Proceedings of the 2nd International Conference on Software Engineering and Machine Learning
DOI: 10.54254/2755-2721/74/20240442

Optimization of 4-links robot in stimulating robot area

YanYi He

Southwest Jiao tong University, Chengdu, China

el22yh@leeds.ac.uk

Abstract. Nowadays, robots can be considered as a symbol of advancement of internet and the multi-link robots represent interesting reference systems among various kinds of robots. 4-links robots can be obviously thought as a symbol of muti-robots and bionic robots owing to it takes inspiration of human's body parts, foot, leg, thigh, and torso, consisting of four links [1]. The technology of 4-links robot is still in its infancy. At the same time, the invention of hybrid robots gets more recognition and widely applied. Thus, it is necessary to analyze and optimize 4-link robots, to contribute to the progress in bionic robots and provide convenience for human life systematically and further. This report studies stimulation method of muti-links robots, which combines spring-mass robots and 4- links planar robots as a kind of hybrid robots and aims to conclude the relationships between springs and length per step, mass distribution and increase energy efficiency.

Keywords: optimization, 4-links robot, the stiffness of springs, the location of springs, length per step, mass distribution, energy efficiency

1. Introduction

This article's main theme is about one kind of robot called multi-links robots' improvement. The current situation is that there are three kinds of robots. The first one is serial robots, whose advantages consists of large work scope, the active motion of the final controlling element with the disadvantages include low stiffness, accuracy, and heavy structure [2]. Thus, the second kind of robots using closed-loop kinematic chains have been invented with low weight, compact structure, better accuracy, and stiffness lengths' advantages. While at the same time, the disadvantages like small work scope, a complex design and procedure cannot be avoided. Finally, inventors combine the two kinds of robots above--hybrid robots that are developed to meet the increasing demand for a wide spectrum of hybrid robotic applications [3].

Robots, within the purpose of facilitating people's lives, become increasingly complicated and comprehensive, gradually moving from the most basic assembly line factory to artificial intelligence that can replace some jobs and think or analyze. Robots are now gradually entering various fields, such as education, service, organization, transportation and so on.

Although the topic of this article multi-links robots seems quite easy and simple, with the condition that the scope of planar multi-links robots' s function is limited and the geography of the area in which robots operate is definite as well--they can only drive on flat ground, while walking on desert or muddy land is quite difficult for them-- multi-links planar or pendulum-type robots has been thought as an attractive evaluation systems in management and robotic domains. It is not only because the simpler

DOI: 10.54254/2755-2721/74/20240442

design of the robots can be combined with other actuators in more numerous ways to achieve complicated purposes, but also due to the reason that multi-links robot is a kind of basic robot inspired by the design of human body gymnastics. In other words, once we solve the problems of basic robots, the problems of other complex robots will be solved obviously.

The movement of multi-link robots is like human' s movement. Humans now depend on model dynamics to finish complex movements. Thus, human limbs and bodies can be seen as an analogy for robots' links. And the best analogy to the legs' extension force and muscle contraction is spring expansion. This report focuses on one point of optimization 4-links robots and studies the optimization method of muti-links robots within Matlab, which combines spring-mass robots with 4- links planar robots as a kind of hybrid robots and aims to conclude the relationships between springs and length per step, mass distribution and increase energy efficiency.

2. Literature review

2.1. The history of Bionic robot

- The first stage— for the imitation of appearance and movement.

The representative products are Mosher in the United States in 1968, Wabot-1 in Japan in 1973, MicroBat in 1984 and so on. Among them, the Mosher robot, simulate four-legged walking as a four-legged robot, is thought of as a milestone.

- The second state— because of the focus on integrating traditional structures with bio-resistant materials, this phase includes electron-mechanical systems and biological properties.

The representative products include Asimo from Japan in 2000, Big-dog from the United States in 2008, and Smart-bird from Germany in 2010.

2.2. Current research on multi-links robots

- In 2006 back handspring of a multi-link gymnastic robot by reference model approach[4]. The process is in figure 1.

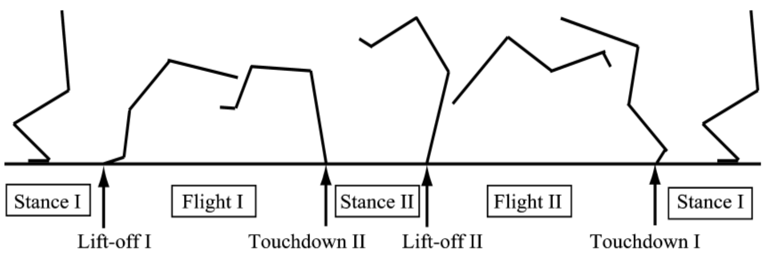

Figure 1. Phase transition of the back handspring

- In 2014, through proving several known properties and present several new properties on the mechanical parameters in the motion equations of the robot, an n-link planar robot with one or more under actuated joints such as the ability of controlling and the swing-up and stabilizing control regarding the changes of the number and location of actuators of the robot.
- In 2016, an n-link under actuated revolute planar robot is linearly controllable and observable around the upright equilibrium point, only there are at least two active adjacent joints of n -2 intermediate joints and the corresponding joint angles are measured[5].
- In 2020, Kinematic and Dynamic Modelling for a Class of Hybrid Robots Composed of m Local Closed-Loop Linkages Appended to an n-Link Serial Manipulator[3].

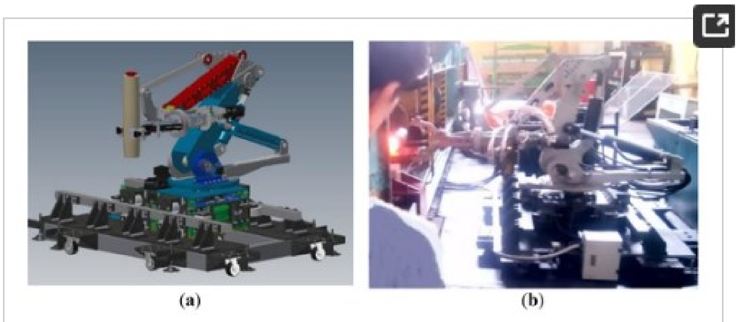

Figure 2. the robot using innovative approach in (a), the original robot is (b)

- In 2023, the Robogymnast recreates the movements of a human gymnast, with a high bar with ball0bearing mountings, which can rotate freely. Teaching-Learning-Based Optimization (TLBO) and Particle Swarm Optimization (PSO) algorithm were used for tuning the hybrid In addition, and MATLAB was used to simulate performance and show the effect of altering parameters[6].

2.3. The research of Spring-mass model

- In 2017, an extension of bipedal spring-mass model with variable slack length and stiffness was proposed to deal with the problems of stepping and low speed walking. Moreover, the stiffness of spring is changed to get running gaits with different frequencies in order to imitate the human foot rolling behavior and produce heel-strike and toe-strike running[7].

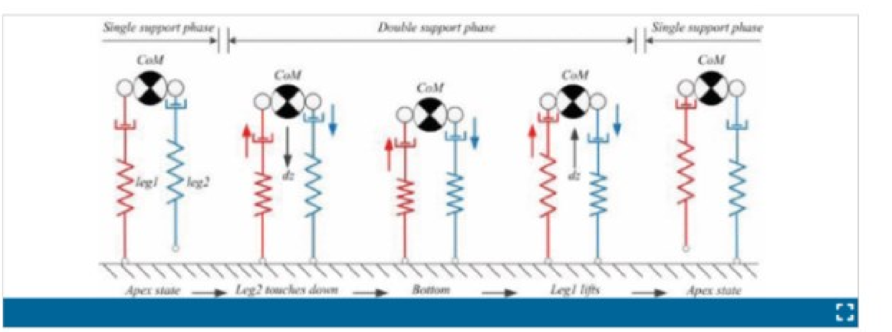

Figure 3. the landing and lifting process of slack length variable biped spring-mass model.

- In 2019, an approach that aims to improve the movement performances of the biped robot, was invented by adding spring damper on legs and an attitude controller that can adjust and stabilize after robot landing from the jumping improvement [8].

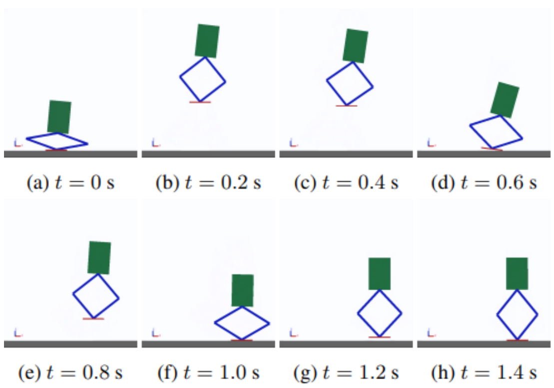

Figure 4. state of jumping and landing

2.4. Conclusion of the literature review

Above are the articles and progress about multi-links robots, we can learn that the technique of multi-robots is still in the developing period, and there are still many problems waiting to be solved.

According to these, we can also get the key point that the movement of multi-links robots is based on the human and animals' s movement. The one point of optimization 4-links robots focused by the article within Matlab method, will aim to conclude the relationships between springs and length per step, mass distribution and increase energy efficiency.

3. Research methodology and result

Based on the known research data, results of multi-links robots and spring-mass robots, I systematically analyze the possibility of hybrid 4-links robots that combing the characters of two kinds of robots.

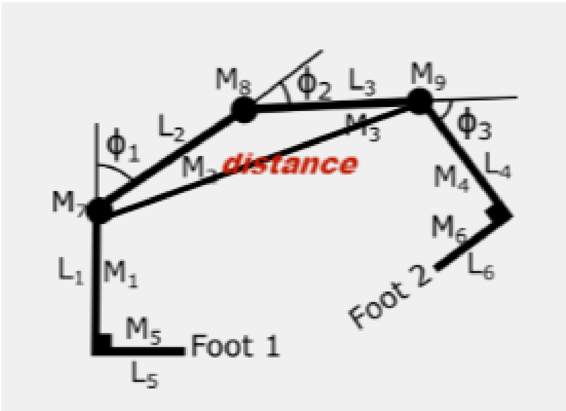

Figure 5. Profile sketch of the manual stride 4-links robot

3.1. Units

- L1 in figure 4 means link1, L2 means link2, the same as L3, L4, L5, L6
- Foot 1 in figure 4includes L5, L1, L2 Foot 2 includes L6, L4, L3
- M1 in figure 4 means the mass of link1, the same as M2, M3, M4, M5, M6
- Alpha 1 in figure 4 means pi minus the angle between link1 and link2
- Alpha 2 in figure 4 means pi minus the angle between link3 and link2
- Alpha 3 in figure 4 means pi minus the angle between link3 and link4
- Joint 1 means the point between link1 and link2
- Joint 2 means the point between link2 and link3
- Joint 3 means the point between link3 and link4
- Original distance between links1 and link4 when the manual stride 4-links robot is still is d
- The distance the manual stride 4-links robot make in one step is D

DOI: 10.54254/2755-2721/74/20240442

```
%%Hard-coded robot walking

for i = 1:5
    pos1 = [-2;0]+[(i-1)*(lVec(2)+lVec(3))*(1-sin(pi/3));0];
    %%Stride Out
    %lift joint 1
    updateangles([0.8;pi/3;pi/3],[pi/3;pi/3;pi/3],1Vec,mVec,pos1,footsep,1)
    %lower joint 1, extend joint 2 & curl jo/int 3
    updateangles([1.3;0;pi/2],[0.8;pi/3;pi/3],1Vec,mVec,pos1,footsep,1)
    %lower 1 & 2 to ground
    updateangles([pi/2;0;pi/2],[1.3;0;pi/2],1Vec,mVec,pos1,footsep,1)

    pos2 = [pos1(1)+1Vec(2)+1Vec(3);0];
    %%Stride In
    %lift joint 3
    updateangles([pi/2;0;1.3],[pi/2;0;pi/2],lVec,mVec,pos2,footsep,2)
    %bring together
    updateangles([pi/3;pi/3;pi/3],[pi/2;0;1.3],lVec,mVec,pos2,footsep,2)
end
```

Figure 6. the code of the manual stride 4-links robot is shown

- Pos1 in figure means coordinates of intersection of link1 and foot1
- 1Vec means the lengths of the links and feet
- 1Vec (2) means the length of link2 or foot 2
- mVec means the relative masses of links and feet
- PhiVec means the angles in radians of the 3 joints

3.2. Original process of manual stride 4-links robot

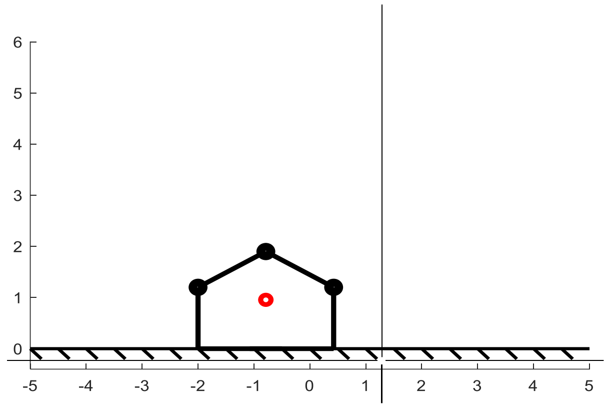

Figure 7. when the manual stride 4-links robots are still

- When the manual stride 4-links robots are still, the alphas 1, 2 and 3 are all pi/3
- Firstly, lift joint 1. The link1 and link6 remain and alpha2 and 3 keep, while alpha1 decreases from pi/3 to 0.8. That means link2, link3, link4 and link5 can be thought of as an entirety, and the entirety takes joint 1 as fulcrum to rise.

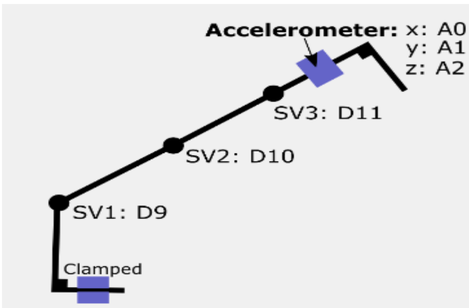

Figure 8. when the robot lower joint 1, extending Joint2 and curl joint3

- The second part contains lowering joint 1, extending joint 2 and curl joint 3. During this process, the alpha 1 increases from 0.8 to 1.3, the alpha 2 decreases from pi/3 to 0, and the alpha 3 increases from pi/3 to pi/2.
- The third part is lowering joint 1 and 2 to ground. It is like the first part, the alpha 1 increases from 1.3 to pi/2. And link2, link3, link4 and link5 can be thought of as an entirety, and the entirety takes the joint 1 as fulcrum to descend.
- The fourth part is lifting the joint 3. During this step, only the alpha 3 will decrease from p1/2 to 1.3. However, alpha 1 and 2 will remain. Link1, link2, link3 and link6 will be considered as an entirety, and the entirety take joint3 as fulcrum to rise.
- The last part of this process is bringing together. Link4 and link5 remain unchanged while alpha1, alpha2 and alpha3 all change from pi/2, 0, 1.3 to pi/3.

3.3. The properties and formulas of springs

The formula of spring between force and length:

$$F=k*x \tag{1}$$

F means the composition of force on spring, including extending and compressive force.

k means the stiffness of the spring, which is intricately connected with the material of spring as a constant.

x means the length change of spring caused by the force, including extending and compressive force working on it.

According to the Newton's second formula,

$$F=a*m \tag{2}$$

F means the composition force on objects, *a* means acceleration, *m* means the mass of objects.

w means angular frequency; *f* means the frequency.

And,

$$f=2\Pi/w \tag{3}$$

Once there is only constant force on the spring, the formula (1) equal to formula (2).

$$F=a*m =k*x \tag{4}$$

Combine the formula (4) with formula (3).

The natural angular frequency is constant.

$$\omega0=\sqrt{(k/m)} \tag{5}$$

From the process mentioned above in method, the distance the robot making is depends on the length of link2 and link3.

The formula can be got

$$D=link2+link3-d \tag{6}$$

3.4. The optimized design of links

According to the (7), it is obvious that the distance per step depends on the length of link2 and link3 and d. Traditionally 4-links robots or multi-links robots often use immutable links to ensure the robots' stability. While aiming to make the distance per step larger, the length of link2 and link3 can be larger, and the length of d can be decreased.

Replace the links to springs seems possible, while there comes a question, the location of the spring. Because when the spring have the advantages of extending and compressing length and more light weight, it also has the disadvantages like unstable, the disability of support and the mass center's change.

DOI: 10.54254/2755-2721/74/20240442

- Overall Link2: link 2 works as a joint relating the foot 1 and foot 2. Moreover, during the second parts of moving process, link2 need to move like drawing arc with the point on alpha1 as fulcrum and support the entirety. Thus, overall link 2 cannot be replaced by spring.
- Overall link3: similarly, to overall link2, link3 also plays the role in drawing arc and supporting link4 and link5. Thus, overall link3 cannot work as well.
- Overall link2 and link3: obviously impractical.
- Partly link2 and link3: if the scope of spring is in the media of link2 or link3 partly, the function of link2 and link3 will not be influenced. Moreover, the mass center will remain.

3.5. The revised moving process of the hybrid robot

After adding springs on the media of link2 and link3, hypothesis the original length of per string is X0, which is equal to the length of link2 and link3while hypothesis the spring in figure 8 is compressed, whose length is X1. And the name of the spring in link2 is spring1, the spring in link3 is spring2.

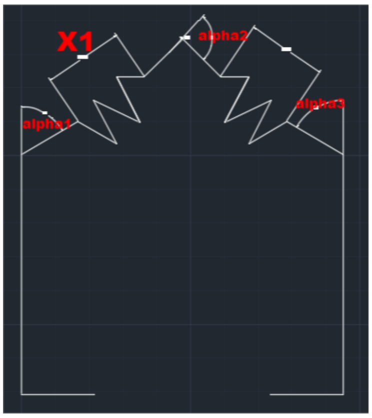

Figure 9. the revised hybrid robot by CAD

According to the process mentioned in method part, in the first part of lifting foot1, the gravity of link2, link3, link4, link5 and link6 objects will partly work on spring1 and spring2, like figure 9 shows.

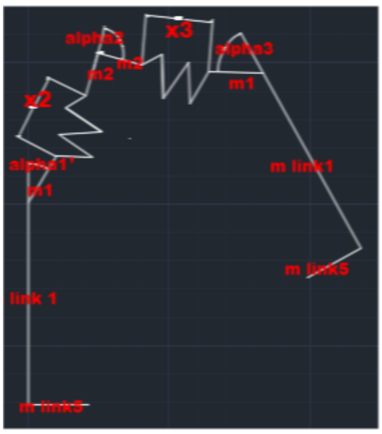

Figure 10. lift joint 1by CAD

In figure 9, the mass of link 1 and link 4 are both m link 1, and the mass of link5 and link6 are both m link5, while the link2 and link3 are separated by spring, there are three parts on link2 or link3, which include m1, m2 and spring.

Draw analysis of force on the two objects, which means taking the two distinct parts connected with two springs as two kinds of entirety.

DOI: 10.54254/2755-2721/74/20240442

Form the formula (1) and (2),

$$X2 = X1 - (2*m2+m1+m\ link1+m\ link5) * \cos(alpha1')/k$$

And,

$$X3 = X1 + (m1+mlink1+m\ link5) * \cos(180-alpha1'-alpha2)/k$$

The second part is lowering joint 1, extending joint 2 and curling join3.

Figure 11. lower joint1, extend joint 2, and curl joint 3 by CAD

Currently,

$$X4 = X1 - (2*m2+m1+mlink1+mlink5) * \cos(alpha1)/k$$

Because alpha1' < alpha1,
thus, cos (alpha1')> cos (alpha1), and the force compressing spring1 in figure 10 is smaller.
Compare X4 and X2 and get X4>X2.
And $X5 = X1 - (m1+mlink1+m\ link5) * \cos(alpha1)/k$

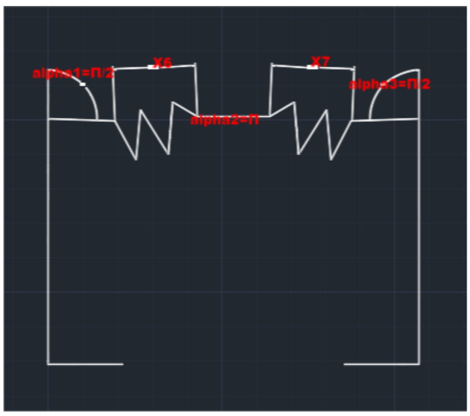

Figure 12. lower joint1 and joint 2 to the ground by CAD

The spring1 and spring2 reverse from the compressive to extending condition, and the length of compressive is equal to the extending length.

$$X6 - X0 = X0 - X4$$

$$X7 - X0 = X0 - X5,$$

DOI: 10.54254/2755-2721/74/20240442

Thus,

$$X6=2*X0-X1-(2*m2+m1+mlink1+mlink5)*cos(alpha1)/k$$

$$X7=2*X0-X1-(m1+mlink1+mlink5)*cos(alpha1)/k$$

After the last part, lifting the joint 3 and bringing together, one step has been finished.

From the part of method, the distance per step made dependent on the length of link2 and link3, and the original distance between robot's link2 and link3.This per step of revised hybrid robot can be larger.

Just like **formula (6)**,

$$D = link2 + link3 - d$$

Hypothesis the original length of link2 and link3 is L before revising.

The original length of link2 + link3 is 2*L before revising.

During this process, the largest lengths of link2 and link3 are at figure 11.

$$X = X6 + X7$$

Thus,

$$X=4*X0-2*X1-(2*m2+m1+mlink1+mlink5)*cos(alpha1)/k-(m1+mlink1+mlink5)*cos(alpha1)/k$$

The distance between link2 and link3 when the robot is still, is smaller.

The original distance is

$$d = 2*L*sin(alpha1)$$

The revised robot distance is 2*X1 *sin(alpha1)

Thus, the original D is

$$2*L*(1-sin(alpha1))$$

The revised robot's D is

$$4*X0-2*X1*(1+alpha1)-(2*m2+m1+mlink1+mlink5)*cos(alpha1)/k-(m1+mlink1+mlink5)*cos(alpha1)/k$$

Moreover, X0=L from preceding part of text.

Because both revised length of link2+link3 is larger, and the distance between them is smaller can be proved, the D obviously becomes larger.

4. Conclusion and recommendations

4.1. Conclusion

By completing a very shallow article based on 4-links robot, the more content and knowledge of muliti-links robot can be learned. This article is mainly about the idea of combining the 4-links robot and the spring-mass robot, which is inspired by the introduction of different articles about the two robots. In theory, basic mathematics and physics are used to prove whether this idea is feasible to replace some links with springs and whether the per step length of the robot can be increased. Due to the addition of the springs on the two links, the distance of per step has been increased from 2*L*sin(alpha1) to 4*X0-2*X1*(1+alpha1)-(2*m2+m1+mlink1+mlink5) *cos(alpha1)/k-(m1+mlink1+m link5) *cos(alpha1)/k.

And the increase of distance is obvious and huge for a small 4-link robot.

4.2. Recommendation

There are two fatal problems. The first is that there are limited articles on combining the two robots, as well as limited code and further research. This is because with the progress of science and technology,

DOI: 10.54254/2755-2721/74/20240442

and these two types of robots are one of the most basic robots, people pay more attention to more complex and accurate robots with more functions. Second, due to the limitations of time and capabilities, this paper cannot conduct actual simulation of the changed robot, and is limited to theoretical research and data calculation. The idea of combining 4-links robot and spring-mass Robot is not mature enough.

Although what I have learned is only a superficial part of knowledge, I have a systematic understanding of this field. I know that this is a big, wide-ranging field that requires deep study and understanding in many fields. Although this field is easy to get started, because it is closely related to people's lives, everyone can talk about robots. But to understand more about bionic robots, it takes a long time and effort. As a sophomore, I have a long way to go and a lot of knowledge to learn.

Thus, what in this article I have talked about is only just one piece of whole robot domains and could do only little for development. While I think it can be used in some simple and low-cost robots within the research result of 4-links robots added springs in their links that can do some basic activities and help to release people's hands.

Lastly, I am grateful to the professor who taught us systematical knowledge and the teacher assistance teacher.

References

[1] Y. Liu, X. Xin, and Jing long Wu, "On n-link planar revolute robot: Motion equations and new properties," Proceeding of the 11th World Congress on Intelligent Control and Automation, Shenyang, China, 2014, pp. 3286-3291, Doi: 10.1109/WCICA.2014.7053259.

[2] Zeng, Q.; Fang, Y.; Ehmann, K.F. Design of a novel 4-DOF kinematotropic hybrid parallel manipulator. *J. Mech. Des.* 2011, *133*, 121006.

[3] Chu A M, Nguyen C D, Vu M H, Duong X B, Nguyen T A and Le C H 2020 Kinematic and Dynamic Modelling for a Class of Hybrid Robots Composed of m Local Closed-Loop Linkages Appended to an n-Link Serial Manipulator *Applied Sciences* 10 2567 Online: http://dx.doi.org/10.3390/app10072567

[4] Hyon S, Emura T. Back handspring of a multi-link gymnastic robot – reference model approach. Adv Robot. 2006;20(1):93–113.

[5] X. Xin, "Controllability and observability of an n-link underactuated planar robot with different actuator-sensor configurations: Active intermediate joint or joints," 2016 IEEE 55th Conference on Decision and Control (CDC), Las Vegas, NV, USA, 2016, pp. 821-826, doi:10.1109/CDC.2016.7798369.

[6] B. Abdul Samad, M. Mohamed, and F. Anayi, "Enhanced the Control Strategy of a Triple Link Robotic System (Robogymnast)," in IEEE Access, vol. 11, pp. 31997-32005, 2023, Doi: 10.1109/ACCESS.2023.3262190.

[7] Z. Xu and J. Gao, "Robot Simulations Based on Bipedal Spring-Mass Model with Variable Slack Length and Stiffness," in IEEE Access, vol. 5, pp. 1156-1163, 2017, Doi: 10.1109/ACCESS.2017.2652128.

[8] Ahn, D., Cho, BK. Optimal Standing Jump Trajectory Generation for Biped Robots. *Int. J. Precis. Eng. Manuf.* 21, 1459–1467 (2020). https://doi.org/10.1007/s12541-020-00360-6