Research on the Locomotion of German Shepherd Dog at Different Speeds and Slopes

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Abstract. Quadruped can take the initiative to adjust their gait for adapting to different external environment. Its superior coordination ability provides bionic design inspiration for the quadruped robot. The motion of three German Shepherd Dogs on a treadmill was recorded using a three-dimensional motion capture system VICON MX. The speed of the treadmill was respectively set at 4 km·h^{-1} and 10 km·h^{-1}, and the slope was set at 0° and 20°. Workstation, Polygon and MATLAB were utilized for data processing to obtain the joint angles of the German shepherd dog's forelimbs and hind limbs. The motion frequency of the dog increases, it indicates that the joints move faster to adjust the speed of the treadmill. As the speed of the treadmill increases, the cycle and the stance phase of each limb decrease, the percentages of the stance phase in total cycle are 68.0%, 49.0%, respectively for 4 km·h^{-1}, 10 km·h^{-1} at 0° slope of the treadmill and 65.6%, 47.1% for 20° slope of the treadmill, it indicates that speed affected the time characteristics, while the slope had little effect on the time characteristics. The joint angles of forelimb and hindlimb show that movement of different joints between different speeds and slopes are various.

Keywords: Dog · Kinematics · Joint angle · Swing phase · Stance phase

1 Introduction

The traditional terrain-machine is lack of mobility under complicated road condition [1]. Compared with traditional machine, legged robot especially the bionic legged robot has strong ground adaptability. Researchers focus on quadruped robot in developing the bionics robot because of its better carrying capacity and stability than biped robot, and simpler configuration than hexapod and eight-legged robot. Quadruped such as canine and goat have outstanding locomotion capability in extremely rough unstructured environment. They can adjust their gestures to ensure that they move safely, stably and efficiently when the topography changes. The behavior of each animal is described by the spatio-temporal features [2, 3] of its joint angles [4] and patterns of locomotive cycles. An application of the measurement system is designed to study the motion in the shoulder joint of a dog [5]. Values of stride parameters were compared between Greyhounds and Labrador Retrievers, and apparent differences in the trotting gait between these two breeds are mainly attributable to differences in size, and that

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dogs move in a dynamically similar manner at the trot [6]. The kinematics and kinetics of dog in different gait patterns were investigated [7–10]. The foot-ground contact biomechanics of German Shepherd Dog (GSD) in normal walking, trotting and jumping gaits were investigated using a pressure plate system [11]. The quantitative gait analysis showed that there was no significant difference between the movements of the left and right sides of the dogs in a trot gait [12].

In this work, we focused on the kinematic characteristics of German Shepherd Dog (GSD), and the motion properties on treadmill at different speeds and slopes were investigated.

2 Materials and Method

The study was approved by the Institutional Review Board Committee of Jilin University, Changchun, China. Three adults GSDs (body weights 35.3 ± 1.5 kg) were the subjects of this work, and 10 reflective markers were placed on the left side of the GSD, respectively scapula, humerus, elbow, carpus, and metacarpophalangeal joint of the forelimb, coxa, trochanter, knee, ankle, and metatarsophalangeal joint of hindlimb, as shown in the Fig. 1. GSDs were trained at the treadmill, and the speeds were set at 4 $\mathrm{km{\cdot}h^{-1}}$ and 10 $\mathrm{km{\cdot}h^{-1}}$, the slopes of treadmill were set at 0° and 20°. The kinematic data were collected using an 8-camera three-dimensional motion capture system (Vicon MX, Vicon Motion Systems Co., UK), and processed in the software of Workstation. From the motion of the metatarsophalangeal, it was determined when the limbs were in contact with or off the treadmill surface, and the stance phase (contact with the ground of single limb) and swing phase (off the ground of single limb) were divided. The joint angles (less than 180°) of forelimb (hip, knee and ankle) and hindlimb (shoulder, elbow and wrist) were computed using Matlab based on the collected data, and changes in these joint angles of forelimbs and hindlimbs were analyzed.

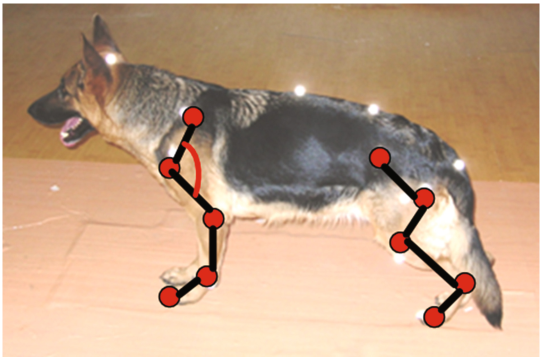
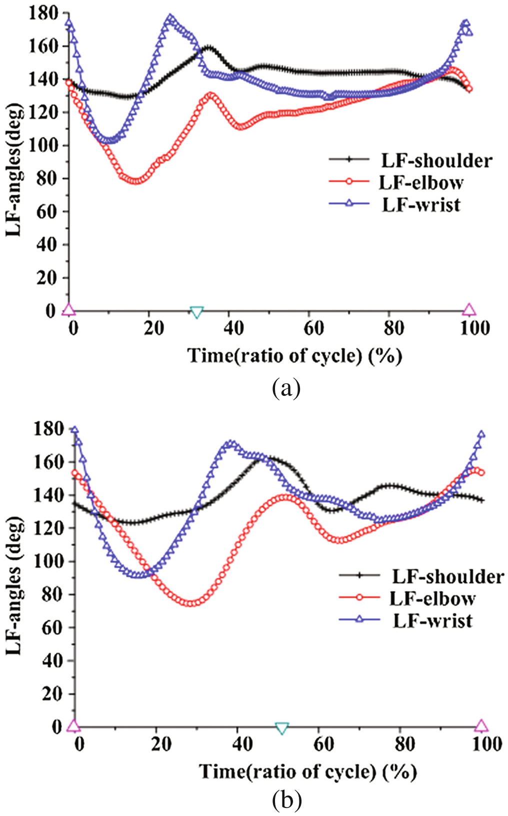


Fig. 1. GSD and markers

3 Results and Discussion

3.1 Joint Angles of Forelimb

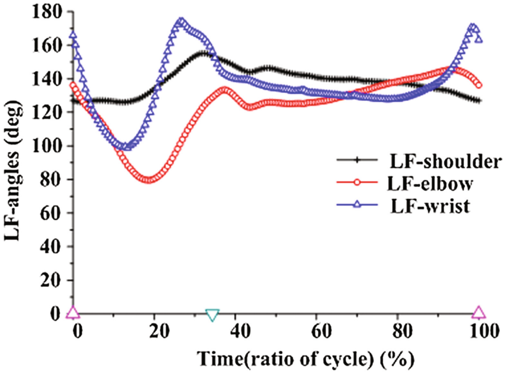
The period of motion is normalized, and joint angular curves of forelimb over a gait cycle are shown in Fig. 2. Figure 2(a), (b), (c) and (d) are the angles of forelimb at treadmill speed of 4 km·h^{-1} and 10 km·h^{-1} when the slopes of the treadmill are 0° and 20°.



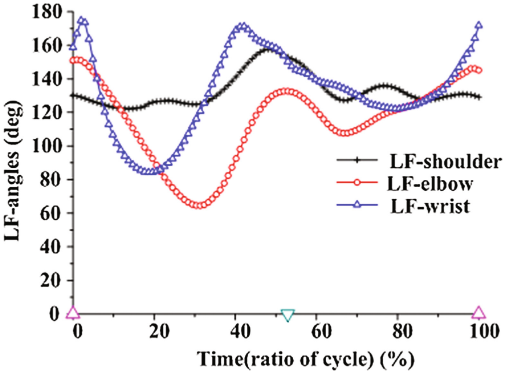
(a)

(b)

Fig. 2. Joint angles of forelimb at treadmill speed of 4 km·h^{-1} (a) and 10 km·h^{-1} (b) when the slope of the treadmill is 0°, and corresponding angles of 4 km·h^{-1} (c) and 10 km·h^{-1} (d) when the slope of the treadmill is 20°. Open uptriangle is used to mark the moment when limb detaches from the ground, and open downtriangle is the moment when limb hits the ground.



(c)



(d)

Fig. 2. (continued)

The rules and trends of the different speeds and slopes are similar. The Figures show that wrist extension is maximal (about 174° of 4 km·h^{-1} and 179° of 10 km·h^{-1}) at the beginning of the swing phase, and then wrist joint angle decreases because the wrist joint flexes backward. When the metatarsophalangeal joint reaches the highest point, the wrist joint has the largest angle value. The metatarsophalangeal joint moves forwards, so that the wrist joint extends forwards, which leads to increase of the wrist joint angle. After the wrist joint extends forwards to the maximum, it flexes forward until the forelimb contact with the treadmill. At the beginning of the stance phase, the wrist joint flexes gently so that it can provide cushion when the impact happens. At the end of the stance phase, wrist joint extends for the next swing. The shoulder and elbow joints extend and flex simultaneously, the maximums decrease with the backward swing of forelimb because the shoulder and elbow joints flex backward. Then these two joints swing forwards freely, and the joint angles increase to the maximums while the stance phase begins. During the stance phase, the shoulder and elbow flex to adapt to the impact.

Figure 2 shows that the slope of the swing angle is greater in the swing phase than that in the stance phase, it indicates that the joints move faster to adjust the speed of the treadmill. When the speed increases, the time of the stance decreases. Specifically, the percentages of the stance phase in total cycle are 68.0%, 49.0%, respectively for 4 km·h^{-1}, 10 km·h^{-1} at 0° slope of the treadmill and 65.6%, 47.1% for 20° slope of the treadmill.

Table 1. Extrema and ranges of forelimb angles (°)

		0° slope		20° slope	
		4 km·h^{-1}	10 km·h^{-1}	4 km·h^{-1}	10 km·h^{-1}
Shoulder	Max.	159.0	162.2	155.1	157.7
	Min.	129.3	123.3	126.0	122.1
	Ra	29.7	38.9	29.1	35.5
Elbow	Max.	145.5	155.0	145.4	151.4
	Min.	78.2	74.5	79.6	64.5
	Ra	67.3	80.5	65.9	86.9
Wrist	Max.	177.0	179.2	174.0	174.8
	Min.	102.4	91.2	98.8	84.3
	Ra	74.6	87.9	75.2	90.5

The extrema and ranges of forelimb angles are listed in Table 1. The differences among angle ranges of forelimb at different speeds on the same inclination are larger than 6.4° (the shoulder joint between 4 km·h^{-1} and 10 km·h^{-1} the at 20° slope), and the largest difference is 21.0° (the elbow joint between 4 km·h^{-1} and 10 km·h^{-1} the at 20°slope). The change of the angle ranges on different inclination at the same speeds are less than 6.6°.

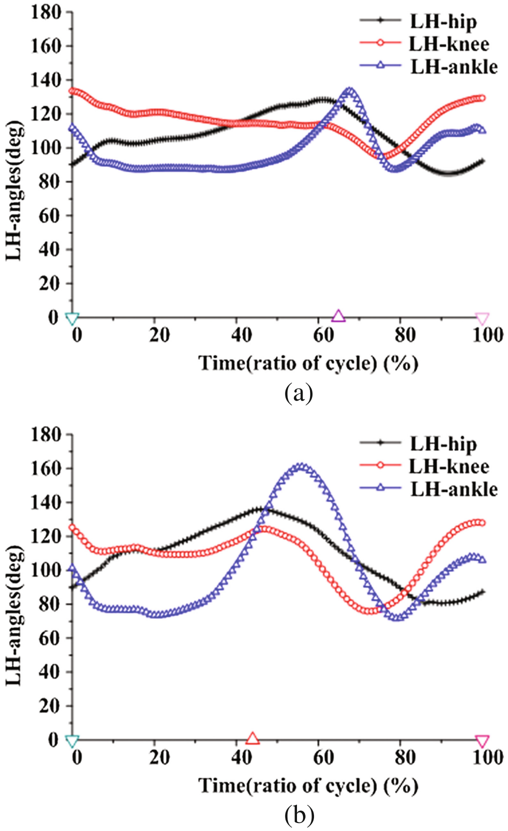
3.2 Joint Angles of Hindlimb

The joint angular curves of hindlimb over a gait cycle are shown in Fig. 3. Figure 3(a), (b), (c) and (d) are the angles of hindlimb at treadmill speed of 4 km·h^{-1} and 10 km·h^{-1} when the slopes of the treadmill are 0° and 20°.

The trends of the different speeds and slopes are also similar. Since the beginning of the stance phase, hip extends so that joint angle increases until to the maximum, and then hindlimb begins to swing, the hip flexes from this moment. At the end of the stance phase, hip extends for the next swing. Knee begins to flex gently, and there is one wave in the swing phase. During the stance phase, ankle and knee flex simultaneity, and there are two waves and one peak troughs in the ankle curves.

When the speed increases, the time of the stance decreases. Specifically, the percentages of the stance phase in total cycle are 64.9%, 44.0%, respectively for 4 km·h^{-1}, 10 km·h^{-1} at 0° slope of the treadmill and 66.3%, 43.8% for 20° slope of the treadmill.

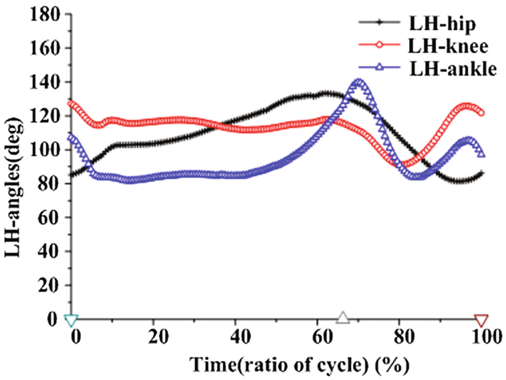
The extrema and ranges of forelimb angles are listed in Table 2. When speed increases, the angle ranges of knee and ankle expand significantly on the same inclination. The difference among angle ranges of hip at different speeds is larger when the slope of treadmill is 0°, while that difference is inconspicuous when the slope of treadmill is 20°. The difference among angle ranges of knee on different inclination at the same speeds are less than 2.7°, and that of hip is 8.3° at 4 km·h^{-1}, 6.4° at 10 km·h^{-1}.



(a)

(b)

Fig. 3. Joint angles of hindlimb at treadmill speed of 4 km·h^{-1} (a) and 10 km·h^{-1} (b) when the slope of the treadmill is 0°, and corresponding angles of 4 km·h^{-1} (c) and 10 km·h^{-1} (d) when the slope of the treadmill is 20°. Open uptriangle is used to mark the moment when limb detaches from the ground, and open downtriangle is the moment when limb hits the ground.



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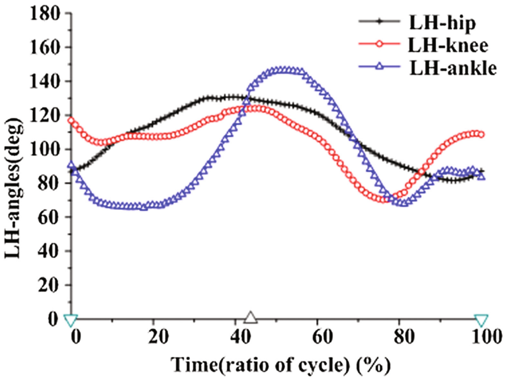

(d)

Fig. 3. (continued)

Table 2. Extrema and ranges of hindlimb angles (°)

		0° slope		20° slope	
		4 km·h^{-1}	10 km·h^{-1}	4 km·h^{-1}	10 km·h^{-1}
Hip	Max.	128.4	136.0	133.3	130.7
	Min.	84.8	80.5	81.4	81.6
	Ra	43.6	55.5	51.9	49.1
Knee	Max.	133.5	128.4	127.2	124.0
	Min.	94.8	75.8	91.2	70.2
	Ra	38.7	52.5	36.0	53.8
Ankle	Max.	133.3	160.9	139.6	146.3
	Min.	86.8	71.6	81.7	65.5
	Ra	46.5	89.2	57.9	80.9

4 Conclusions

The results of this work disclosed the rules of dog when it moved at different speeds and different slopes of treadmill. With an increase in treadmill speed from 4 km·h^{-1} to 10 km·h^{-1}, the percentages of the stance phase in total cycle decreased, and there was little variation between different slopes. The movements of different joints at different speeds and slopes are various. The quantitative analysis for the locomotion at different slopes will be useful for climbing ability improving of quadruped robot. Further studies on the mechanism of each joint and the skeletal-muscle-nervous system will help us to understand the motor strategies to regulate quadruped motion stability.

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