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Parameter Adaptation using Ground Contact Force for a Humanoid Walking Control

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Abstract: In this paper, the ground contact force during a walking cycle is used as the feedback for walking parameter adaptation. The force is measured from piezo-resistive force sensors attached at the corner of the robot's footplate. The neural networks process the force measurement input and calculate the current observed leaning angle of the robot. The body leaning angle parameter is adjusted according to the observed leaning angle. With a good leaning angle parameter, the robot can walk with well balanced force on both feet and shows greater stability. The proposed process was tested with various initial conditions. The walking parameter controller can automatically adjust the leaning angle of the robot to the correct value which resulted in good walking performance.

Keywords: humanoid robot, walking control, force sensors

1. INTRODUCTION

Recently, robotics researchers have studied about the biped-humanoid robot motion control system, for example, walking control. Generally, the walking cycle can be divided to two phases—single support phase (SSP) and double support phase (DSP). In SSP, the whole robot weight acts to only single robot's foot. The Zero moment point (ZMP) can be used as a measure for a stability of walking. Shimojo et al. [1] and Erbatur et al. [2] used force sensing resistors (FSR) to measure the force which effecting to robot's feet and to estimate the ZMP of the robot. Aoki and Watanabe [3] used the pressure sensor to calculate the ZMP.

In this paper, a piezo-resistive sensor is used to measure the ground contact force at the robot's foot plate. Four force sensors are attached at the corner of each foot. The ground contact force measurement is not used to estimating the ZMP, but is used as the feedback in order to adapt the walking parameters in the walking control system

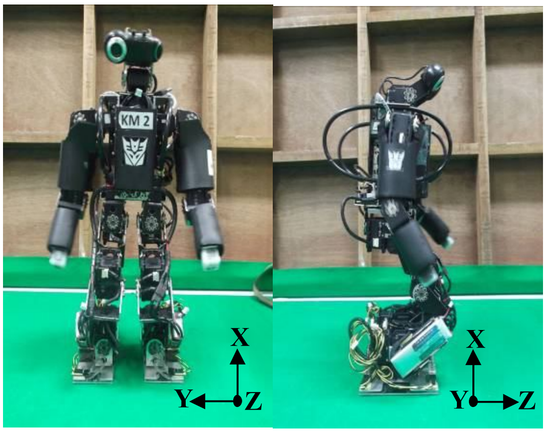

Fig. 1 KM humanoid robot.

2. HUMANOID ROBOT SYSTEM

Our experiment was performed on the FIBO Kid Size Humanoid Robot (KM-Series) which has 20 degree-of-freedom (DOF), 6-DOFs on each leg, 3-DOFs on each arm and 2-DOFs on the head. The robot uses a commercial servo motor (Robotis) as an actuator (i.e. 18 of RX-28 and 2 of RX-64). The locomotion control system is implemented on the ARM-7 microcontroller which connects to all motors via RS-485 bus.

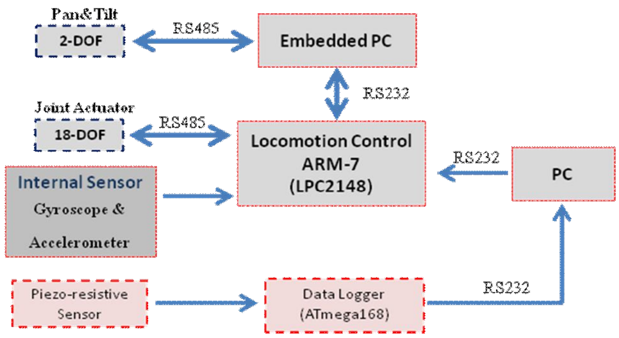

Fig. 2 KM's system diagram.

3. ADAPTIVE WALKING CONTROL

3.1 Walking control parameters

In our humanoid robot walking controller, the triangular foot lifting trajectory is generated and the leg joint trajectory is generated from inverse kinematics calculation. The gyro feedback is used to stabilized the walk by an ankle compensation adjustment. Several walking parameters have to be specified in advance including: step height, step length, step time and body's forward/backward leaning angle(β_{robot}), hip height, left and right foot position(x_l, y_l), (x_r, y_r). In the existing walking control system, human has to adjust these parameters manually based on visual observation by trial-error. The body's forward/backward leaning angle can be visually observed as shown in fig.3.

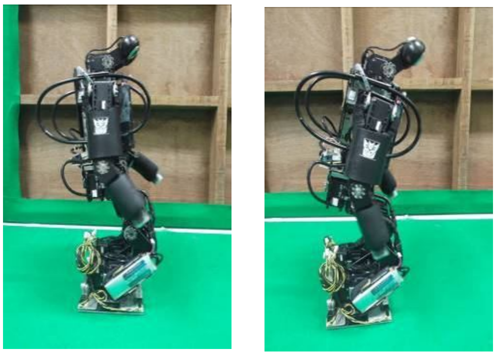

Fig. 3 Forward/backward leaning angle
a) 0 degree, b) -8 degrees

3.2 Force sensor module

The piezo-reistive force sensors (Flexiforce) with the measurement range of 0-25lb were attached at the foot of the robot. 4 sensors were attached at each corner of the robot's foot as shown in fig.5. The output of the force sensor is connecting to the signal conditional module which is an inverting amplifier (shown in fig.4) as described in Eq.(1).

$$V_o = \left(\frac{R_1 + R_2}{R_{Piezo-resistive}} \right) V_i \qquad (1)$$

where V_o is the output of the amplifier circuit and
V_i is the input voltage of the amplifier circuit.

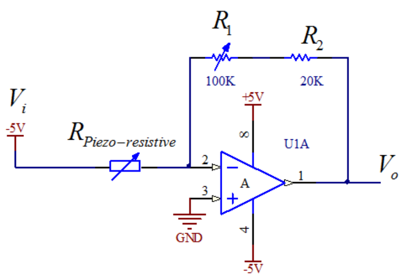

Fig.4 Inverting amplifier circuit.

Fig.5 Force sensor attachment at the foot of the robot.

The output voltage is sampled by a 10bit ADC using ATMEGA168 microcontroller at 50 Hz. All force sensors were calibrated before using as the control input of the robot.

3.2 Static and dynamic force measurement

By installing the force sensor at the foot plate, we can find the static balancing posture which the force in the left and right foot of the robot are equal. In this posture, the robot uses minimum torque to maintain its static stability. Fig.6 shows the static force measurement on the left and right foot of the robot when the robot is standing with balancing posture.

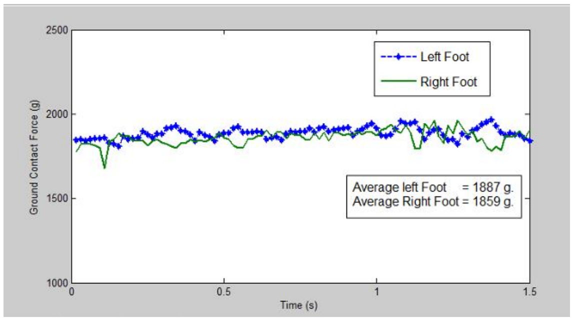

Fig.6 Static force measurement on left and right foot.

The walking experiment was performed on the RoboCup soccer field and the ground contact force was measured during the walk. The walking phase can be separated into two phases: the single support and the double support phase. In the single support phase, only one foot is on the ground and in the double support phase, both feet are on the ground. The graphs in in fig.7 and 8 showed that the ground contact force during the walk in single support and double support phase which can be used as an indicator for the walking performance. The magnitude of the impact force when the foot hits the ground and the difference in the ground contact force between the left and the right foot relates to the dynamical imbalance in the system and the heading error. At different leaning angle, the ground contact force shows different characteristic. Therefore the relationship between a forward/backward leaning angle and the walking stability and walking speed was observed.

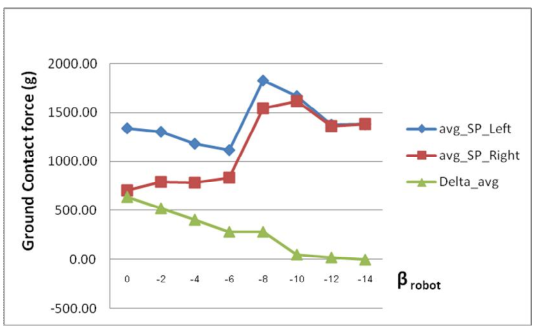

Fig. 7 Relationship between the difference of left/right ground contact force during the single support walking phase and the leaning angle

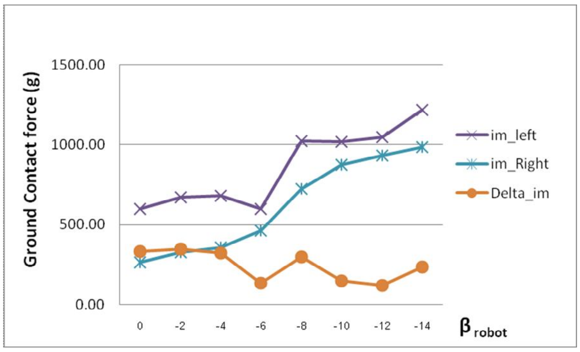

Fig. 8 Relationship between the difference of left/right ground contact force during the double support walking phase and the leaning angle

4. NEURAL NETWORKS WALKING CONTROLLER

4.1 Neural networks leaning angle compensation

In this work, we designed the neural networks controller which takes the ground contact force from the left and right foot of the robot as an input and adjusting the leaning angle of the robot to improve its walking performance. The feed-forward multilayer perceptron with 2 hidden layers (16,8) is used to learn the relationship between the input from force sensors and the leaning angle. The ground contact force input is sampled at 50 Hz, then the data is averaged over 5 sample window in the preprocessing step as shown in fig.9. After preprocessing is performed on the force sensor readings, the neural networks controller generates the target leaning angle which minimizes the ground contact force magnitude and difference between left and right foot. By applying the proposed neural network controller to adapt the leaning angle parameter of the current walking controller from the ground force contact information, the robot can improve its walking performance with minimal effort compare to human tuning.

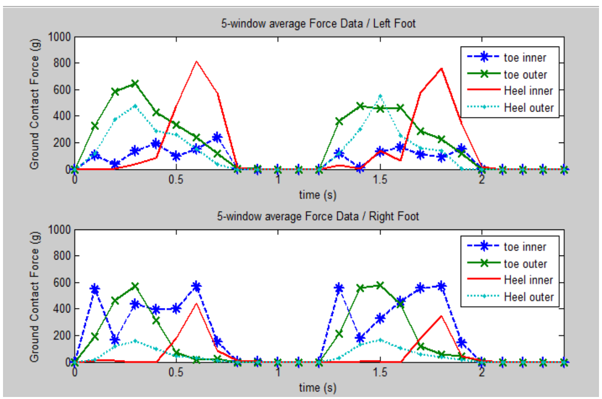

Fig. 9 Preprocessed force input to the neural networks of two walking cycles.

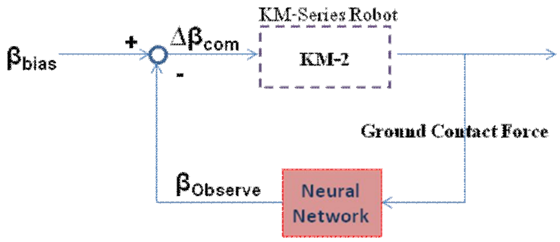

Fig.10 Neural Networks leaning angle compensator block diagram

4.2 Experimental results

In this experiment, four piezo-resistive sensors attached at the corner of each foot is used to measure the ground contact force at the robot's foot plate. The ground contact force is used as the feedback to the neural networks leaning angle compensator as described in section 4.1. The overall walking control system is shown in fig.11. The robot was initialized to have different leaning angle (varied from 0 to -14 degrees, 20 trials for each initial condition). For each walking cycle, the ground contact force was sampled and processed by the neural network controller. The leaning angle compensation was then generated from the neural network controller as described in fig.10. The leaning angle bias is set to -6.5 degrees in this experiment. The graph in fig.12 and Table 1 shows the relationship between the observed leaning angle from the neural networks and the leaning angle compensation.

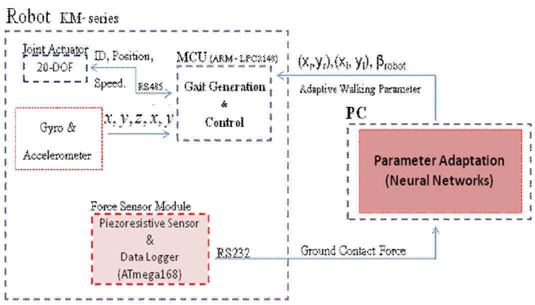

Fig. 11 The neural networks walking controller system diagram

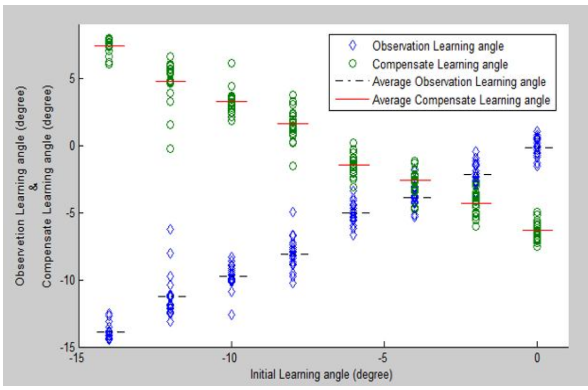

Fig. 12 The observed leaning angle from neural networks and the leaning angle compensation (the leaning angle bias = -6.5 degrees).

Table 1 The average observed leaning angle from neural networks, the difference between the initial and the observed leaning angle and the average leaning angle compensation for initial leaning angles. (unit: degree)

Initial β	Observed β	Observed error	Compensated β
0	-0.29	-0.29	-6.21
-2	-1.78	0.22	-4.72
-4	-4.11	-0.11	-2.39
-6	-5.55	0.05	-0.95
-8	-8.80	-0.80	-2.30
-10	-9.46	0.54	2.96
-12	-11.76	0.24	5.26
-14	-14.00	0.00	7.50

The experimental results shows that the neural networks can observed the leaning angle with the accuracy up to 0.8 degrees. However, we should note that the initial leaning angle meant the programmed walking parameters at the initial condition. When the neural networks processed the force input, it correlated the characteristic of the ground contact force input with the leaning angle from the learned example. Therefore, the observed leaning angle output from the neural networks represents the ground contact force that has the same characteristics as the learned example at that leaning angle. With the output from the neural networks, the robot can automatically compensated its leaning angle parameters so that it will behave as close as possible to the best case where the difference of ground contact force between the left and right foot is minimized as shown in fig.13.

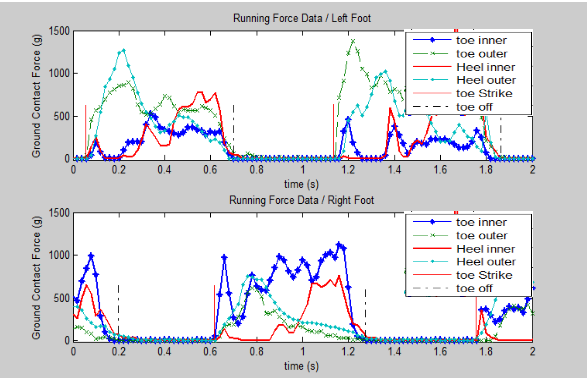

Fig. 13 The ground contacting force of one walking cycle after the body learning angle was compensated by the proposed controller.

4. CONCLUSION

In this paper, the ground contact force during a walking cycle is used as the feedback for walking parameter compensation. The forward/backward leaning angle of the robot can be adjusted so that the difference between the ground contact force in the left and right foot of the robot during a walking cycle is minimized. The ground contact force is measured by four piezo-resistive force sensors attached at four corners of each foot. The force measurement were processed by a neural networks which associated the force characteristic with the leaning angle. The observed leaning angle from the neural networks was then used to adjust the leaning angle of the robot. From the experiment where the robot was set to various leaning angle parameter, the neural networks can correctly observes the leaning angle and automatically adjusted the leaning angle parameter. The walking performance can be improved when the ground contact force is well balance between the two feet. This method is very helpful for walking parameter tuning process because the walking performance can be better represented by force information than visual observation in the manual tuning method.

5. ACKNOWLEDGEMENT

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