Unbalanced walking of a two leg quadruped robot design

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Abstract

To overcome any uncertain environment that may encounter, we present a quadruped robot design with two active legs in the front, constructed with five-bar linkages and two brushless DC motors, and passive wheels for support body weight and balancing. An experiment is performed to decide the height sensing method between current and angle error of motors. A platform with 0.5m height was placed in front of the right leg for experiment. We decided to take the angle error as our sensing method and conducted an experiment to determine the threshold of activating the functionality of changing gaits trajectory.The results show the angle error threshold to be 50 degrees when the platform height is over 0.4m and 20 degrees under 0.4m. In the future, we can smooth the gap of changing trajectory and import the ability of stepping downwards for wider adaptation of any uncertain environment.

1. Introduction

Nowadays, many quadruped robots were designed and a lot of research focused on the Cost of transport (CoT), efficiency, energy regeneration and legged locomotion of this kind of robot [5]. Among all those topics, the idea of bioinspired robots attracted our attention. The complexity of robots effectively interact with the environment and the simplicity of adapting unknown environments are the motivation that we are eager to explore.[6] Inspired by the PR-MPC method[2] that could be used in MIT cheetah to automatically generate quadrupedal gaits and address the balance of the robot, we combined the quadruped design idea of MIT cheetah 3[1] and symmetric five-bar linkage design of Minitaur and create a quadruped walking robot that extract the benefit of direct-drive(DD) legged robots, which has transparency, mechanical robustness/efficiency, high actuation bandwidth, and the ability of affording highly energetic behaviors.[4][3] With those benefits of this system, we would like to explore the ability of adapting unbalanced walking gaits trajectory, which commonly happens in the real world scenario where an not entirely flat floor could be, using a simple control method.

2. System design

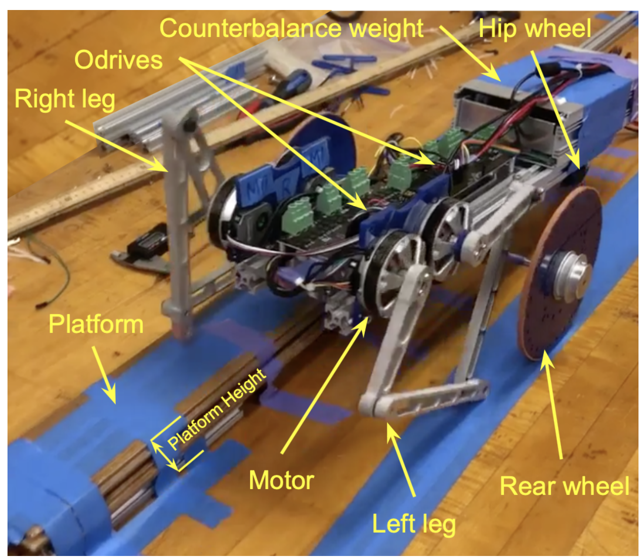


Figure 1: The quadruped robot design with two legs, a pair of real wheels, a counterbalance weight and a hip wheel. For the right leg, a platform of changeable platform height was placed in the front to test the unbalanced walking situation.

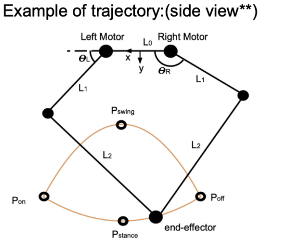
2.1. Hardware

Our robot, as shown in Figure 1, was composed of two five bar linkages legs with two Quanum brushless DC motors on both sides in the front and two ODrive BLDC controllers between them. Each one of the controllers controlled two DC motors. In order to balance the robot, we assembled a quadruped robot design with a pair of circle acrylic plates as rear wheels and added a counterbalance weight (an unplugged power supply) at the end of the robot to compensate for the mass distribution in the front. In this way, the robot can not only support its own weight but walk on its own when importing the gaits trajectory into those legs. However, we later observed a seesaw motion of the robot, which caused an unstable walking behavior. Therefore, we added a passive wheel as a hip wheel to reduce the unstable behavior and made it possible to measure steady current and angle error of motors to calculate the correct x-y position of the end-effector.

2.2. Software

Parameters*	Value
Stance start (P_{on})	(x,y)=(0.05,0.13)
Stance end (P_{off})	(x,y)=(0.05,0.13)
Mid stance (P_{stance})	(x,y)=(0,0.15)
Mid swing (P_{swing})	(x,y)=(0,0.07)
Time period(T)	15
Duty-factor (d)	0.6
Number of points (N)	100

Example of trajectory:(side view**)



*Units: meter, second
**L_0=0.07, L_1=0.09, L_2=0.16

Figure 2: The side view of a single leg design is shown on the right with the example of trajectory below (orange line). In this paper, the origin of the coordinate system is defined in the middle of two motors, where the positive x direction points to the left motor and positive y direction points to the end-effector.

Before controlling motors, we first calculated the desired x-y polynomial gait trajectory for the left and the right leg end-effectors using inverse kinematic with parameters listed in Figure 2. A single Python script was used to control the system. For each loop, motors of both legs were commanded to achieve the desired end-effector x-y position according to the gaits trajectory. The time for each movement and the angle error of each motor were measured to check if legs step into any obstacle or not. The reason of using angle error will be discussed in the next section, If the angle error is bigger than a certain threshold, the current angle of each motor will be recorded and transferred to the end-effector x-y position as a contact point using forward kinematic. Once we get the contact point, we can calculate a height difference by comparing the y value of contact point to that of P_on. Using the height difference, we change the y value of P_on, P_off and P_stance and recalculate the new desired x-y polynomial gaits trajectory of both legs' end-effector. The new gaits trajectory will then be used in the following control loop.

3. Experiments

To test the ability of unbalanced walking, i.e. the left and right leg have different step levels, we did two experiments to determine the criteria of sensing height and the threshold value for changing gait trajectory. In both experiments, we placed a platform in front of the right leg, shown in Figure 1, to make it step on the platform while walking. On the other side, the left leg will maintain walking on the ground. Therefore, we only gave the right leg the ability to adjust the gait trajectory and examined the measurement of the right leg in the following experiment.

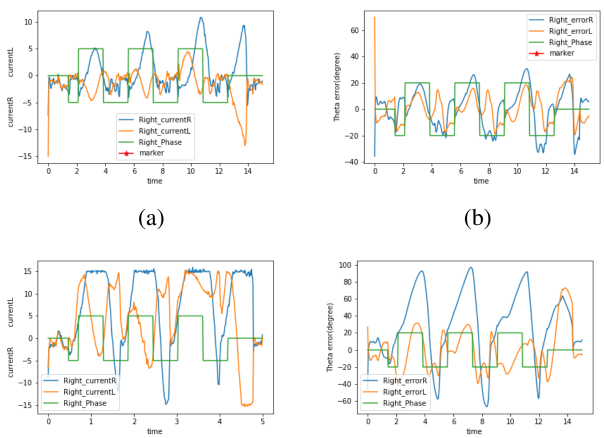
3.1. Sensing Experiment

3.1.1 Method

In this experiment, we set the platform height into 50mm and measure the current and angle error of each motor at the same time. Given the same 4 steps of gait trajectory, we compared the difference of normal walking situation and unbalanced walking situation to determine which measurement is more practical of sensing the platform height. For the normal walking situation, both the left and right legs of the robot walk on the ground, while the right leg walks on the platform under the unbalanced walking situation. The goal of this sensing experiment is to observe the maximum value of current or angle error of motors and determine which parameters are suitable for sensing contact points.

3.1.2 Results

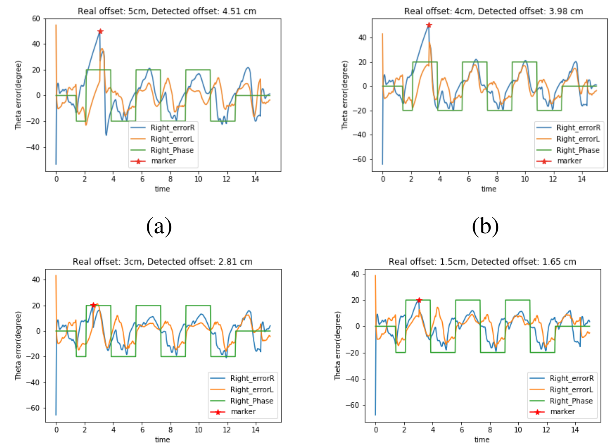
The results of the sensing experiment were shown in Figure 3. For the unbalanced walking situation during the stance phase, since the right leg hits the platform and cannot move further into the platform, both current and angle error value increased drastically. For the current measurement, the difference of maximum current value between two situations was only 5A and the current had a limit of $\pm 15A$ due safety concern. Therefore, it is not a relatively obvious measurement for sensing the platform height. One the other hand, the difference of maximum angle error of the right motor for the angle error measurement was about 60 degrees between two situations. The difference was obvious and ideal for sensing the platform height.



(a) (b)

(c) (d)

Figure 3: (a) and (b) are the measurement of current and angle error for normal walking. (c) and (d) are the measurement of current and angle error for unbalanced walking. The green line represents the phase of the right leg, where the stance phase is the value larger than 0 and the swing phase on the opposite.



(a) (b)

(c) (d)

Figure 4: (a) and (b) are the measurement of current and angle error for normal walking. (c) and (d) are the measurement of current and angle error for unbalanced walking. The green line represents the phase of the right leg, where the stance phase is the value larger than 0 and the swing phase on the opposite.

3.2. Threshold Value Experiment

3.2.1 Method

Based on the result of the sensing experiment, we used angle error of the right motor to determine if the unbalanced walking situation happened or not. An algorithm is developed that if the position error of the right motor of the right leg exceeds threshold value, the robot will initiate forward kinematics by taking the encoder's value as input. This allows the robot to know how much height the gait needs to change for the following movement. In order to determine the threshold value for changing gaits trajectory, we tested the unbalanced walking situation with four different platform height values, which were 0.5mm, 0.4mm, 0.3mm and 0.15mm.

3.2.2 Results

The results of the threshold value experiment were shown in Figure 3. We can see that once the right leg hit the platform and adjusted the gait trajectory according to the platform height it measured, the following angle value was reduced to the similar value of the normal walking situation and the threshold was no longer achieved, therefore, resulted in a more stable walking situation. The threshold value we used for platform height over 0.4m was 50 degrees of angle error and 20 degrees under 0.4m.

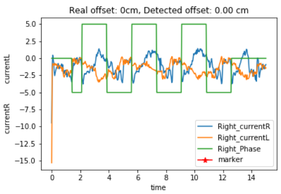
4. Future work

4.1. Gaits changing Improvement

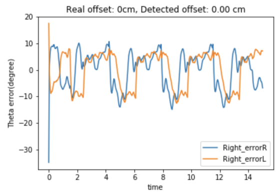
In our model, after sensing the platform height, the robot changes its gaits trajectory immediately. Although the new gaits trajectory changed afterwards, the distribution of end-effector x-y position in the gaits trajectory was different. Therefore, there might have been some inconsistent change of x-y position and caused the end-effector pushing too hard on the platform. This effect might result in a falling or flip over of the robot due to the inconsistent step when testing for a higher platform in the future. To solve this, we can smooth the process of changing gaits trajectory by fitting with a polynomial line.

4.2. Stepping downwards

For now, the robot has the ability to change its own gaits trajectory when facing a positive height difference but not for a negative one like people walking downstairs. Similar to the experiments we have done in this paper, we could figure out the way of sensing and the threshold of changing gaits trajectory. To sense an empty step, we can compare the angle error of normal walking and walking in the air in Figure 5. The angle error of walking in the air was measured when the robot was raised and walked in the air without any contact with the ground. The angle error of walking in the air has 10 degrees less than the angle error of normal walking. Therefore, we can record every angle error during



(a)



(b)

Figure 5: (a) shows the angle error measurement of the right leg during the normal walking situation. The green line represents the phase of the right leg, where the stance phase is the value larger than 0 and the swing phase on the opposite. (b) shows the angle error measurement of the right leg when walking in the air.

the stance phase and lower the gaits trajectory if the maximum angle of error does not exceed a threshold afterwards. On the next step, we can change the end-effector y position 0.01m lower on each step until the maximum value of those angle errors exceed a certain degree of threshold, which represents touching the ground, to detect the level of negative height. It is possible to combine what we have done in this paper and this new idea into one project. So that it could not only detect positive height change, but also a step going downward. Still, this idea does not interact with the height change instantly, rather, it takes a few more steps to modify with the environment.

5. Conclusion

In this paper, we present a quadruped robot design with two legs in the front, a pair of passive wheels in the back and a hip wheel for stable motion. An experiment is performed to decide the height sensing method of a platform in front of the right leg. A threshold is measured to activate the functionality of changing gaits trajectory. In the future, the gap of changing trajectory could be smoothen and the ability of stepping downwards could be imported for wider adaptation of an uncertain environment.

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