Tactile Sensor-Based Detection of Partial Foothold for Balance Control in Humanoid Robots

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***Abstract*— This paper proposes a tactile sensor array to detect partial footholds and a wrench control method for biped humanoid robots using detected partial footholds. The proposed tactile sensor adopts a high-density FSR (Force Sensitive Resistor) array. It can read data within milliseconds. Filtering methods for its high-speed data which provide accurate estimation of contact areas are also proposed. They enable the computation of optimal contact forces. A wrench control method for biped humanoid robots, based on contact area information from detected partial footholds, enables stable force control even in partial foothold situations. The effectiveness of this advanced control system is evaluated through stabilizing experiments on partial footholds using an actual humanoid robot.**

***Index Terms*— biped walking, tactile sensor array, contact area estimation.**

I. INTRODUCTION

For legged robot controllers, acquiring information about environmental contact is extremely important. In legged robots, the force applied to the feet significantly impacts the robot, and various methods have been examined to acquire environmental contact information. In this paper, we propose a biological-inspired synchronization-based terrain unevenness sensing approach [1] by introducing tactile sensors to the soles of existing bipedal robots. The tactile sensors developed in this paper can acquire distributed contact state between the foot and the ground with high resolution by leveraging the sensor characteristics. By providing contact area information instead of force distribution from tactile information, the area can directly used as the actual support polygon. This research has three contributions:

1) Develop high-density sensors and low error reading electronic circuits.
2) Develop contact area estimation methods.
3) Control the contact force using tactile information.

These methods were applied to RHP Friends [2], enabling it to walk with partial foot contact, which was not possible with the existing controller.

II. DEVELOPMENT OF A TACTILE SENSOR SYSTEM

We designed the humanoid robot mechanical foot and reading circuit for this research. Fig. 1 shows the mechanical design of the foot with tactile sensor.

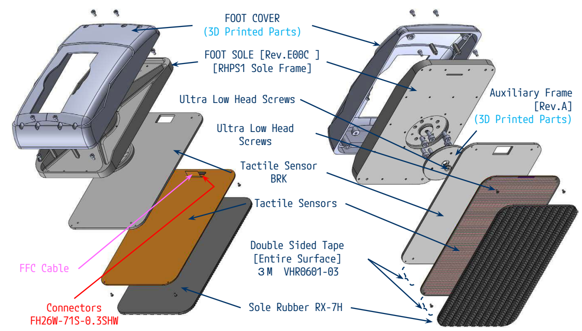

Fig. 1. Mechanical design of the foot with tactile sensor

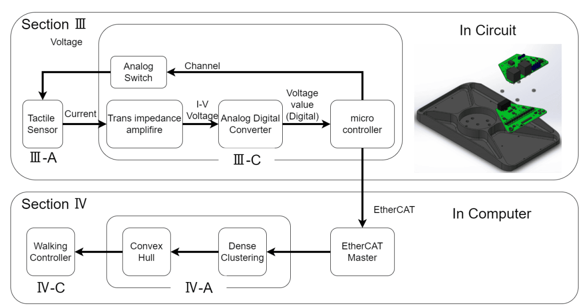

Fig. 2. System architecture of the proposed circuit and filter

In circuit part, We propose the system that is able to read and integrate data from densely packed sensor arrays for control. By using parallel ADCs and IV conversion circuits, the readings can be taken at high speed while reducing reading errors due to ghosting.

The interface board is implemented using a micro controller, an external ADC, and analog switches. The resistance values obtained are converted to force values in the micro controller. This force is then compared to a predefined threshold to determine whether the sensor is in contact or not. This contact information is transmitted to the whole-body motion controller at a frequency of 2kHz using EtherCAT [3]. The system overview is shown in Fig. 2, as well as the image of the interface board created by incorporating the proposed method, and its placement in the foot.

III. CONTACT AREA ESTIMATION

Previous studies [4] have computed the convex hull on tactile data obtained from sensors to estimate the contact area. However, due to the flexibility of common tactile sensors, accurately estimating the boundaries of the contact

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TABLE I

THE RESULT OF CONTROLLER STABILIZATION

	Typical Controller	Tactile-based Controller
Anterior Floating	Fall down	Stabilized
Lateral Floating	Fall down	Stabilized
Medial Floating	Stabilized	Stabilized

area has been challenging. For example, the sensor foot using RoboSkin [4] addresses this issue by defining a margin called the Pre-contact area before computing the convex hull. In this paper, we propose a new contact area determination method to resolve these challenges. This method focuses on a rigid and high-density tactile sensor. In this tactile sensor, the rigidity limits the points where contact force can occur. Therefore, we propose an interpolation method for rigid body contact information, focusing on the fact that the sensors are high-density. After that, we can reduce data fluctuation and robustly get the contact area. The proposed method reduces the error by about 10% in all the scenarios. The proposed method is able to estimate more stable regions with less variation than the existing methods. The combination of the developed sensor and the proposed processing method enables contact area estimation at the boundary, which has been a problem with existing sensors, and also enables accurate determination of the grounding area.

IV. EXPERIMENTS AND DISCUSSION

In this section, the methods described above are experimentally evaluated. The results obtained using tactile sensors are compared to similar methods using solely leg force torque sensors installed at the ankles. We attracted our tactile sensor foot to the foot of RHP Friends.

We have confirmed the effectiveness of the proposed method with stabilization control in several partial contact situations. Fig. 3 shows the situations Anterior floating, Lateral Floating, and Medial floating and the corresponding tactile data. We set up the the robot for each of situation and monitor the values of the foot force sensors when the stabilization controller is enabled. We show the result of the experiments in Table I. According to the result, if there is no tactile contact information, the robot falls down except in the case of Medial floating situation. In this situation, the contact area size differs from the flat ground but the support area is the same. Thus, it could be stabilized without tactile information. However, Lateral floating and Anterior floating resulted in falls in the absence of tactile information.

When the robot is in partial contact state, the force cannot converge to the target value because the impedance control is based on the assumption that the entire sole of the foot is in contact. On the other hand, by providing information on the contact area, an impedance control that takes this area into account is possible, and convergence is doable. By analyzing the log data, the robot during the situation Lateral floating also fell over for the same reason as the Anterior floating situation.

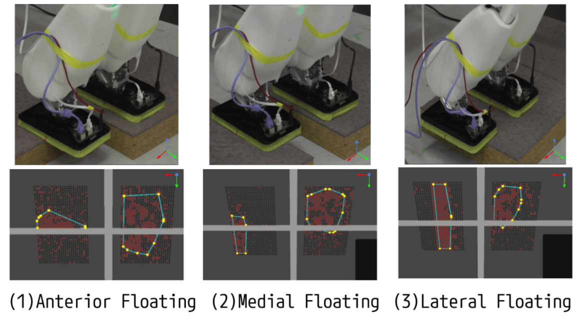

Fig. 3. Snapshots of the experimental and estimated contact area results are presented.

V. CONCLUSION

In this paper, we developed a high-density tactile sensor and a tactile sensor interface then proposed a method for estimating the contact area. The interface has simultaneous readout that accelerated sampling frequency by 25 times. The experiments demonstrated that the proposed method, which binaries the tactile data to estimate the contact area, can clearly and quickly detect the contact area because it suppresses steady sensor noise and reduces the amount of data. Furthermore, incorporating tactile information enhanced stability when the robot is positioned on a partial foothold. The robot could apply appropriate force and torque suitable for the detected contact area. The result confirmed the effectiveness of the method by confirming reduction of the errors on the force and moment during partial contact. This paper contributed to the development of walking robots by showing that when the soles of the feet are in partial contact, the robot can be stabilized by observing the condition and applying the optimum force.

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