Pitching and Catching of an Object between a Pair of Air Jet

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Abstract: We have been studying an air jet manipulation technology to non-contactly carry an object over a long distance using multiple 3D air jet manipulation modules consisting of a single air jet nozzle and a pan-tilt actuator. Here we challenge long distant transportation through object pitching-and-catching between a pair of air jet. In this report, we propose a control algorithm to determine each air jet angle and its flow rate, for both pitching side and catching side. First we try to observe human behaviour in a real catch-ball as a hint to create the algorithm. Next, as a preliminary experiment, a pitching experiment and a catching experiment are independently performed to obtain an air jet output function and a control law for each. After that, we propose an integrated transporting algorithm of pitching and catching, and confirm its validity by demonstration experiment.

1 INTRODUCTION

Non-contact object manipulation technology using air jets has excellent features such as cleanness and no need for a transmission mechanism. It has been extensively studied for some years mainly aiming at an application to a conveying system for relatively smaller and lighter objects. On a flat plane, the 3-DOF (two translational DOF + one rotational DOF) control method for a single object by changing the flow rate and angle of three and four air jet nozzles has been proposed (Yamamoto et al.,2009), (Iwaki et al., 2011), (Matsushita et al., 2014), (Matsushita et al., 2016), (Tsuchihashi et al.,2016) . Furthermore, an extension to position control of multiple objects has been reported (Matsushita et al., 2016). Moreover, in a three-dimensional space, the three translational DOF control method using a single air jet nozzle mounted on a pan-tilt actuator has been proposed (Becker et al., 2009). In this research, it is possible to freely control the translational 3-DOF within the range where the object can be held by the Coandă effect. However, since the range in which an object can be held against gravity is at most about 40 degrees, the driving range is inherently narrow. In order to solve this problem, we reported a relaying transport technique by multiple nozzle (Iwaki et al., 2017). In this research, a long-distance conveyance is realized by arranging multiple nozzles along a conveying line and directly relaying them one by one. However, in order to realize more reasonable conveyance in a three-dimensional space, it is essential to extend the distance between the nozzles. Therefore, we propose an object conveying method between nozzles that are away from each other by exploiting hints of real catch-ball by human. Since it is very difficult to theoretically calculate the force exerted by an air jet on an object with fluid dynamics, we experimentally address to this issue using actual equipment. With this proposed method, we can expect to drastically reduce the number of nozzles required for long distance transport.

2 PROPOSED METHOD

2.1 Formulation of Problem

In a vertical plane YZ as shown in Fig. 1, let's consider a pair of air jet nozzle located at the same height with L_{cp} distance. We challenge to pitch a ball from the pitching nozzle and then to catch it by the catching nozzle. Here our problem is to determine the

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angles θ_p, θ_c [deg] and the air jet flow rate u_p, u_c [V] (input for a proportional solenoid valve) of the both air jet nozzles. The coordinate value of the ball's centre is denoted as $P(y, z)$.

2.2 Observation of Human Behaviour in a Real Catch-Ball

In order to solve the above problem, first let us observe human behaviour in a real catch-ball. Then the following typical features of human behaviour will be recognized.

Pitcher: The pitcher gauges the distance to the catcher and throws a ball to reach the catcher's chest so that the catcher can easily grab the ball by hand. In order to send it in a short time, it is necessary to bring the trajectory close to horizontal. In other words, it is necessary to increase the initial velocity of the ball.

Catcher: The catcher constantly observes and predicts the ball trajectory, thereby determining the catching position of the hand. Furthermore, by pulling the hand along the ball trajectory according to the speed of the ball, the catcher can stably grab the ball catching without bounce when contacting the glove.

2.3 Requirements and Strategies

From the above consideration, the following requirements are set in our proposed method.

Pitching nozzle: Determine the initial speed and pitching angle so that it reaches the tip of the catching nozzle.

Catching nozzle: The nozzle angle is determined by always observing the object position. Capture the object on the air jet, give an air jet flow that cancels its velocity near the nozzle and stop it at the given position. However, due to the nature of the Coandă effect, the nozzle angle is operated within the range of the angle θ_{max}[deg] at which the object can be sufficiently stably held in the air jet.

Based on the above requirements, the following control strategy will be formulated.

(A) Determine the pitching angle based on θ_{max}. Fly the ball toward the tip of the catching nozzle.

(B) The object positon is constantly measured by an external camera and the trajectory is predicted.

(C) The catching nozzle constantly aims at the center of gravity of the object.

(D) The catching nozzle controls the air jet flow rate to keep constant the distance to the object.

2.4 Proposed Control Laws

From the above (A)-(D), each manipulated variable is formulated as follows.

$$\begin{cases} \theta_p = \theta_{\mathrm{p0}} & (1) \\ u_p = f_u(v_0, \theta_{p0}) & (2) \\ \theta_c = arctan\left(\dfrac{z}{y}\right) & (3) \\ u_c = PID(\hat{l_c} - l_c) & (4) \end{cases}$$

Here$\theta_{p0} < \theta_{\mathrm{max}}$, is a constant angle which can be freely determined, where θ_{max} is a maximum nozzle angle in which the object can be stably held with the Coandă effect in a space. $f_u(v_0, \theta_{p0})$ is a pulse function giving the initial velocity v_0 [m/s] to the object, where v_0 is the initial velocity required for pitching the object at the pitching angle θ_{p0}, and is obtained from the parabolic motion equation as follows;

$$v_0 = \sqrt{\frac{gL_{cp}}{2sin\theta_{po}cos\theta_{po}}} \qquad (5)$$

Also, the object position $P(y, z)$ is measured in real time by a camera, or acquired based on the state observation method such as the Kalman filter. Eq. (4) is a speed type PID compensator for controlling so that the distance between the object nozzles l_c[mm] follows the target distance $\hat{l_c}$[mm].

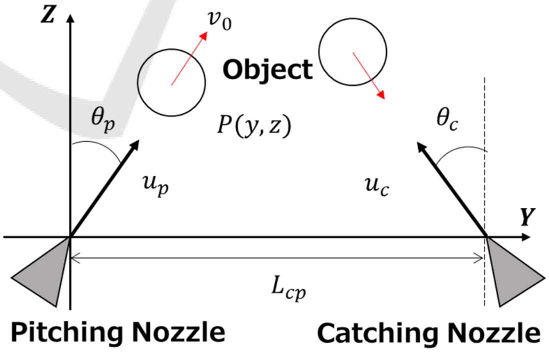

Figure 1: Schematic diagram of proposed system.

3 PRELIMINARY EXPERIMENT

Before an experiment based on the proposed control law, some preliminary experiments were conducted as described below. An overview of the experimental system is shown in Fig. 2. The air pressure supplied to the air jet nozzle is 0.40 MPa.

3.1 Determination of the Pulse Function by Pitching Experiment

Therefore, here we have performed a preliminary test for experimentally determining the pulse function $f_u(v_0, \theta_{p0})$ of Eq. (2). Using a ball with a mass of 10.2 g and a diameter of 100 mm, the floatable minimum output u_{min} = 0.6 V was determined. And from the steady state in open loop control, various pulses were exerted to the ball to measure the flying distance. The pulse width is fixed to 0.2 seconds, the pulse heights are of 3 types of $2u_{min}$, $2.3u_{min}$, $2.6u_{min}$, and θ_{p0} are three types of 20, 25, 30 degrees. The measurement results are shown in Fig. 3. From these graphs, since the behaviour of the object due to pulse output became clear, a pulse function that achieves an arbitrary flying distance was determined in the form of an inverse function.

3.2 Tuning of PID Controller for Catching

In order to adjust the PID parameter, an experiment was conducted in which the object was naturally dropped vertically from a height of about 1 m to catch an object. In order to confirm the effect of feedback control, experiments with no control (u_c = constant) were compared with experiments with speed type PID control (Fig. 4). In Fig. 4, the horizontal axis represents the time, the upper half of the vertical axis shows the displacement of distance between the catching nozzle and the object in during open loop control and PID control, and the lower half shows the air jet flow rate (input for the proportional solenoid valve) in during PID control. Here we define a successful catching if the object stays within 50 mm error for a target distance 180 mm. From these figures, excellent vibration suppression and target value tracking performance by feedback control can be confirmed. In the case where the deviation greatly changes as in this experiment, by using speed type PID control, the responsiveness of u_c can be increased, and as a result, the speed of the object rapidly decreases and l_c can promptly follow $\widehat{l_c}$. Note that there are large vibration in the air jet flow rate graph due to poor resolution of the distance sensor, which should be improved in the future.

3.3 Measurement of θ_{max}

By tilting the air jet angle, the object holding force by the Coandă effect was experimentally investigated. θ_c was varied in the range of 0 to 50 degrees from the vertical while the object was held by the air jet by the control system of Section 3.2. As a result, it was found that in this experimental environment, stable object holding is possible up to about 40 degrees at maximum.

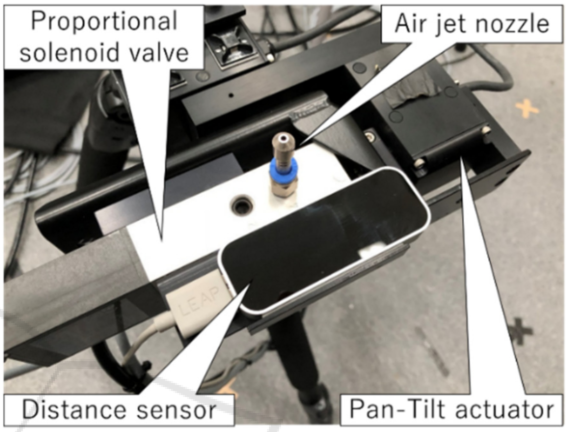

Figure 2: An experimental system overview.

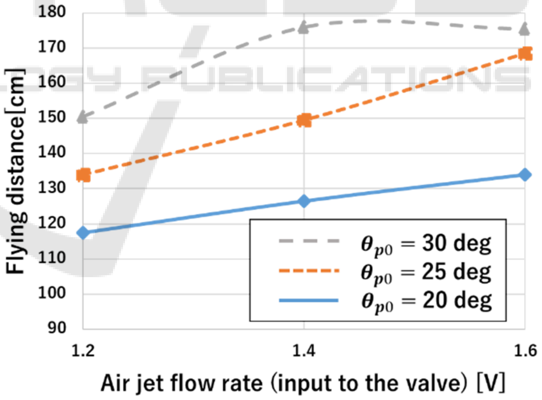

Figure 3: Flying distance of the object from the pitching nozzle.

4 PITCHING-AND-CATCHING EXPERIMENT

We conducted an experiment in which throwing and catching are performed automatically under the same experimental conditions as in the preliminary experiment in Section 3. At this time, the pitching nozzle angle was 25 degrees, the pulse function

$f_u(v_0, \theta_{p0})$ was 1.2 V output, and the pulse width was 0.2 s. From the average value of the flight distance under these conditions, the distance between both nozzles was set to 1.3 m. Trajectory of the object and experimental results at the catching nozzle are shown in Fig. 5, 6. Based on the same reason in Section 3.2, very large vibration are observed in the air jet flow rate graph. Nevertheless, we can confirm that the distance to the nozzle was smoothly stabilized and, as a result of that, the ball was successfully caught by the catching nozzle. From the above, we can confirm the validity of our proposed method.

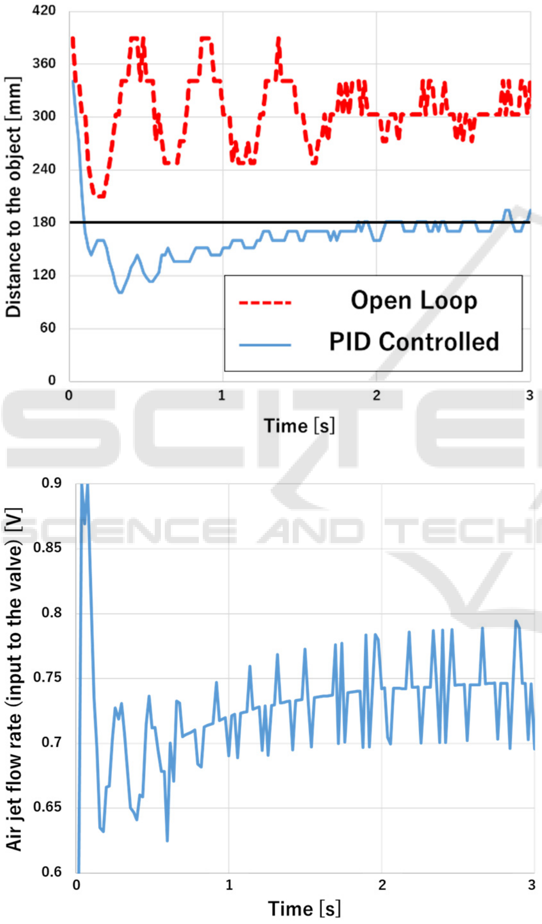

Figure 4: Distance between the object and the catching nozzle, and the air jet flow rate (vertical case).

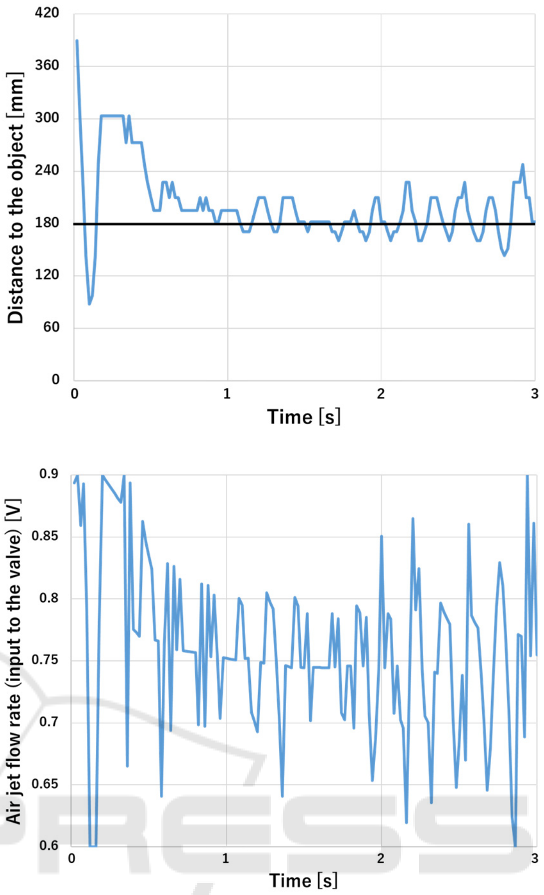

Figure 5: Distance between the object and the catching nozzle, and the air jet flow rate with the proposed method.

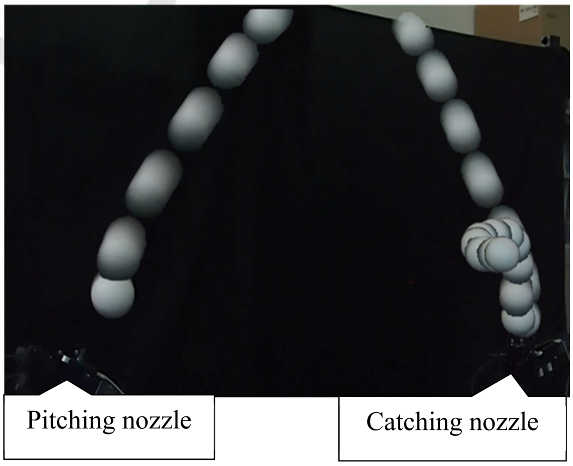

Figure 6: Trajectory of the object.

5 CONCLUSIONS

In this paper, we challenged a long distant and non-contact transportation through object pitching-and-catching between a pair of air jet. We proposed a control algorithm to determine each air jet angle and its flow rate, for both pitching side and catching side. Several experiments results have shown the validity of the proposed method, and it was possible to extend the conveying distance. In the future, we will improve the system, and generalize the object and the experiments.

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