieving stronger turning moments as compared to the previous arrangements seen in Fig.5 and Fig. 6.

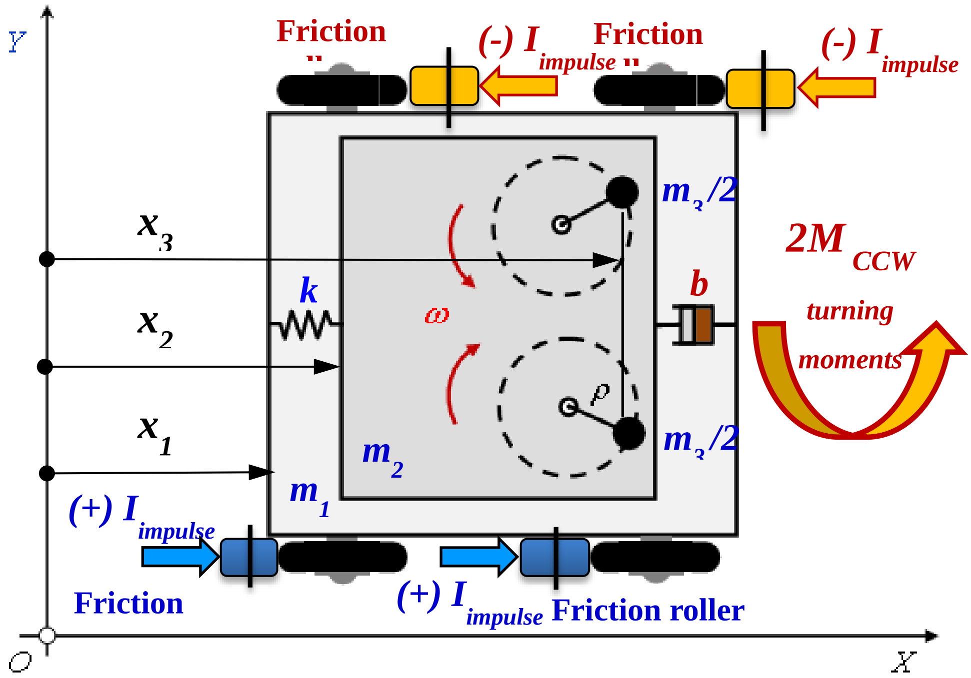

Fig. 11 presents the method employed to turn the robot to the left (CCW)

In fact, when tested the new robot turns quickly, as well as moving faster than the old version, confirming the conclusions made based upon predictions of illustrated schematics. Truthfully, the design of the new robot provides better abilities for steering and control, and for that reason, it is suggested for further advanced testing and analizes. It is proposed that the new robot should be tested for measuring the average speed in forward and backward motion, the time taken for turning at 90 degrees to the right and to the left, as well as the average value of the towing force developed during forward motion on different grounds. It will be beneficial if the robot is also tested against the size of the obstacles it can overcome.

In addition to the above, a comprihencive study is required to find out robot's mechanical parameters such as resonance frequency, forward speed, damping factor, the variation of the frictiom forces and normal reactions between the wheels and the ground to determine their influence on the robot performance. Since similar study is done on vibration-driven robot (Loukanov, 2015) where the four robot's wheels are providing friction contact with the ground. The new and old results might be compared to appreciate the effect of the new design arrangents implemented in the last version of the robot.

CONCLUSION

In this paper, a comparative study between two different designs of vibration-driven robots is performed in order to determine the quality of their steering abilities. Based on studing the schematics illustrating the steering process of both robots it is found that the design of the new robot (seventh version) is more efficient and its performance is better than the old version. This conclusion is proved by many experiments done with both robots. However, more studies and experiments are desirable for the robot to meet the industrial requirements. In addition, to increase the vibration steering effect it is also proposed to change the position of the mass centre of the propulsion mechanism combined with the vibration steering. In this regard, the mass centre of the propulsion mechanism has to be moved perpendicular to the direction of motion to the left or right as desired. This will generate extra turning moments and as a result, the turn-off abilities of the robot may be improved.

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