A proposal of the extended mechanism for Theo Jansen linkage to modify the walking elliptic orbit and a study of cyclic base function

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Abstract

In the present study, we proposed an extension mechanism of the Theo Jansen linkage to generate various walking patterns. The advantage of the linkage is that the best proportions of link lengths provides a smooth locomotive leg movement like animal gaits with a sharp-pointed elliptic orbit while the disadvantage is less flexibility to change the orbit without any change of link lengths. We hypothesized that an additional cyclic motion of the linkage center, which is never going to move in the original system for preventing rising instability, alters the original walking pattern into orbits systematically with various functional aspects. Our results demonstrated that cyclic motions of the linkage center vary grounding points of the leg's orbits not only for walking but also climbing motion, stepping in the same place and rolling back. In consideration of the additional cycle as a base function, the present study suggests that the Theo Jansen mechanism has a capability to extend an adaptive and controllable vehicle on irregular ground.

1 Introduction

A typical transportation system for moving in irregular fields is the crawler system. Crawler has a capability for running even in the sand and rugged fields by using continuous bands of treads which made of modular steel plates in military vehicles, or reinforced rubber in lighter agricultural and construction vehicles. This system has effective traveling performance but it has typically heavy so that continuous bands need enough endurance. On the other hand, multi-legged robots inspired from spiders and insects are expected to elucidate a new link between biological systems and mechanisms of artificial transporters. Such biologically-inspired robotics learn mobile flexibility from the morphology of multiple legs and their coordination [1][2]. Theo Jansen [3], a Dutch kinetic artist who has attempted to create a bridge between art and engineering by focusing on biological nature of walking. He proposed a mechanism consists of eleven rods linking together to mimic a skeleton of animal legs, called "Theo Jansen mechanism," exhibiting artificial animals walking in sand field only by wind power [4].

A serious problem of the Theo Jansen mechanism is ill-equipped to climb obstacles in the road during walking. We investigated a new extension mechanism, which enables the walking mechanism to transit between walking and climbing modes [5]. In our experimental data, the extended Theo Jansen mechanism provided a climbing elliptic orbit by adding another cyclic motion of the linkage center. This result is considered a clue to resolving concerns for extensibility of Theo Jansen mechanism for walking patterns under various conditions. In order to walk in a road with bumps such as blocks and ruins, the mechanism is required to have a capability to change the elliptic leg orbit depending on changes of the road condition. We hypothesized that a parametric shift of the additional cyclic motion, from the precise circle to ellipses, generates various locomotive orbits including climbing motion, stepping in the same place and rolling back. If an appropriate control method is present by a systematic change of the additional cycle as a base function, the Theo Jansen mechanism has a capability to extend an adaptive and controllable vehicle on irregular ground.

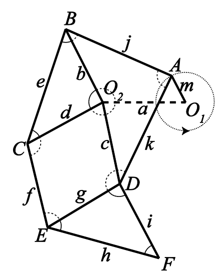

Figure 1: Theo Jansen mechanism that sketch of the essence of the original linkage balance, called Holy Numbers, "*a*" to "*m*". Angles with solid lines and with dotted lines denote respectively fixed and modifiable angles. A to F, O_1 and O_2 are nodes. The node O_2 is an only unmovable node.

2 Method

In the Theo Jansen mechanism, a leg is composed of rods with different lengths connecting through seven movable nodes and an unmovable node (Figure 1). The cycle of the crankshaft around the node O_1 can be transformed to a different shape to be a sharp-pointed elliptic orbit (Figure. 2). By combination of three linkages with the phase difference of 120 [deg], the system provides a smooth leg movement for walking like an animal. The coupling between the cycle around the node O_1 and the unmovable node O_2 enables the system to generate the walking locomotion. In the past study, we found that a systematic movement of the node O_2 changes the shape of the locomotive orbit, lifting up the sharp point of the ellipse [5].

In the present study, we hypothesize that additional motions at the linkage center will transit from walking to climbing locomotion, and investigate the best way to change additional motions for providing expected locomotive patterns. In the previous experiment [5], the up-down motion with an appropriate phase difference between the crankshaft rotation and the motion provide a morphological change of the elliptic orbit which can be applied to climbing motion against obstacles on the ground (Figure 3). This result indicates that possible parameters to change the orbit are 1) shapes of the additional motion at the node O_2, 2) timings, or phase difference between cycles at the node O_1 and the node O_2. In this case, the shape of the additional cycle is determined by three variables: the vertical width of the cycle, *dV*, the horizontal width, *dH*, and the squashed factor, *fs*. The phase difference is given by $\phi - \varphi$, where ϕ is the cycle phase of the crankshaft rotation at O_1 and φ is the cycle phase of the linkage center at O_2.

For analyses of functional aspects generated from the orbit change, we focus on the ratio of the length when the toe is on the ground, which is called "duty factor," and investigate the change of the duty factor with respect to changes of above parameters (Figure 4). Therefore, it is necessary to investigate the effect of the parametric shift for changing the orbit.

3 Results

Firstly, we classified types of orbits, which are generated by the parametric change, and we found three types of orbit: elliptic orbits with a sharp point at the peak, elliptic orbits without the sharp point and intermediate figure-eight orbits (Figure 5). Interestingly, the original orbit sharpens at the grounding point and the toe moves parallel to the floor, which works as walking mode, while the orbit is modifiable to keep a similar shape of

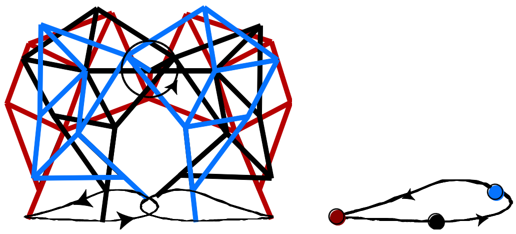

Figure 2: Coordination among multiple legs in the Theo Jansen mechanism. (left) A crankshaft rotation, a center circle, is transformed to an elliptic orbit. (right) Three legs cycling with the phase difference of 120 [deg], generate a systematic toe movement according to the elliptic orbit, such as grounding, supporting and taking off.

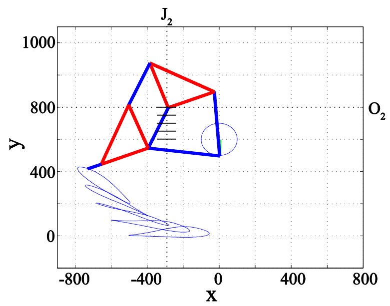

Figure 3: Change of leg movements with respect to the position of joint center (J_2, O_2). Figure from [5].

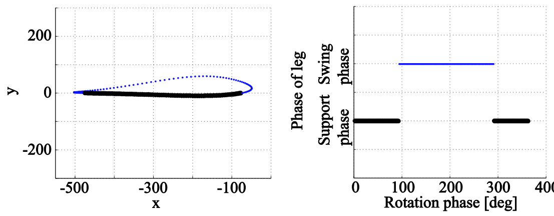

Figure 4: The definition of "duty factor" which indicates the ratio of the length when the toe is on the ground. The black and blue lines respectively denotes support phase (α) and swing phase (β). (left) Two phases on the original orbit. (right) Distribution of the two phases with respect to the rotation phase [deg] at the crankshaft. The duty factor γ is obtained from the ratio between two phases (α, β), such as $\gamma = \frac{\alpha}{(\alpha + \beta)}$, which is 0.46 in this case.

orbit (Figure 5a) yet working as a climbing mode. According to the change of parameters, the orbit once shrinks a smaller orbit than the original (Figure 5b), which seems not to work for transportation like a stepping in the same place, and it goes back to the same orbit.

The crossing point at the figure-eight orbit gradually moves from the superior end to the inferior end (Figure 5c). Mostly orbits with points close to the inferior end have no function in transportation, while orbits with points close to the superior end have functions such as walking and climbing. This result suggests that a limited range of the parametric shift is functionally valuable for transportation vehicles.

We observed that a forward tilting and narrow width circle at the node O_2 generate various functional orbits in an effective manner in the sense of a systematic orbit change related to the locomotive function (Figure 5c), rather than other circles (Figure 5a,b). The tendency partly appears in the analysis of the duty factor with respect to the phase difference $\phi - \varphi$ (Figure 5d). It is noted that the duty factor of the case (c) varies widely than that of other cases, suggesting a flexibility to change the orbit shape.

4 Conclusion

We proposed that a parametric shift from the precise circle to ellipses of the additional cyclic motion generates various locomotive orbits including climbing motion, stepping in the same place and rolling back as shown in Figure 5. In observation of orbit changes by the parametric shift, our proposed system generates not only functional orbits but also unstable ones in the sense of locomotion, suggesting a necessity of restriction of parameter ranges to use. In phase analyses, the duty factor demonstrated the significant difference of the grounding ratio of the toe depending parameter changes as an important indicator and the result suggests that further indicator on positions of the crossing point at the figure-eight orbit may clarify the performance of this extended Theo Jansen mechanism. Our proposal of the extension mechanism renews the potential of Theo Jansen mechanism to apply a walking system in paved and rugged conditions.

In consideration of biological plausibility of walking mechanism, this fact may be interpreted as an importance of movement at knee-joint of human walking. Such figure-eight orbit is considered to be an exception to a rule of the walking but a minor report exhibits a similar pattern of leg movements when athletes are running at an intermediate speed. This interesting coincidence between the extended Theo Jansen and the human running will open a new door in research of biological locomotion, expanding the existing view of sport science to include concepts of artificial transporters and should help elucidate the complex interplay between body kinetics and the environment.

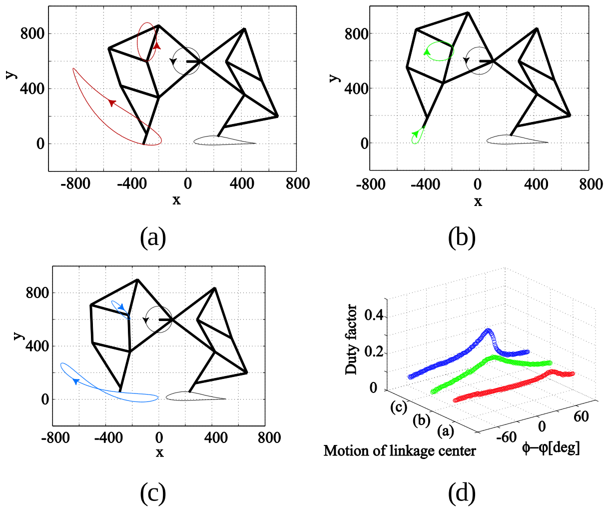

Figure 5: Extended orbits generated from various cyclic motion of the linkage center. (a) An orbit from a up-and-down cyclic motion, providing a climbing function. (dV =280, $\phi - \varphi$=0[deg]). (b) An orbit from a side-by-side cyclic motion, providing stepping in the same place. (dH=100, $\phi - \varphi$=120[deg]). (c) An orbit from a forward tilting and narrow width circle, providing rolling back (fs =315, $\phi - \varphi$=300[deg]). (d) Duty factors with respect to the phase difference $\phi - \varphi$ in cases of (a) to (c). Highest duty factors are 0.13 (a) , 0.21 (b) and 0.27 in (c).

5 Open Questions

Our experimental results demonstrated that various elliptic orbits for walking, climbing, stepping in a place and rolling back by using the cyclic motion of the linkage center. Exploring the similarity with human body kinetics, the linkage center may correspond to the knee-joint of legs. We would like to discuss on the relevance, and a possibility of analyses of the extended Theo Jansen to be a good tool to investigate an appropriate running forms of athletes.

References

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