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ORIGINAL ARTICLE

Comparison of the specific behavior of the insect in the Motion path: the relation between motion behavior and distance in a longitudinal path

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Animal behavior has long been the center of attention of biologists and manufacturers of modern robots. The special behavior of these creatures such as climbing vertical surfaces or hanging from ceilings has gained special consideration. It is, therefore, important to carefully study such behaviors in different conditions. In this study, we examined the movement of the American Cockroach in a straight path and within two different slopes. Surprisingly, we found that a cockroach does not make the same leg movements within a specific straight path. This means that the arrange of every leg strides in each cycle is completely different from the other. Furthermore, the results obtained from investigating the simultaneous stride of the two legs in different tests were remarkable. These new findings are in contrast with current findings. In addition, we examined these behaviors in three different slopes and observed the different behavior of the cockroach compared to normal movement. These findings while offering new insights about the behavioral science and physiology of insects could also assist in manufacturing biomimetic robots that come even closer to reality.

Keywords: Insect behavior; cockroach; slope; motion mechanism; unusual motion; locomotion; image processing

Introduction

Studies on kinetics and the kinematics of locomotion help to find the connection between outlying force inputs and neural locomotion control (Cruse, 1976; Delcomyn, 1985).

Graham proposes that stick insects, in general, are principally different in their walking behavior compared to birds and mammals (Graham, 1983).

Cockroach movements have been studied for a long time. Cockroaches are probably the most famed for escaping extermination by humans. Most probably because of this trait, cockroach locomotion and biomechanics have been predominantly investigated in the course of such escapes (Tom et al., 1978; Full & Tu, 1990, 1991; Nye & Ritzmann, 1992; Wong et al., 1997; Jindrich and Full, 2002; Lee et al., 2006; Tsukada et al., 2010).

One of the significant aspects of the analysis of insect studies is the simulation and modeling of them, and eventually, fabricating them using smart materials (Mehrabian and Yousefi-Koma, 2007; Basaeri et al., 2014). In addition, solving equations derived from research and analysis is of great significance (Khajeh et al., 2010).

Studying insect reactions to different situations is very important for research. Therefore, systems should be designed to conduct quantitative and qualitative measurements of animal reactions. Increasing attention toward this topic appears to be the result of an inquiry into finding systems and mechanisms capable of controlling and operating animal locomotion. One of the methods of initiating and regulating motor activity is the exposure of an animal to its basic mechanisms existing under natural circumstances as well as the sudden stimulus that trigger different sensory systems (Camhi et al., 1978; Zill, 1987; Laurent, 1991; Matsuura et al., 2002; Ye et al., 2003).

The vast body of research on this topic has been carried out on different species of cockroaches. Some studies pertaining to this research involve the examination of the leg performance of the death-head cockroach, Blaberus discoidalis (Full and Tu 1990, Ting, Blickhan et al. 1994). When examining a high-speed treadmill, the running movement of the cockroach is one of the most extraordinary movement behaviors seen among all species. It is amazing to see a comparison of the capacity for cockroach movements rather than the small motion of legs on a harsh ground (Jindrich and Full, 2002; Sponberg and Full, 2008). Usually, the cockroach leg strides are considered regular. Cockroaches usually stride within a tripod gait, a trotting, or a running gait in which their front and rear legs on the one side of the body synchronously change positions with the middle leg on the other side of the body (Hughes, 1952). The two reflective tripods stride in an irregular arrangement in such a way the insect continuously maintains at least three legs on the ground-this makes the movement pattern stable and efficient (Ting et al., 1994; Nishii, 2000).

The research has been conducted under specific lab conditions along with the slow walking of the cockroach. Its results relate to cockroach strides, the method of stepping, and how the time of each step has continuously evolved (Hughes 1952, Delcomyn 1971, Spirito and Mushrush, 1979).

The test with cockroaches has been performed in an encircled area to obtain their crawl and sliding capabilities (Jayaram and Full, 2016). The stride of insects with adhesive legs accompanied by lurching of the body in parallel with motive and holding forces are studied in a repetitive cycle. In this paper, the insect's movement on a rotating wheel has been studied (Graham, 1983). Finally, the insect's stride pattern has been derived (Spirito and Mushrush, 1979).

It should be considered that owing to environmental conditions, systems inspired from nature have a stable situation that might be unstable considering other environmental conditions. Even simplified mechanical systems can behave like stable systems in some directions and behave as unstable or neutrally stable systems in other directions relative to their motions (Bauby and Kuo, 2000; Schmitt and Holmes, 2000).

Therefore, it is very important to achieve precise strides in new.

In this study, we examine certain movements of the cockroach in 0, 45, degrees, among others, on the treadmill. This article differentiates itself from previous articles in terms of an accurate study of the cockroach movement and finding out new movements in reaction to new surfaces and different slopes. Acceleration is precisely calculated in each part. By clarifying the new responses, novel simulated robots could be empowered to perform better while encountering new surfaces. In addition, future studies on cockroach behavior could enhance the evolution of our understanding of this topic by assessing cockroach behavior complexities in relation to different terrains and surface conditions.

Materials and methods

Insects

The studied insect is an American cockroach species, which was kept in the laboratory at 23.0 ± 2 °C. The sample population comprises 15 cockroaches with a mean weight of 0.84 g.

The center of mass of these cockroaches is separately measured according to the recommendations given by previous articles (Kram et al., 1997).

Methodology

Movements with a yaw angle of greater than 15 degrees and movements in which the cockroaches stride at a speed lower than that at the treadmill are discarded from this analysis.

The cockroaches struggle in places and or slides on greater slopes-the resulting data is considered in this analysis.

Experimental system

When the cockroach is placed in the corridor, the device is turned on and the cockroach starts to move. The treadmill speed varies from 5 ± 0.1 cm/s to 50 ± 0.1 cm/s. All the tests used in this paper are carried out at the speed of 2 ± 0.1 cm/s. Considering that the cockroach's speed is approximately 19 ± 4 cm/s (Full et al., 1989), the effect of this device on cockroach movement is insignificant; the frequency generated by the engine is 300 pulses per second, which is much more than the natural frequency of a cockroach's leg that is about 25 Hz (Wilson, 1965). Figure 1 depicts the experimental device used to measure the cockroach's movement in different angles.

Selection criteria

We identified acceptable trials for analysis. Owing to normal data distribution, we rejected trials in which the step variable of interest was significantly different before and after the compliant surface using a paired sample t-test and a two-way ANOVA test (P<0.05 resulted in rejection). It is worth noting that the reliability at all times has been compared to the one obtained by the Wilcoxon Rank-Sum test.

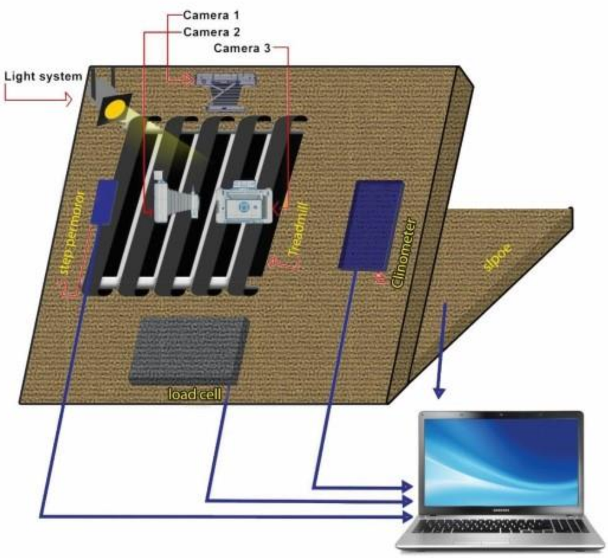

Figure 1. Schematic representation of the device, which is capable of changing the angle having three perpendicular cameras installed.

Experimental and methodology

Two methods were employed to achieve a more accurate observation of leg movements. The first method uses conveyor belts with irregular patterns, which enable close detection of the cockroach's leg hook in fast-paced video review. The second method utilizes the relative speed of the treadmill to detect whether the cockroach's leg claws is locked or sliding on the conveyor belt. When the claw is unlocked, the leg slides on the treadmill belt. Considering the irregular pattern of the treadmill belt's surface, the movement of the irregular pattern causes differences between these points versus the cockroach claws in the photos taken by the high-speed camera. This difference indicates that the claws are locked if the spacing of the paws is fixed with the moving points of the designs, and the claws are unlocked and slide if the spacing between the design and the claws increases=(Figure 2). Movements of the cockroach were examined in three different angles: 0, 40 and more than 40 degrees. The conveyor belt is covered with a tile with a hardness of 48 ± 0.5 shore A that directly contacts the insect's leg. As mentioned previously, this tile possesses an irregular pattern that clearly differentiates the differences in the cockroach's leg claws.

Figure 2. Shows how the leg claws are locked in the treadmill.

Rhythm of harmonious and special movement of cockroach legs in the straight direction

The following different behaviors are seen in a cockroach's leg movement:

- Harmonious movement of three legs that includes a front leg and a back leg on one side, and the middle leg on the other side (Figure 3).
- Movement outside the normal rhythm was observed in all experiments. The arrangement of the movement of the cockroaches is unlike the first rhythm, however, it follows a certain order. The previous order presented by the researchers was only after completion of the movement of one leg, which was followed by the movement of the other leg. In other words, no two legs moved at the same time. However, our observations show that this movement involves a combination of a simultaneous two-leg movement. This movement changes in each cycle.

In the 40-degree inclined surface, the cockroaches struggle to climb or maintain themselves in the same position on the surface. In this type of movement, their legs move in an irregular pattern and struggle to maintain their position.

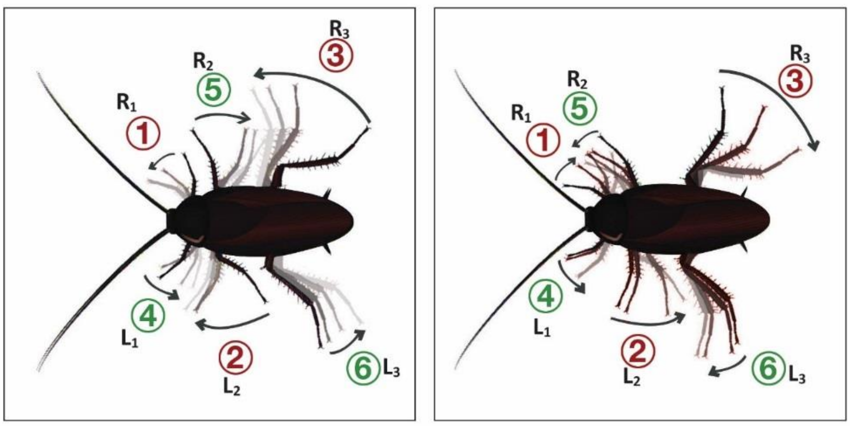

Figure 3. A view of the step-by-step motion that changes the sign in any part of the acceleration (Force). (a) The first half-step

motion and (b) The second half-step motion.

Zero-degree angle

The method of stepping is the same as described in other articles (Schmitt and Holmes, 2000)-this means that the movement progresses with the left leg up and the middle right leg and the bottom left leg down, followed by the right arm up and the middle left arm and the bottom right leg down. Acceleration changes during stepping are as follows: When the first leg is up, acceleration is positive and is toward increasing the initial acceleration. Acceleration is positive when the second leg is up and the third leg starts to move upward. At this time, the first and third legs from one side and the second leg on the other side are locked, while the rest of the legs are on the ground in free mode. Meanwhile, we have seen a strange move in all experiments with beetles that is like a forward throw, called a hop. Turning left starts when the first leg is up. Then, the cockroach, by locking its front legs, an average angle of 12 ± 0.1 degree of the yaw angle with P=0.14 in the opposite direction of the leg and makes a forward motion, the acceleration of which was positive at first and eventually becomes negative due to the backward motion of the cockroach's body.

There was also a movement outside the normal rhythm, as shown in Figures 4 and 5. This motion does not follow the above pattern and is recorded in all cockroach of the same type.

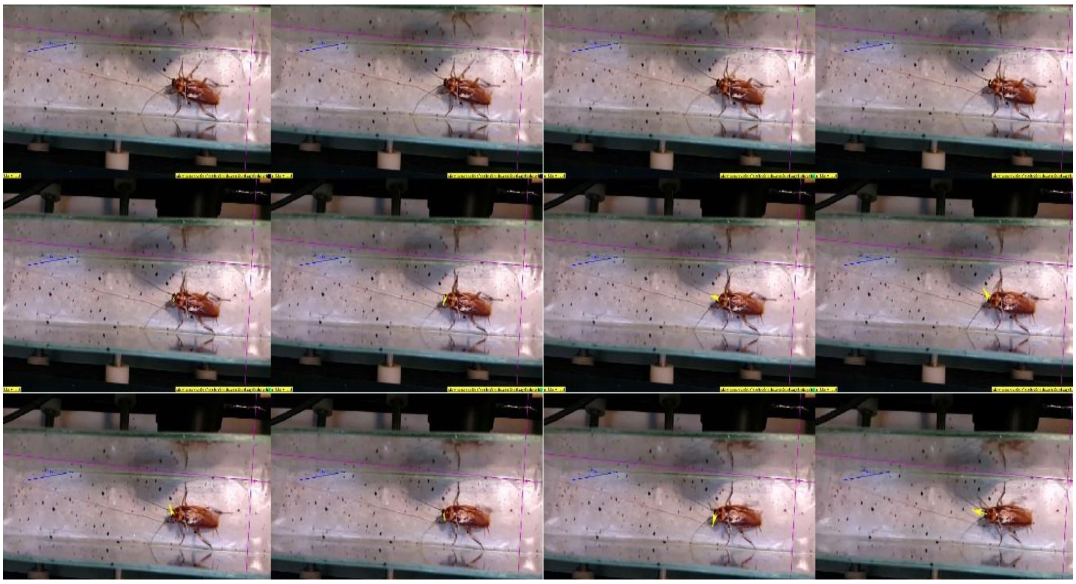

Figure 4. Non-rhythmic motion.

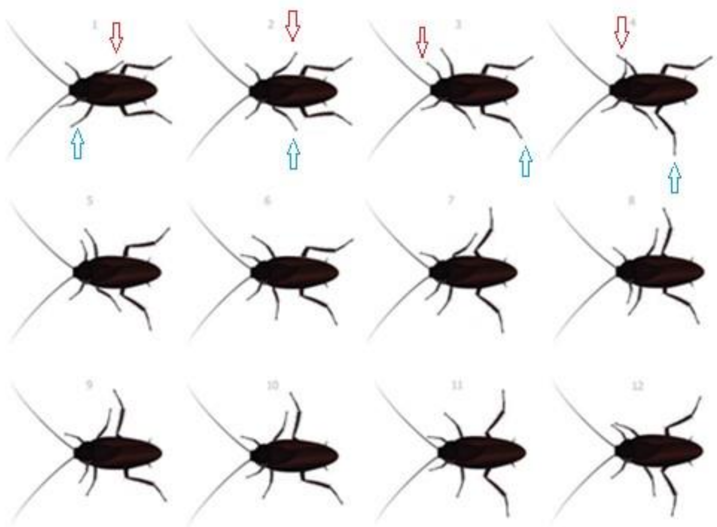

Figure 5. exact diagram of Non-rhythmic motion which shows that the movements of the two legs coincide in two consecutive numbers.

45-degree angle

In this state, the cockroach slides on the treadmill to some extent; its leg movement is irregular; and nothing significantly meaningful is obtained in this situation.

Movement on highly steep surfaces over 45 degrees

At the beginning, the movement of legs is performed separately from each other after finishing each movement: the first left leg to the first right leg, the second left leg to the second right leg, and the third left leg to the third right leg. In this movement, contrary to the previous movement, all five legs are locked and help the cockroach to move up and down. In addition, accelerations range from zero to the maximum positive value and then shifts to the maximum negative value for each leg. At slopes more than 45 degrees on the treadmill, the struggling movement of the cockroach was observed on the selected hard plastic cover and nothing specific was observed.

Discussion

The movement of the cockroach has been investigated on a treadmill at different angles from 0 to 45 degrees. The speed of the treadmill was less than 1/3 of the cockroach's speed, and the hardness of the plastic strip was about two times harder than Russian fir wood. Therefore, the claws of the legs are locked with more difficulty than on normal surfaces.

Investigating movement

One of the most important novelties of this paper is the investigation of different types of movements of the cockroach due to changes in angles that have not been dealt with in other studies. One innovation of this paper is the investigation of the special hop movement whose mechanism and functions were explained previously. One of the other achievements is the description of the force moment (acceleration) with respect to the leg movements.

The mechanics of six-legged runners were investigated by an innovative method and the force-time curve of the legs was achieved in normal movement (Full et al., 1989). Correspondingly, the other article investigated the behavior and movement disturbances of the cockroach by installing a new system called RIP (rapid impulsive perturbation) (Jindrich and Full, 2002). In this study, the reaction of the cockroach was studied in different angles of movement and the position of the COM was calculated during running. The other article measured the acceleration of the COM in three directions in Blaberus discoidalis by installing an MMA7260 accelerometer sensor along the fixture (Spence et al., 2010). The differences in acceleration were obtained on surfaces with different elasticity. One of the other works is the study of static load on the behavior of the American cockroach (Gorelkin et al., 2008). The effect of different loads at loading times was investigated in the cockroach's behavior. Correspondingly, in an interesting experiment, the dynamics of cockroach movement were investigated on a vertical wall (Goldman et al., 2006). One of the findings of this study is power in terms of step as well as forces in the three directions in terms of time. The Blabbers discoidalis cockroach has been used in the study in which surface quality was studied carefully. Interesting works have already been conducted on this topic. However, none of them has investigated the special behaviors of the cockroach hop. In addition, non-rhythmic motion has not been addressed in any research yet. Furthermore, the condition of leg force during these special movements has not been emphasized. This paper has considered these aspects in the overall movement of the cockroach.

Kinematic analysis

The normal motion of the cockroach become stretched with the movement of the right first and third legs and the second left legs forward. When these three legs are locked and the opposite three legs move, the cockroach's legs and arms become spring-like.

In the movement toward the sloped surface while moving forward, the movement is only performed by putting one leg to maximum elongation-the leg is clawed and moves the body forward along with the help of the other legs.

In total, these two movements are like a spring that has a single balance point, but the balance point is not in the middle. It moves to the positive side at the beginning and toward the balance point that resides at the highest acceleration point of the spring. Then, by moving from the balance point, the acceleration becomes negative and eventually returns to zero.

Conclusion

In its movement on a flat surface, the cockroach's legs move in the following order: the first leg left, the second leg right, and the third leg left (Schmitt and Holmes, 2000). We call this normal movement.

In 45-degree inclination, the cockroach moves its legs in an irregular form to climb the inclined surface.

In surfaces with an inclination of more than 45 degrees, the cockroach locks all of its legs and proceeds by moving each leg separately from the first leg to the sixth leg to climb the highly inclined surface.

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Competing interests

The authors declare no competing or financial interests.

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