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Terrain recognition by using proprioceptive sensors of a soft quadruped robot

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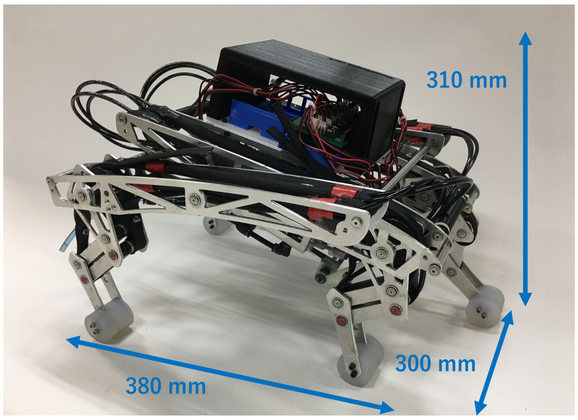
1 Introduction

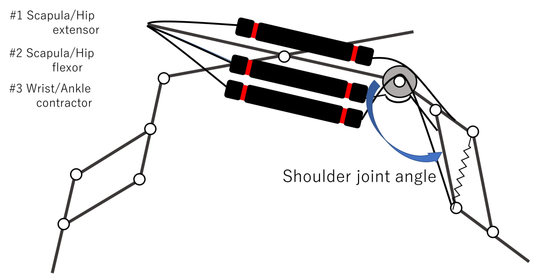
Terrain recognition is an important topic for legged robots to achieve better performance in various situations. Many methods have been developed for terrain recognition of legged robots, such as those using vision [1], inertial measurement units [2], and tactile sensors [3]. These sensors are so-called external sensors and can observe the state of the external world, in this case the terrain, directly. If the robot's body is soft, on the other hand, its behavior emerges through the interaction between its soft body and terrain. In this case, the robot can get information about the terrain by observing its behavior by proprioceptive sensors. This report describes how a soft quadruped robot can acquire information about slop angle by proprioceptive sensors. We show some preliminary experimental results.

2 Robot design

Figure 1a shows the photograph of our developed quadruped quadruped robot "PneuHound". The mechanical design of the robot is based on the previous work [4]. The robot has four legs: the length of fore and hind legs are 160 and 180 mm. The physical dimensions of the robot body are 380 mm long, 300 mm wide and 310 mm high. The robot has 12 pneumatic artificial muscles located in the legs, a micro-controller (Arduino Due), and 10 valves which result in a total weight of 3.43 kg.



(a)



(b)

Figure 1: (a)Pneumatic quadruped robot "PneuHound". The forward direction of the robot is right. (b)Structure of the leg. The fore and hind legs have the same structure, although the length of the legs is different.

Figure 1b shows the structure of the leg. The leg has a pantograph structure with springs which generates a spring-like behavior seen in animals' locomotion. The spring with stiffness 2.4 N/mm in the fore legs extends the wrist joint, and that with stiffness 2.9 N/mm in the rear legs extends the ankle joint. When legged robots realize fast locomotion on sloping terrain, output joint torque has to be sufficient and adjusted according to the terrain topology. For this reason, we employed pneumatic artificial muscles with high force output and soft actuation to drive the leg. Each leg is driven by three pneumatic artificial muscles: extensor and flexor that drive scapula/hip joint and contractor that drive wrist/ankle joint. Since the shoulder joint (Figure 1b) is driven by the pneumatic artificial muscles, the shoulder joint angle reflects the length of the pneumatic artificial muscles. Therefore, we measure the shoulder joint angle as a proprioceptive sensors of the pneumatic artificial muscles. All pneumatic artificial muscles are controlled by a valve control pattern that realizes the trot gait of the robot. We install a rubber surface on the toes to avoid slippage. The robot can also walk over sloping terrain without slippage.

3 Experiment and Result

We conducted a preliminary experiment to validate whether the slope angle can be classified by using the proprioceptive sensors of the soft quadruped robot. The slope angle was set to -15, 0, and 15 deg, and all experiments in each slope angle were conducted without changes of the valve control pattern. The pressure of compressed air supplied to the robot was 0.75 MPa, and the period of the valve command cycle was 200 ms.

Table 1: Average velocity. The velocity is calculated by using five trial data for each slope angle.

Slope angle [deg]	Average velocity (m/s)
-15	1.19
0	0.93
15	0.55

Table.1 shows the average velocity, and Figure 2 shows the time-series data of the shoulder joint angle measured by the video camera (fps:120 Hz). As the load on the pneumatic artificial muscle increases, the contraction length of the muscle decreases. Therefore, the shoulder joint rotates slower when the robot's leg contacts the ground. Based on this, we find out that if the robot walked on the ascending terrain, the shoulder joint was rotated further before the robot's leg contacted the ground (Figure 2).

4 Discussion

This report described an initial investigation of terrain recognition by using proprioceptive sensors of a soft quadruped robot. In the preliminary experiment, the time-series data of the shoulder angle was different when the robot walked on the ascending slope or not. It suggests that by using the proprioceptive sensors, the robot can classify the ascending slope. In the near future, we would like to equip the pneumatic artificial muscles with pressure sensor sensors and load cells. Moreover, we would like to develop a terrain recognition algorithm for a soft robot by using output data of the pneumatic artificial muscles.

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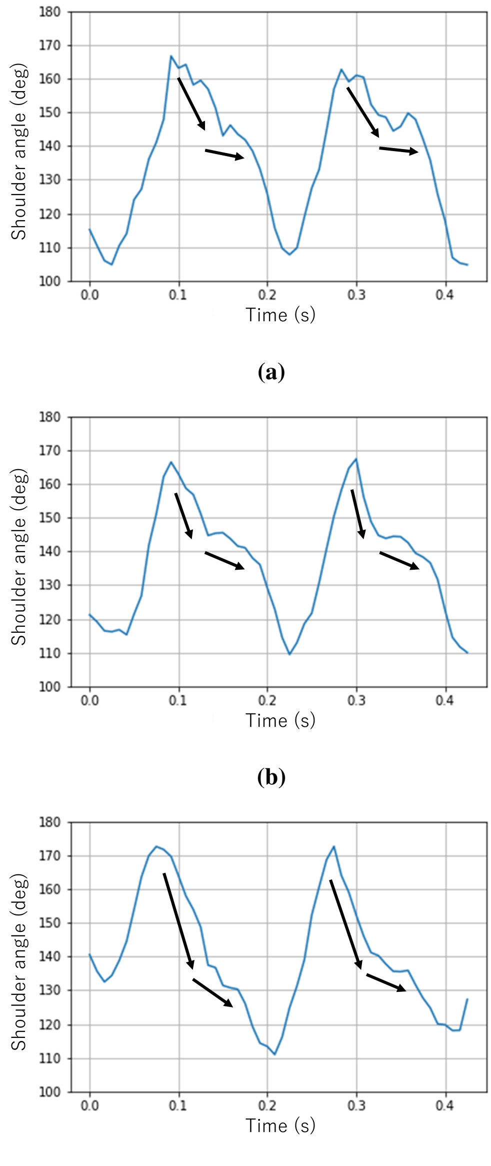

Figure 2: Typical behavior of the shoulder angle when the slope angle is (a)-15, (b)0, and (c)15 deg.