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The Wave Theory Principles of Human Motion

Feng Wen[1], Yabin Peng[2], Hongfei Li[1], Sanming Hu[1], Kai Liu[3], Ganming Li[4*]

[1]School of Biomedical Engineering and Medical Imaging, Hubei University of Science and Technology, Xianning, China
[2]School of Automation, Hubei University of Science and Technology, Xianning, China
[3]The First Affiliated Hospital of Hubei University of Science and Technology & Xianning Central Hospital, Xianning, China
[4]School of Electronics and Information Engineering, Hubei University of Science and Technology, Xianning, China
Email: *466787449@qq.com

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Abstract

This paper presents a meticulous analysis of the alterations in the human body's center of gravity and static friction during movement. The objective is to comprehend the autonomous locomotion of the human body without external propulsion or tension. A wave theory model is proposed to elucidate the fundamental process of human motion on the ground. By considering one foot as a fulcrum, the other foot functions as a lever, generating torque and propelling the forward movement of the human body. The force model of an individual is affected by the vertical gravitational force-rebound force and the horizontal forward static friction force-backward static friction force. These forces exhibit a cosine wave pattern, with a 90-degree phase difference (at maximum efficiency). The achievement of horizontal movement necessitates vertical movement, reflecting a unique principle that enhances comprehension of the occurrence of relative displacement or force between two objects.

Subject Areas

Theoretical Physics

Keywords

Interaction Forces, Ultrasonic Motor, Static Friction, Transverse Wave, Longitudinal Wave, Phase

1. Introduction

In the context of terrestrial locomotion, the human body is subject to the theoretical influence of static friction, which propels its forward motion. Nevertheless, in the absence of any external horizontal force, the static friction acting in this direction becomes nullified, rendering it insufficient to propel the human body forward. This study employs the mechanical stretching of human feet to investigate the mechanics underlying human locomotion [1] [2] [3] [4].

The paper's innovation stems from the utilization of ultrasonic motors, wherein piezoelectric ceramics (stator) produce mechanical waves that propel the movement of a metal ring (rotor) [5]. The interface between the stator and rotor exhibits mechanical waves with distinct phases and directions, leading to the generation of relative motion. Notably, relative motion can also arise between the human body and the ground. Consequently, the investigation commences by examining the principles of wave theory governing the interaction between humans and the ground.

2. Step

2.1. Beginning Walking

In the depicted configuration illustrated in **Figure 1(a)**, the human body exhibits a distinct separation between its two feet, with the left foot positioned anteriorly. The center of gravity is situated between the two feet, serving as the initial reference point. The left side is designated as the positive direction.

When an individual initiates movement towards their left foot, their center of gravity shifts towards the left side. Subsequently, the left foot assumes an upright position while the right foot gradually elevates. The right foot contacts the ground, starting from the heel and progressing towards the toe, thereby elevating the center of gravity of the human body. Concurrently, the right foot applies a backward force, capitalizing on the static friction force exerted by the ground to generate a reaction force that propels the human body forward. This phenomenon is depicted in **Figure 1(b)**.

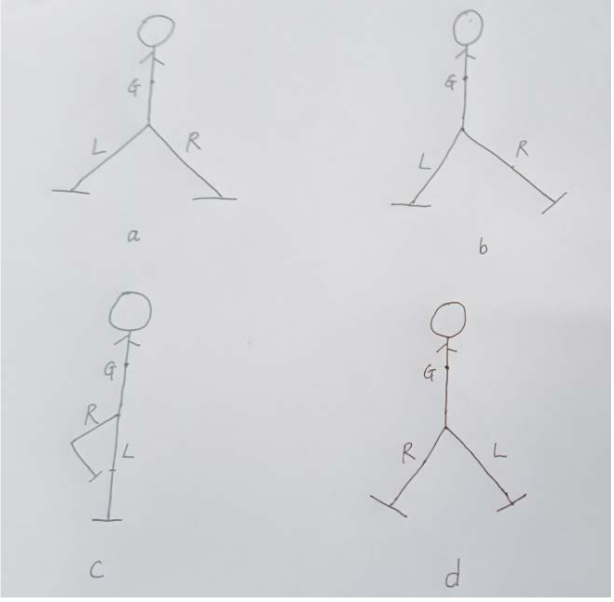

Figure 1. Structure diagram of human body movement.

Characteristics: The elevation of the center of gravity occurs as it ascends from its lowest point. The right foot experiences a positive rebound force, characterized by positive static friction, which progressively intensifies from zero while in contact with the ground. Conversely, the left foot serves to stabilize the human body and encounters a backward rebound force, denoted as negative static friction, commencing from zero upon contact with the ground. This article does not delve into the equality of friction magnitude between the left and right foot, nor does it explore the synchronization of their respective action durations.

2.2. The Center of Gravity Begins to Move Directly Above the Left Foot

At this point, the left foot undergoes further tightening until the elevation of its tip, concomitantly leading to a continued rise in the center of gravity. Simultaneously, the utilization of inertial force facilitates the crossing of the right foot over the left foot, as depicted in **Figure 1(c)**.

Features: To a certain degree, the elevation of the center of gravity has been achieved, thereby enabling the utilization of inertial front wheel drive. In the event of requiring acceleration, it is advisable to progressively raise the left foot from the posterior to the anterior position, thereby further elevating the center of gravity.

2.3. Surpasses

Upon crossing the left foot, it is advised to subsequently swing the right foot in a positive direction prior to contacting the ground. This action results in a repositioning of the human body, with the right foot assuming a front position and the left foot positioned at the back. As the right foot gradually encounters the ground, it experiences a force of rebound in a backward direction originating from the ground. Conversely, the left foot encounters a static friction force directed forward, as visually depicted in **Figure 1(d)**.

Feature: The phenomenon observed is the gradual decrease in the center of gravity, accompanied by the lifting of the tip of the left foot to ensure uninterrupted locomotion.

Consequently, the act of advancing with the right foot can be considered as a repetitive cycle. Subsequently, the subsequent action of stepping with the left foot can be analyzed in a similar manner.

3. Wave Theory Representation

3.1. Wave Equation

The autonomous movement of the human body necessitates the simultaneous application of vertical and parallel forces. This phenomenon can be categorized as a lever, wherein one foot serves as the fulcrum and the other as the power arm. As forces can only be transmitted horizontally and vertically on the ground, their decomposition results in one force acting in the direction of gravity and the other as static friction against the ground in **Figure 2**. Analogous to the relationship between transverse and longitudinal waves, these two forces are inherently perpendicular to one another. The two forces exhibit a phase difference of 90 degrees, wherein the apex of the transverse wave aligns with the zero point of the longitudinal wave.

The movement of the human body is characterized by its directional nature, which is attributed to the ground reaction force exerted upon the center of gravity elevation. As a consequence of the inherent instability of the human body, it is subsequently propelled forward by the mechanical advantage provided by the lever power arm.

As depicted in **Figure 2**, when the left foot L serves as the fulcrum and the center of mass is positioned at G, it is theoretically postulated that the thrust acting perpendicular to LG yields the highest velocity for body movement. Consequently, the lever force F exerted by the right foot on the surface (excluding the gravitational support force) and perpendicular to LG can propel the lever through the Point O. At a given moment, let θ represent the angle between F and the ground. It illustrates the upward support force F_G exerted by the ground on the human body, as well as the left static friction force F_f.

$$F_G = F\sin\theta = F\cos(\theta - \pi/2) \tag{1}$$

$$F_f = F\cos\theta \tag{2}$$

The two forces exhibit a perpendicular relationship, with a phase difference of 90 degrees.

$$F * OL \approx G * GL\cos(wt + \varphi) = G * GL\sin\theta \tag{3}$$

And F itself exhibits periodic changes if there is no switching between the left and right feet.

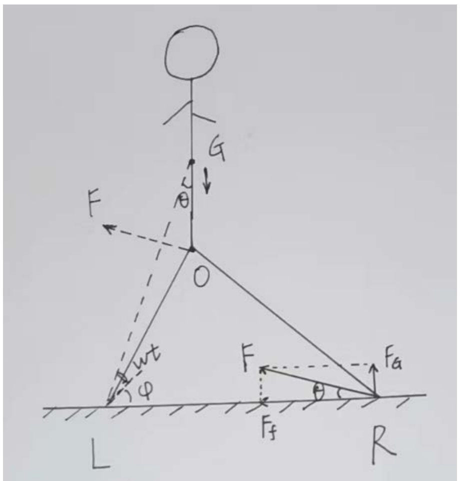

Figure 2. Schematic diagram of the lever movement of the human body with the left foot as the fulcrum and the right foot as the power arm.

3.2. Analysis of Vertical and Horizontal Forces on the Contact Surface between Human and Earth

The displacement of the center of gravity of the human body is observed to be perpendicular to the ground, resembling a transverse wave as depicted in Figure 3(a). The center of gravity initiates its motion from the lowest position, ascends, and subsequently descends to its lowest point during the process of taking a step. This cyclical motion perpetuates continuously. Initially, the support force exerted by the ground on the human body's gravity is equivalent to the force of gravity itself. However, this support force gradually increases over time, while concurrently diminishing as the legs descend. Consequently, the alteration in the position of the center of gravity can be interpreted as a cosine wave. Indeed, there is a parallel alteration observed in the gravitational pull experienced by the human body and its connection to the Earth's surface.

The right foot experiences static friction from the ground, which begins at zero and gradually increases to its maximum value. This frictional force acts parallel to the ground and is representative of periodic movements being regard as a longitudinal wave. The peak compression of this wave aligns with the midpoint of the transverse wave, as depicted in Figure 3(b). The region of highest density within the longitudinal wave corresponds to the maximum static friction force, while the most comfortable region experiences no force. When the right foot is lifted, as illustrated in Figure 1(c), the left foot undergoes changes in the longitudinal wave upon contact with the ground.

Disregarding the influence of the right foot as a lever power arm, the horizontal force exerted on the left foot is entirely antithetical to that exerted on the right foot.

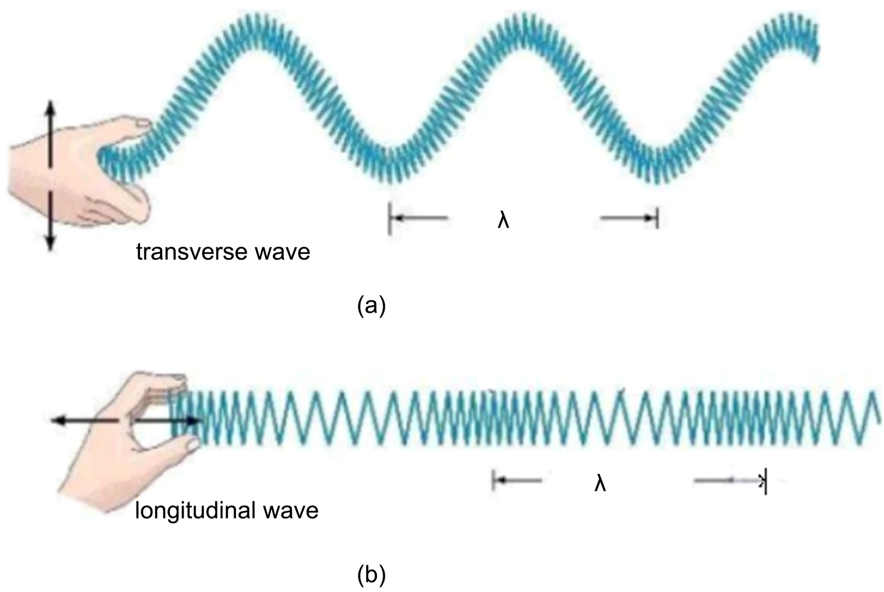

Figure 3. The transverse and longitudinal waves, with the top showing the center of gravity time curve and the bottom showing the lever foot subjected to ground force time curve.

4. Analysis

1) Similar to the interplay observed between the stator and rotor components of an ultrasonic motor (**Figure 4**), an analogous interaction force exists between the human body and the ground. This interaction, occurring in both the horizontal and vertical dimensions, facilitates the movement of the human body. By elevating its center of gravity and utilizing one leg as a propulsive lever, the human body can initiate horizontal displacement. The broad soles of the feet enable the alternating and continuous movement of the feet. However, unlike the rotor, the human body lacks multiple limbs, necessitating careful consideration in the design of materials.

2) If the human body solely relies on the static friction force parallel to the ground, without any displacement of the center of gravity due to gravity, the contact of one foot with the ground will result in the generation of a reaction force. Similarly, when the other foot makes contact with the ground, it will generate an equal and opposite static friction force, thereby preventing significant forward movement or oscillation of the human body.

In order to enhance the efficacy of exercise, it is imperative to harness the body's chemical energy and maintain a considerable distance between the body's center of gravity and the ground. The magnitude of the vertical oscillation of the center of gravity directly influences the magnitude of the horizontal velocity. It is postulated that quadrupedal animals possess the ability to achieve higher running speeds compared to humans, owing to the robustness of their hind limbs, which induces a substantial alteration in the center of gravity.

3) The waveform theory of human motion allows for the exploration of connections between various physical phenomena, potentially leading to more intriguing findings. An illustrative example can be observed in the sport of cycling, where the horizontal swing and the propagation of electric and magnetic fields of light play a crucial role in the mechanics of human high jump, as depicted in **Figure 5**.

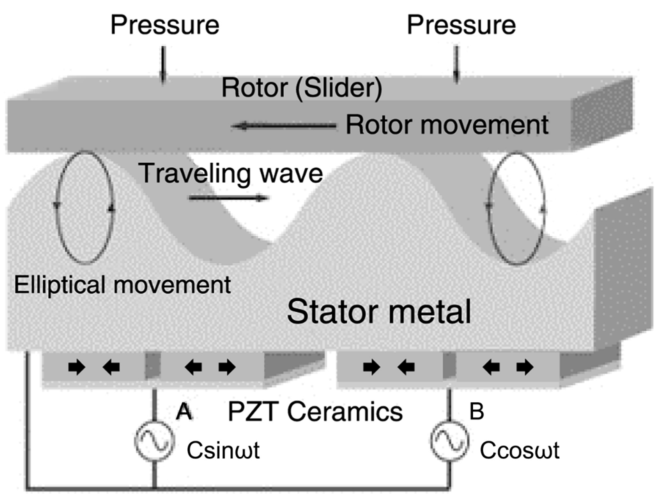

Figure 4. Ultrasonic motor.

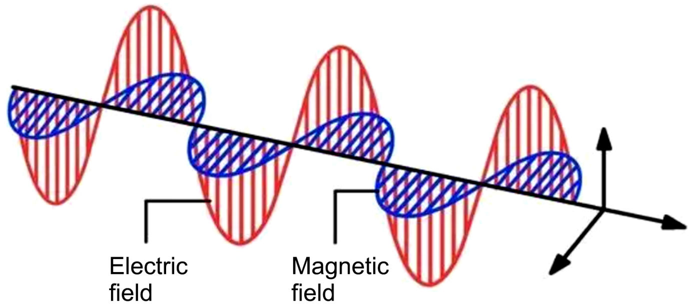

Figure 5. Composition of electric and magnetic fields of light.

5. Conclusion

The occurrence of object motion does not necessarily necessitate the presence of an external force. Rather, internal chemical energy is harnessed to initiate lever movement and bodily position alteration, thereby instigating motion. This process is contingent upon the interaction of attraction and static friction between two objects. The relative displacement between these objects engenders acceleration and force. It is important to note that the generation of force is, in essence, an outcome of energy conversion.

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Conflicts of Interest

The authors declare no conflicts of interest.

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