Biped walking of a humanoid robot on sand

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ABSTRACT
This paper presents load-sinkage characteristics of sand as a fundamental research for realization of biped walking of a humanoid robot on sand. Dominant characteristic parameters of sand are estimated through load test using a test plate which is same size of foot of the robot.

1. Introduction
Most of studies for walking of biped robots have been assumed to walk on the stiff ground. The walking of the biped robots on loose soil such as sand is greatly challenging research in the field of humanoid robot. If the robot achieves stable walking on the loose soil, the robot can perform variety of tasks in various activities. To develop such an advanced technology, it is important to acquire proper knowledge of dynamic behavior of the biped robot on sand. Yoshida and Hamano investigated dynamic motions of a rover based on dynamical model between wheels and sand [1]. Muro estimated tractive performance of a bulldozer on the basis of the model between crawler and loose soil [2]. However, the study of the walking on sand by the biped robot has not been investigated yet.

The aim of this paper is to estimate load-sinkage characteristics of sand to obtain static contact model between foot and sand.

2. Dominant Parameter Estimation Method
As shown in Fig. 1, feet of the robot on sand sink depending on weight of the robot. The relationship between ground contact pressure \( p \) acting on the sole and static sinkage \( s \) is generally expressed as follows [3]:

\[
p = k s^n,
\]

where \( k \) is a coefficient of sinkage and \( n \) is an exponent of sinkage. These two parameters are required to be experimentally identified.

In logarithmic space, eq. (1) is expressed as follows:

\[
\log_{10} p = \log_{10}(k s^n) = n \log_{10} s + \log_{10} k.
\]

Eq. (2) can be expressed as a linear function as follows:

\[
Y = AX + B,
\]

where the symbols are defined as:

\[
X = \log_{10} s,
Y = \log_{10} p,
A = n,
B = \log_{10} k.
\]

From the above relationship, the pressure \( p \) [kg/mm\(^2\)] is expected to be in proportion to the sinkage \( s \) [mm] in logarithmic space. Therefore, \( k \) and \( n \) can be estimated by linear regression analysis on the experimental data in logarithmic space.

3. Experimental system

3.1 Load machine
A load machine is developed as shown in Fig 2. It consists of a test plate, a loading platform, frames, a dial gauge and a sand box. This machine is fixed in a perfectly horizontal position. There is a pair of vertical rails on the frames, and it constrains movement of the loading platform for the vertical direction. The loading platform has a table to hold weights and a frame to attach the test plate. The size of the test plate is equal to the foot of the humanoid robot (235 x 135 [mm]) and the thickness of it is 5 [mm]. Therefore, it is not necessary to consider scale effect. Additionally, to avoid deformation of the acrylic test plate, it is attached to metal frame.

The dial gauge measures the sinkage when the loading platform is moved horizontally. The range of the measurement is about 0–10 [mm], and the resolution is 0.01 [mm].

3.2 Ground material
In this experiment, the Toyoura sand is used that is one of the standard sand in the tera mechanics.
The sand has following characteristics, the specific gravity is 1.53, the grain diameter is about 0.075–2 [mm]. The sand box of 370 [mm] in length and 250 [mm] in width is filled up to 95 [mm] with Toyoura sand.

3.3 Weights
Some metal blocks are stacked on the weight table as weights. By changing the combination of the blocks, the following weights are realized, namely 5, 10, 15, 20, and 25 [kg]. The ground contact pressure can be calculated by using the total load and the area of the test plate.

4. Experimental result
Fig. 3 shows the relationship between calculated pressure and measured sinkage. Fig. 4 shows the same relationship in logarithmic space. The experimental data are shown by a blue round sign in these figures. It is observed that there is a positive correlation between the pressure and the sinkage from the distribution of experimental data.

As the result of linear regression analysis on the experimental data, the following relationship between pressure and sinkage is estimated:

\[
\log_{10} p = 0.76 \log_{10} s + (-3.03) \quad (R = 0.998), \quad (4)
\]

where \( R \) is the coefficient of correlation.

When the equation in logarithmic space is transformed into a equation like eq. (3), eq. (4) is expressed as follows:

\[
p = 0.00094232 s^{0.76328}.
\]

Therefore \( k \) and \( n \) are estimated as follows:

\[
k = 0.000942, \quad n = 0.763. \quad (6)
\]

5. Concluding remarks
This paper presented load-sinkage characteristics of a standard sand to develop the static contact model between the robot foot and the loose soil. In this paper, static sinkage was measured when load is applied to the test plate on sand. From the experimental data, dominant parameters were estimated.

References