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A NOVEL WALKER WITH MECHANICALLY ESTABLISHED WALKING AND STANDING MECHANISM

Raša Andrejević, Goran Šiniković, Miša Stojićević, Miodrag Stoimenov, Ljubomir Miladinović, Branislav Popkonstantinović, Gordana Ostojić, Stevan Stankovski

Original scientific paper
This paper discloses the synthesis and fundamental kinematic analysis of mechanically established walking and standing mechanism, as well as the design and motion simulation of mechanical walker 3D model. Results of this simulation are exposed in various kinematic diagrams by which the operation characteristics of the mechanism and the walking ability of the proposed mechanical walker can be discussed and evaluated. Practical application of this mechanical walker covers the fields of walking rehabilitation and training in the treatment of spinal cord injured patients, as well as for standing and walking assistance of elderly and disabled people.

Keywords: *dyad, four bar linkage, kinematics, mechanism, rehabilitation, walker, 3D model*

Novi šetač s mehanički ostvarenim mehanizmom hodanja i stajanja

Izvorni znanstveni članak
Ovaj članak iznosi sintezu i temeljnu kinematičku analizu mehanički uspostavljenog mehanizma hodanja i stajanja, kao i simulaciju konstrukcije i gibanja 3D modela mehaničkog šetača. Rezultati ove simulacije izloženi su u različitim kinematičkim shemama po kojima se mogu razmatrati i ocjenjivati radne karakteristike mehanizma i sposobnost hodanja predloženog mehaničkog šetača. Praktična primjena ovog mehaničkog šetača pokriva područja rehabilitacije hodanja i osposobljavanje u liječenju pacijenata ozlijeđene hrptene moždine, kao i pomoć starijim i nemoćnim osobama za stajanje i hodanje.

Ključne riječi: *dvovalentni element, četveropolužna povezanost, kinematika, mehanizam, rehabilitacija, šetač, 3D model*

1 Introduction

Consideration, analysis and synthesis of various types of walking mechanisms can be important at least in two different fields of science. First, this study offers the contribution to the theory of kinematics, mechanisms, machines and similar fields of science and techniques. And secondly, but not of less importance, this research can be applied to the design and practical construction of walking and standing mechanisms by which the walking rehabilitation and training in the treatment of spinal cord injured (SCI) patients can be obtained. Moreover, various types of mechanical walkers and walker systems can be applied for establishing the standing and walking assistance functions for elderly and temporarily or permanently disabled people.

The problem of synthesis and design of different categories of mechanical walking mechanisms represent the respectable subject of research in modern science and technique. Thus in [1], Hong Hong Guo and co-authors described a basic method of mechanical design and virtual teaching of a two-leg walking mechanism. The fact proves that this two-leg walking mechanism is of high stability and efficient teaching. In [2], Katarina Monková and joint authors exposed kinematic analysis of quick-return mechanism that is executed by three various methods. These modern methods are CAD with the special software for analysis processing, which can simulate not only the motion of the mechanism, but can define the position, velocity, acceleration, forces, moments and other parameters at every moment of time, but verification and mechanics laws understanding are necessary. The exposed methods are significant for the motion simulation, and analysis of kinematic characteristics of the mechanical walker model accomplished in this paper by CAD application. In [3], Takeshi Muto and co-author replicated the interpersonal cooperative walking motions of two humans and analysed their motor-control mechanisms. The results indicate that the hierarchical dynamics were derived from an interpersonal footstep entrainment process and an intrapersonal interaction of arm and footstep motions. In [4], Kalman Babković with co-authors, explored the possibility of using a short unbalanced state of the biped robot to quickly gain speed and achieve the steady state velocity during a period shorter than half of the single support phase. They verified the proposed method by simulation. In [5], Erika Ottaviano with joint authors, presented a 1-degree of freedom (DOF) biped walking system as a part of a rickshaw robot and its suitable kinematic analysis. Authors emphasized that main features for the proposed biped machine are low-cost design and easy-operation in terms of compactness, light weight, and reduced number of DOFs. In [6], Jungwon Yoon and co-authors present a 6-DOF gait rehabilitation robot that allows patients to update their walking velocity on various terrain types and navigate in virtual environments through upper and lower limb connections. During a pilot clinical test, a hemiplegic patient could use the suggested gait rehabilitation robot with a slow walking speed. The rehabilitation plan was also suggested for the patient and the possible therapeutic effects of the suggested rehabilitation robot system are discussed. In [7], S. Pastor et al., generates and analyses various types of curves by the using of math, CAD tools and simulation of complex harmonic motions. This research is particularly important for the motion simulation, trajectory generation and analysis of other kinematic characteristics of the mechanical walker 3D model obtained in this paper by CAD (Solid Works) application. In [8], Yongming Wang and co-authors exposed the design of a new-style bionic walking mechanism by using two tandem planetary gear trains, which is composed of one first swivelling arm, one second swivelling arm, two striding rods and mechanism bracket. On the basis of analysis of interference and motion coupling relationship of joints, they obtained non-interference condition of the bionic walking mechanism. Motion simulation was done in COSMOS Motion software, and the motion path curves of rotating joints of the bionic walking mechanism were accomplished. In [9], Zhengyan Qi with co-authors, introduces a quadruped/biped reconfigurable walking robot used for the elderly and disabled people. The implementation of mechanism for the reconfigurable quadruped / biped walking robot is described and its application is discussed. In [10], Nakayama, T. and joint authors proposed a new mechanical gravity compensation mechanism suitable for the wearable lower limb rehabilitation system. The gravity compensation ability of the proposed mechanism and the effectiveness of the proposed system as a lower limb rehabilitation system are examined by some computer simulations and experiment using the actual equipment. Authors claimed that the proposed gravity compensation systems are safer than the previous ones since the proposed mechanisms which generate the gravity compensation torques are totally embedded to the body link. In [11], Ryan J. and co-authors generated a conceptual design for a prosthetic ankle-foot mechanism that can automatically adapt to the slope of the walking surface. The mechanism simulates the behaviour of the physiologic foot and ankle complex by having low impedance in the early stance phase and then switching to higher impedance once foot-flat is reached.

In [12], Conghui Liang et al., described a novel biologically tripod walking robot inspired by the tripod gaits existing in nature. The proposed leg mechanism was modelled for kinematic analysis and equations are formulated for simulation. By this simulation, authors exposed the operation characteristics of the leg mechanism and the feasible walking ability of the proposed tripod walking robot. In [13], Chugo, D. with joint authors, proposes a robotic walker system with standing and walking assistance function. Their system focuses on domestic use for aged persons who need nursing in their daily life and comprises two topics. The first topic is combination of standing and walking assistance function and the second one is steady standing assistance operation using an assistance manipulator and an active walker. Good performance of the proposed system was verified by experiments using the prototype. In [14] Aleksandar Veg and joined authors described a new rehabilitation device that allows walking without hand support of individuals with limited ability to control posture. In [15], Aleksandar Veg with co-authors presented an improved planar biomechanical model of a human leg which comprises three body segments and two joints. The model was developed to investigate automatic control for functional electrical stimulation.

This paper exposes the synthesis and principal kinematic analysis of mechanically established walking and standing mechanism. Moreover, the design and motion simulation of mechanical walker 3D model is shown, elaborated and documented by various kinematic diagrams.

2 The mechanical walker mechanism

The curved sliding mechanism OABC, with special parameters, extended with dyad CC' and DC' is the fundamental mechanism of the model of the mechanical walker (Fig. 1).

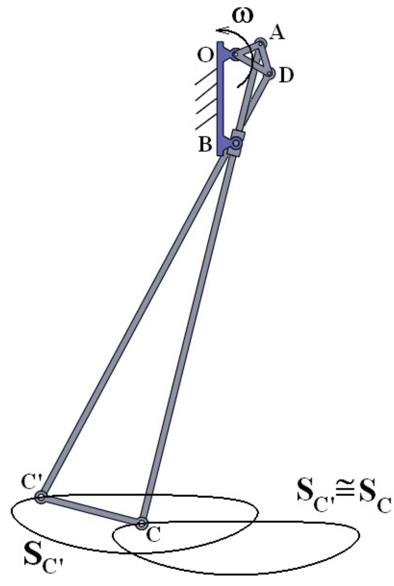


Figure 1 The fundamental mechanism of the model of the mechanical walker

Since the point A of a crank OA of the leading link has a circular trajectory S_A, the point C of the link AC, of the leaded member moves over the trajectory $S_{C'}$, the symmetrical 6th order curve with special characteristic are of interest for application.

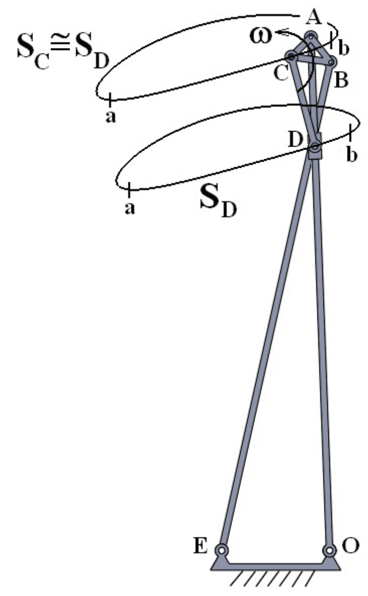


Figure 2 Four bar linkage CADC' with the added link OB and slider B

By transforming of the curved sliding mechanism on the equivalent four bar linkage [16] it is possible to synthesize the six member joint mechanism. One of the members has the curve translation law of motion, which can be described by the law of motion of the point C of link of the curved sliding mechanism [17, 18]. Because the link and the moving link of the equivalent four bar linkage are infinite, its practical application is inconvenient. This fact improves the use of the quasi equivalent joint four bar linkage with the members of infinite length. The law of motion of the point C of the quasi equivalent mechanism is close to the law of motion of the point C of the link of the curved sliding mechanism [18].

By applying the Robert-Chebyshev theorem on the quasi equivalent joint four bar linkage it is possible to obtain the parameters of the added dyad, in which one of the members does the curve translation [17, 18].

By the invention of curves sliding mechanism extended with the dyad, whose one member does the close to translation, it is possible to treat it as a four bar linkage CADC' with the added link OB and slider B (Fig. 2).

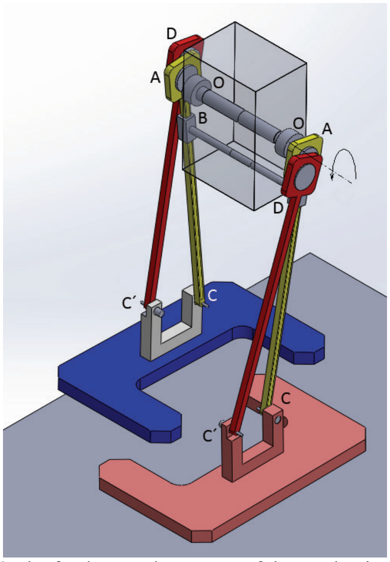
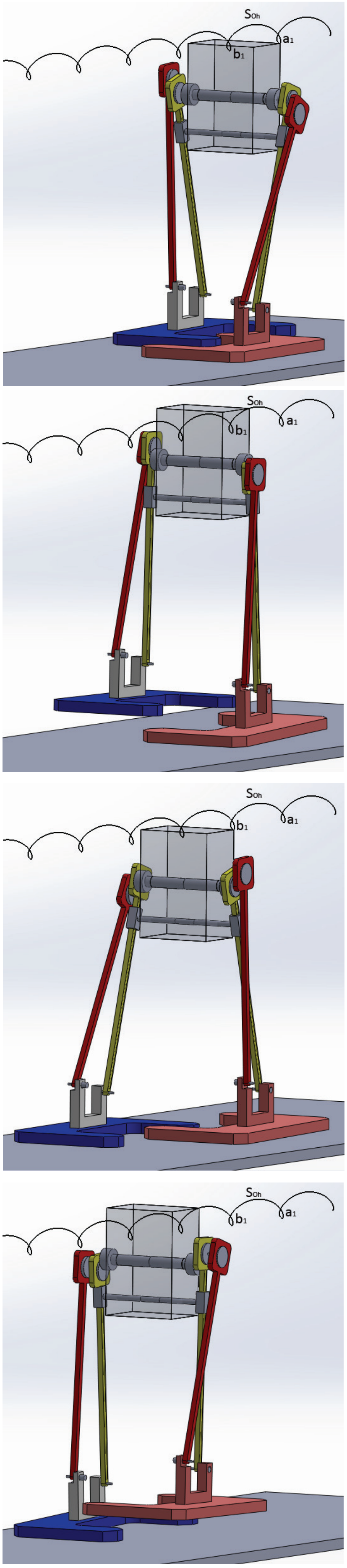


Figure 3 The fundamental structure of the mechanical walker

Two of such identical six member mechanisms, placed in two parallel planes, with the common crank phasic shifted for 180°, able to rotate around the point C, forms the fundamental structure of the mechanical walker (Fig. 3). The members CC', the feet, has the floor contacts with the unmoving ground, one after the other. The trajectory SOb of the translatory moving couple of the walker is to be obtained by assembling of the upper parts of the trajectory SB, from a to b (Fig. 2), that is from a_1 to b_1 in a continual curve in the sagittal plane (Fig. 4). Detail of the walker mechanism is shown in Fig. 5.

The mechanical walker, synthesized by the use of mentioned method, does not imitate the human pattern of walking. The conditions necessary for motion stability are based on the explained mechanical structure. Because of the low walking speed of the walker, the static stability is of the main interest, the dynamical influence of the stability is of the second order [19].



(4a)

(4b)

(4c)

(4d)

Figure 4a-4d The trajectory of the translator moving couple of the walker

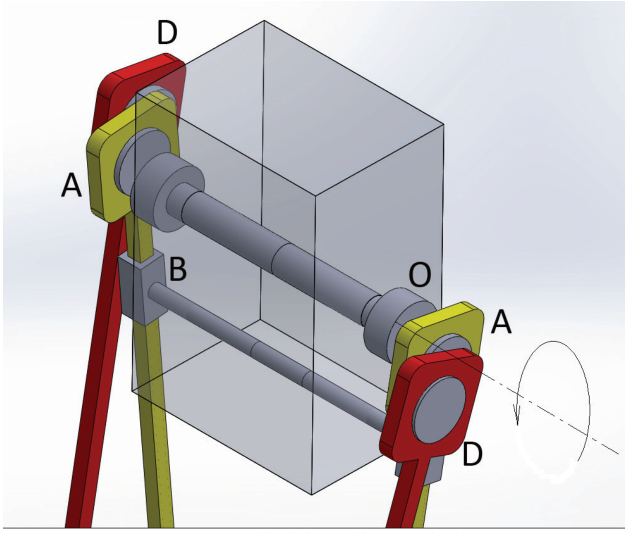


Figure 5 Detail of the walker mechanism

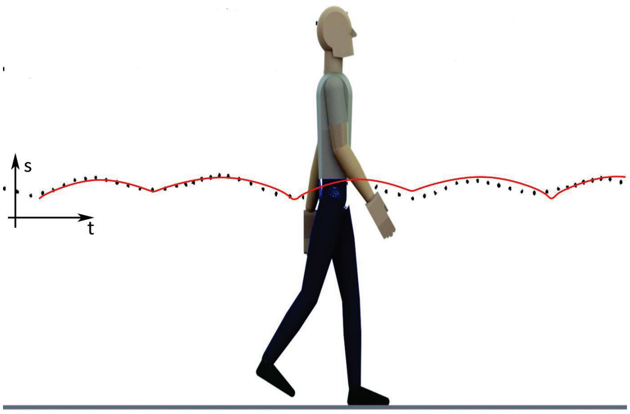


Figure 6 The mechanical walker trajectory (red curve) and the positions of the walking man's center of mass (black dots)

By analysing the human walk [20] it could be concluded that the head and shoulders are moving approximately uniform, with a constant velocity during walk cycle. Comparing the trajectories of the mechanical walker (Fig. 2) and the man's head it is to be pointed out that it is necessary in the first approximation to build in the horizontal moving component to the point of the seat (predicted for the handicapped person) OB, for obtaining close to constant velocity during walking.

This is possible to be realized by harmonical mechanism, with the initiating angular velocity ω_1, doubled to the angular rate of the fundamental mechanism $\omega_2 = -2\omega$. Superposition of the motion laws of the fundamental mechanism and the harmonical one show that the moving of the seat of the walker is obtained with the close to constant velocity.

3 Evaluation and verification of the solution

Since the mechanical walker, proposed in this paper, is expected to be used for walking rehabilitation and training in the treatment of spinal cord injured patients, its kinematic characteristics should be compared with the kinematic characteristics of human walk. That comparative evaluation can offer the verification of mechanical walker as a useful medical tool for the purpose of walking rehabilitation.

The positions set of the mass centre of the walking man is obtained by corresponding anthropometric measurements and are graphically exposed in Fig. 6 by the series of dots. The trajectory of one chosen point on the 3D model of mechanical walker is shown in the same Fig. 6 by the continuous red curve. This 3D model is created by the using of CAD [7] (Solid Works) application and the trajectory is generated by the motion simulation tools of the same CAD application. The comparative consideration of this trajectory and the positions of the walking man centre of mass represented by the series of dots shows significant fitting, i.e. almost trivial differences. Thus, it can be regarded that designed mechanical walker is a practical and beneficial medical device for walking rehabilitation.

4 Conclusion

This paper describes a novel walker with mechanically established walking and standing mechanism. The exposed synthesis of mechanism of the mechanical walker can be compared with the similar solution given in [12]. Conghui Liang and co-authors, described a novel biologically tripod walking robot inspired by the tripod gaits existing in nature. Tripod walking robot is based on a mechanism composed of 8 linkages and our mechanical walker comprises just 6 elements. Moreover, in comparison with the walker described in this paper, whose fulcrum is the structural member of the mechanism, tripod walking robot rests upon the surface in singular points. Finally, tripod walker has larger overall dimensions than the proposed mechanism. Since both mechanisms generate a similar walking path, it can be concluded that the design exposed in this work is more practical and reliable, as well as less expensive.

In further establishment, it is possible to develop new mechanisms, function generators, which will take into account horizontal component, as well as the vertical one. It is of interest to correct the vertical component of the velocity of the seat of the mechanical walker. The goal for the correction is to obtain better coincidence of the motion laws of the walker to the walking patterns described in gate analysis [12].

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Authors' addresses

Raša Andrejević, M.Sc.
Mechanical Engineering Faculty, University of Belgrade
Kraljice Marije 16
11000 Beograd, Serbia
E-mail: randrejevic@mas.bg.ac.rs

Goran Šiniković, M.Sc.
Mechanical Engineering Faculty, University of Belgrade
Kraljice Marije 16
11000 Beograd, Serbia
E-mail: gsinikovic@mas.bg.ac.rs

Miša Stojićević, M.Sc.
Mechanical Engineering Faculty, University of Belgrade
Kraljice Marije 16
11000 Beograd, Serbia
E-mail: randrejevic@mas.bg.ac.rs

Miodrag Stoimenov, Ph.D.
Mechanical Engineering Faculty, University of Belgrade
Kraljice Marije 16
11000 Beograd, Serbia
E-mail: mstoimenov@mas.bg.ac.rs

Ljubomir Miladinović, Ph.D.
Mechanical Engineering Faculty, University of Belgrade
Kraljice Marije 16
11000 Beograd, Serbia
E-mail: lmiladinovic@mas.bg.ac.rs

Branislav Popkonstantinović, Ph.D.
Mechanical Engineering Faculty, University of Belgrade
Kraljice Marije 16
11000 Beograd, Serbia
E-mail: dr.branislav.pop@gmail.com

Gordana Ostojić, Ph.D.
Faculty of Technical Science, University of Novi Sad
Trg Dositeja Obradovića 6
21000 Novi Sad, Serbia
E-mail: goca@uns.ac.rs

Stevan Stankovski, Ph.D.
Faculty of Technical Science, University of Novi Sad
Trg Dositeja Obradovića 6
21000 Novi Sad, Serbia
E-mail: stevan@uns.ac.rs