AERIAL MANIPULATOR WITH DOOR OPENING FUNCTION

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ABSTRACT
This paper presents an aerial manipulator robot for door opening mission. Although general aerial robots had the advantages of flying in the air without affected by the ground condition, they could not move to another room when the door was closed. To overcome this difficulty, we propose a new configuration of the aerial manipulator with perching function, knob-twisting function, and door-pushing function. With regard to knob-twisting function, the design concept of a manipulator for the aerial robot is introduced, which is to decouple the access motion from the force-requiring one to be composed of the lightweight actuator. To realize this concept, an airbag actuator with variable restriction is newly introduced. The validity of the proposed methods were experimentally verified by using the developed prototype.

KEY WORDS
Aerial Robot, Manipulator, Rescue Operation, Pneumatic Actuator

INTRODUCTION
In disaster area such as place which have radioactive leakage or fire accident, there is a need to make a robot which can collect information inside the place while ensuring the safety of the operator. Taking the example, wheeled robots which can be operated manually and move inside Fukushima nuclear power plant have been proposed [1]. Wheeled type robot have a high payload and preferred in many exploring robot movement design. However, at disaster site, the environment severe many obstacle that scatter everywhere, even on the middle of the stairs. This condition made wheeled type robot become more difficult to move. To overcome this condition, the use of flying type robot have many advantages, one of them is to open the way when encounter a blocked path.

In this paper, we proposed a new method for door opening mission by using aerial robot. Our proposed for flying manipulator is using four rotor as the main actuator for flying and lightweight manipulator using pneumatic actuator. On previous report, opening door mission by perching to the door, push the door using force generated by rotating propeller, and turning door knob using lightweight Access-operation Decoupled Drive-Arm (ADD-Arm) had been reported [2].

This paper explain the development of ADD-Arm which reduce the weight and increase capability on opening door knob. Airbag structure with variable restriction mechanism and it driving principle is then introduced.
DOOR OPENING BEHAVIOR

The process of door opening can be seen in Figure 1 above. First, the robot approaches the door location and locates the door knob position. Second, it then perches to the door by sticking the front suction pad and performs attitude changing function until the robot orientation is parallel with the door plane. Third, the robot moves the manipulator to the knob position and twists it. Finally, it then pushes the door using force generated by the propeller.

The demonstration picture of door-pushing operation is shown in Figure 2.

Flying Manipulator Configuration

Flying manipulator which made by using four rotor/quad-rotor configuration consist of attitude changing function, fixed support parts to attach on the door, and manipulator to turn the door knob. Attitude changing function was meant to stick on an initial position of the door, while fixed support parts meant to support the robot from reaction force when performing door opening mission. Manipulator that used to turn the door knob consist of servo for joint, link, and linear actuation using airbag actuator. Manipulator was designed to be lightweight but able to generate high output force.

Perching Function

It was reported that quad-rotor that can perch in the environment had been developed [3]. However, this quad-rotor perching method has a problem when performing door opening mission because this robot stayed on the environment whereas door trajectory is swinging. Our proposed aerial manipulator perching method is attaching the robot to the door plane so that it can follow door swinging trajectory and support the body from reaction force.

Perching method is explained as attitude changing function. It divided in two parts, front parts and fixed support parts. Front parts relying on two suction pad in the forepart of the robot and spring hinge. To attach front suction pad, the robot will move forward slowly and hit the door until the front suction pad attach properly. It then perform forward pitching movement to rotate the robot body to the door plane as illustrated in Figure 3. Rear suction pad then serves as support fixed parts so that all robot body could attach properly on the door plane.

Door-Pushing Function

To open the door by pushing, torque required to push the door depend on the existence of the damper. This time we are not considering damper so torque required to push the door is around 3 N.m. One rotor could generated 2.5 N, so the total of lifting force is 10 N. this lifting force is then used to push the door after the robot perch on the door. Even if the robot attach on the closest side to the door hinge (300 mm), it still possible to push the door with all the rotor rotated. Illustration can be seen in Figure 4 below.
ACCESS DECOUPLED DRIVE-ARM (ADD-ARM)

Required Specification
There are two points for the specification. The first one is access motion from robot body to approach door knob. From the prior experiment, the robot might attach on any location on the target area as shown in figure 5, then distance error to the door knob is around 200 x 150 mm will occur. Second specification is torque required to turn door knob. To open the door knob, in this case we considering only bar-type knob, 40 degree of turning angle and torque 0.9 N.m is required.

Manipulation Concept
Generally, after the robot perch and hold the position on the environment, the manipulator then could works separately with the main body. The main task for the manipulator is approach the door knob and applying force on it. In case most manipulator, the actuator use for access the door knob and for applying force must be mounted together as can be seen in figure 6(a). Not only access the position of the door knob, but also the actuators must be able generated sufficient force to handle reaction force. This problem tend to make the actuator become heavier and not suitable for flying robot which is having limited payload.

Our proposed manipulator called ADD-Arm have a characteristic lightweight and high power generated as can be seen in figure 6 (b). This arm separated the function to access door knob and generation of force for turning the door knob. Actuator for access the door knob can be used with smaller power than conventional, as for actuator for turning door knob can be made lightweight but high output force.

ADD-Arm Link Composition
The prototype structure of ADD-Arm can be seen in figure 7. It contain two servo with two link for access operation, one linear actuator (WTA) to attach the wrist to the door so that another one linear actuator can produces high force to turn door knob while maintaining the reaction force. The weight of this structure is 210 gr.

ADD-Arm SOFT-BAG

ADD-Arm Improvement
Improvement for ADD-Arm is shown in figure 8. Most of the link was changed with airbag actuator. This configuration shown that not only reducing the total weight of the manipulator, but also making the size become compact. The stopper to hold the link can also minimized. As for the force generated, it still can generated with high force even with small air pressure. However, since airbag actuator can only generated force in one direction, the movable range is then became narrowed. Therefore, by adding variable restriction mechanism, we can control the movement direction of the airbag actuator.
Airbag Actuator
For power actuation parts, airbag actuator was used as shown in figure 9. Actuator configured in flexible bag have been reported in many research [4], [5]. In this research we made from urethane sheet pleated into rectangular shape. In order to turn the door knob, there are 3 feature need to be consider when configuring these airbag. First is the initial shape must be small and folded. Second is folded section must ended in rigid rectangle structure when pressurized so that the force can be fully transferred to the door knob. Third is at the bottom part, there should not be any pleated portion so that it would be able to grip bar-type door knob.

Variable Restriction Mechanism
As can be seen in figure 10, the variable restriction mechanism consist of pulling spring which can generate restoring force and restraining wire, switch ON and OFF by SMA actuator. At the initial state, SMA actuator is at OFF condition to lock the wire so that when the airbag is pressurized, it generate large bending angle. When SMA is turn ON, it then unlock the wire so that the wire can be release and the airbag in straight position. When the pressure released, then it return to folded condition pulled by the spring.

Figure 8 ADD-Arm with Airbag

Figure 10 Variable Restriction Mechanism

Figure 11 Airbag Actuator with Restriction Mechanism

Figure 12 Door and Actuator Torque Comparison
Overall Structure
Figure 13 shows the overall structure of the aerial manipulator. Total weight is 1700 gr with ADD-Arm mounted on the right side and two micro pumps on the opposite side as counter weight for balancing. It used Ardupilot2.6 as a main controller, standard 2.4 GHz transceiver and 2200 mAh battery with flight time around 5 minutes. Two micro pump were used for adsorption purpose and for power actuation.

Experimental Demonstration
The proposed aerial manipulator then verified through experiment by doing door opening mission as shown in figure 14. First, the robot approached the door and attached the front suction pad on the below side of the door. Second, it then performed perching function to the door by increasing the speed of rear rotor so that it performed pitching motion until parallel with door plane and properly attached with fixed support parts. Third, it then used ADD-Arm to perform door knob-twisting function with help of suction pad and variable restriction mechanism. Last, by rotating all the rotor, it then generated lift force and the force transferred to push the door. It was shown that it was possible to do door opening mission with performing time around 3 minutes.

CONCLUSION
In this paper, the design and implementation of aerial manipulator for door opening mission had been proposed. After examined the required specification to realizing the mission, we then developed ADD-Arm manipulator which had high power actuation, compact size and lightweight to be mounted on aerial robot. We also improved the capability with variable restriction mechanism so that it could target the knob properly. The implementation and experimentation showed that the proposed design could achieve door opening mission. For future plan, we plan to continue developing the manipulator more lightweight and more workspace area so that even if the aerial robot could not perch on the right place, the manipulator would able to reach door knob. We are also planning to improve the airbag actuator structure so that the performing time become much faster than current version.

REFERENCES
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