Humanoid fall recovery strategy using air thrust

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***Abstract*— In this paper, we propose a fall recovery strategy for humanoid robot against an external force applied to lateral direction by using air thrusts. Each air thrust is attached on both sides of the shoulder of humanoid robot to recover from a fall. To distinguish the state of the humanoid robot, stable state (not falling) or unstable state (falling), we use capture point (CP) which is commonly used for fall detection of the humanoid robot before falling. Considering that the humanoid robot is falling when CP leaves the supporting foot, the air thrust generates force opposed to falling direction to recover the humanoid robot from a fall. After CP comes back inside of the supporting foot, the air thrust stops generating force. This paper also shows the real experimental results of the proposed method for fall recovery using DYROS-JET with air thrusts.**

I. INTRODUCTION

To interact with people or perform tasks in unstructured environments, the humanoid robot should maintain balance against external forces. However, excessive large external forces can be applied to robot and it may lose balance and fall. Humanoid robots have small support area of the feet and the position of the center of mass (COM) is higher than other robot platforms such as mobile robot. Due to the humanoid robot's characteristics, recovering from a fall poses a challenge. Especially for position controlled humanoid robots with pre-generated pattern walking, it is difficult to recover from a fall.

To solve the problem of the position controlled humanoid robot with the pre-generated pattern in falling recovery, Many studies have been conducted using a simple humanoid model. One research proposed the method that ankle, hip, stepping strategy integrating with walking controller to recover from a fall using LIPM [1]. Another research proposed the method to recover from a fall using a walking stick [2].

In this paper, we propose a method for fall recovery strategy using air thrust attached on humanoid robot's shoulder as shown in Fig. 1. Using Capture Point (CP), we can detect the humanoid robot fall before falling. When CP leaves the supporting foot, air thrust generates force in the opposite direction of falling to recover from a fall. Using our method, fall recovery can be easily implemented for humanoid robot with pre-generated pattern walking without complex algorithms of the balancing controller. Also, in the situations such as an external force is applied to the lateral direction toward the outside of supporting foot during single support phase, our proposed method can be more effective.

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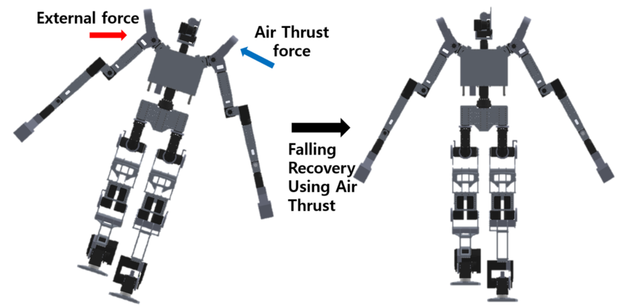

Fig. 1: Humanoid robot fall recovery strategy using air thrust

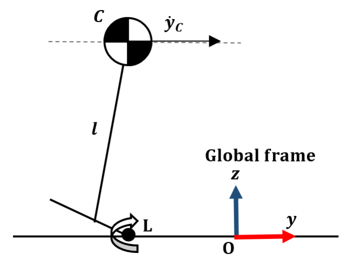

Fig. 2: LIPM with supporting foot

II. PROPOSED STRATEGY

A. Estimation of the CP of Humanoid Robot When It Falls

To estimate CP of the humanoid robot, we should know the velocity of COM. Also, to estimate the velocity of COM when the humanoid robot falls, the rotation around the edge of the supporting foot which is in contact with the ground should be considered. So, we propose the method to estimate COM velocity using Inertia Measurement Unit (IMU) sensor when humanoid robot fall. Before deriving the equation, we assume all the vectors of position, velocity and angular velocity and Jacobian matrices are represented in the global frame fixed on the ground. From the LIPM with supporting foot as shown in Fig.2, we can derive the equation of COM velocity, as below.

$$\boldsymbol{v_C} = \boldsymbol{J_C}\dot{\boldsymbol{q}} + \boldsymbol{\omega_B} \times \boldsymbol{r_{BC}} + \boldsymbol{v_B}, \tag{1}$$

where the term $\boldsymbol{J_C}$ is Jacobian of COM from the base, $\dot{\boldsymbol{q}}$ is joint velocity, $\boldsymbol{\omega_B}$ is angular velocity of base which can be measured by IMU sensor, $\boldsymbol{r_{BC}}$ is the position vector from the base to COM and $\boldsymbol{v_B}$ is the velocity of base.

Let us assume that the edge of supporting foot is a pivot point and not moving. From the assumption, we can derive