Humanoid fall recovery strategy using air thrust

Junhyung Kim\textsuperscript{1}, Jaehoon Sim\textsuperscript{1}, and Jaeheung Park\textsuperscript{1,2}

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 \cite{1}. Another research proposed the method to recover from a fall using a walking stick \cite{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.

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.

\[ v_C = J_C \dot{q} + \omega_B \times r_{BC} + v_B, \]

where the term \( J_C \) is Jacobian of COM from the base, \( \dot{q} \) is joint velocity, \( \omega_B \) is angular velocity of base which can be measured by IMU sensor, \( r_{BC} \) is the position vector from the base to COM and \( v_B \) 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
the base velocity from the edge of supporting foot, as below.

\[ v_B + \omega_B \times r_{BL} + J_L \dot{q} = v_L \simeq 0, \]  

(2)

where the term \( r_{BL} \) is the position vector from the base to edge of the supporting foot, \( J_L \) is the Jacobian in the global frame from the base to the edge of supporting foot and \( v_L \) is the velocity of the edge of the supporting foot.

Finally, the equation of the estimated COM velocity using IMU sensor can be rearranged

\[ v_C = J_C \dot{q} + \omega_B \times r_{BC} - \omega_B \times r_{BL} - J_L \dot{q}. \]

(3)

From the estimated COM velocity using the IMU sensor in (3), we can estimate the CP of the humanoid robot when it falls. In this experiment, we only use the CP of the humanoid in y-direction.

\[ \zeta_y = y_C + \frac{\dot{y}_C}{\sqrt{g/z_C}}, \]

(4)

where the term \( \zeta_y \) is CP in y-direction, \( g \) is the gravity force \( y_C \) is the COM position of the robot, \( \dot{y}_C \) is the COM velocity of the robot and \( z_C \) is the COM height.

B. Fall Recovery Strategy Using Air Thrust

After detecting the fall of humanoid using CP, the air thrust will be actuating and generating force to bring back CP inside of the supporting foot. When CP comes back into the supporting foot, the air thrust will stop actuating.

III. EXPERIMENTAL RESULTS

We use our humanoid robot DYROS-JET with air thrusts to demonstrate our proposed method through real robot experiment. We use air thrust (Dr. Mad Thrust 90mm 12-Blade) which can generate force of 14N and motor drive (DRUM 70/60, Elmo Co.). Also, we use a pendulum of 15kg to compare the experimental results under the same conditions.

Fig. 3(a) shows the experimental results of humanoid fall recovery using the air thrust. Without air thrust, the humanoid robot fell down losing balance after colliding with the pendulum. In contrast, by using the air thrust, the humanoid robot maintained balance and recovered from the fall. Also, Fig. 3(b) shows that CP comes back to the inside of the supporting foot when using air thrust. As a result, using our proposed method, we can recover from a fall of the humanoid robot.

IV. DISCUSSION

The air thrust can be used to compensate for the limited magnitude of the external force that will cause the humanoid to fall. However, there are three limitations in our current fall recovery strategy using air thrust. First, the air thrust can generate low maximum force of 12N. If excessive large force is applied to the humanoid robot, the air thrust cannot recover humanoid from fall. Second, the air thrust has 250ms of long rise time. It may be solved using the variable pitch propeller. Finally, a loud sound is generated when the air thrust is actuating. When a humanoid robot is used to interact with people in the human environment, the loud sound can be a problem.

V. CONCLUSIONS

This paper proposes a fall recovery strategy for humanoid robot against the external force applied to lateral direction by using the air thrust. When CP leaves the humanoid robot’s supporting foot, the air thrust will be actuated to recover from fall. After CP returns to the inside of the supporting foot by the air thrust force, the air thrust will stop generating force. Our proposed strategy to recover from a fall is verified by real robot experiment using DYROS-JET.

Some limitations exist in our current fall recover strategy using the air thrust. The air thrust has long rise time and low maximum force. Also, loud sound is generated during actuating. If the limitations of air thrust are resolved, our proposed strategy can be effective for the humanoid robot to recover from a fall.

REFERENCES
