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Development of an Inflatable Robotic Arm on Mobile Platform for Fetch-and-Give Tasks

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***Abstract*— This paper proposes a novel inflatable robotic arm on a mobile platform. To date, inflatable structures have been utilized for robotic arms to provide the workforce in the welfare and nursing care fields. In these fields, inflatable robots, which is lightweight, soft and compactable, is suitable to perform daily tasks near humans and things because of safe contact. In our research group, an inflatable robotic arm consisting of inflatable links, inflatable actuators and a gripper with pleated sheet structures have been developed.**

In this paper, the robotic arm is utilized in combination with a mobile platform in order to realize practical daily tasks. As an example of the task, a fetch-and-give task is demonstrated. The posture of the robotic arm and the position of the mobile platform is measured by a motion capture system. The whole system is controlled based on the visual information. Finally, it is confirmed that the inflatable robot has sufficient performance for a daily task in living space.

Fig. 1. Inflatable robotic arm on a mobile platform in living space

I. INTRODUCTION

To date, inflatable structures have been utilized for robotic arms to provide the workforce in the welfare and nursing care fields. In these fields, robotic arms composed of inflatable structures is suitable to perform daily tasks near humans and things due to their features: lightweight, soft and safe. Therefore, many robotics researchers have developed inflatable robotic arms [1]–[7]. Sanan *et al.* have developed inflatable link and proposed a method to control its contact force [1], [2]. Viosembert *et al.* have proposed a mechanical design using an inflatable structure which connects links and joints continuously [3], [4]. Ronghuai *et al.* have developed a telepresence robot that has inflatable robotic arms for human-robot interaction [5]. The robot is able to mimic human behavior and realize remote interaction. In particular, manipulation tasks with the use of a mobile platform such as fetch-and-give tasks have been conducted by some researches. A compactable inflatable robotic arm on a mobile platform which is called AIRarm prototype has been proposed by iRobot in DARPA challenge [8]. However, experimental verification of practical usefulness and detail of the performance of the robot has not been reported sufficiently.

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Our research group has been focusing on inflatable structure and developed an extremely lightweight and soft inflatable robotic arm using plastic materials for all components [9], [10]. However, the performance of the robot has been evaluated by simple PTP control. The performance of daily practical tasks has not been discussed and confirmed. Therefore, the purpose of this paper is to experimentally verify the practical performance of the robot. A mobile platform is attached to the robotic arm to extend its range of motion and to perform various tasks. The whole system is controlled by using Robot Operating System (ROS) and illustrated in **Fig.** 1. Finally, it is confirmed that the inflatable robot has sufficient performance for daily tasks in living space by the fetch-and-give task as an example of a practical experiment.

In the following, we first introduce the whole system including the inflatable robotic arm and a mobile platform. Next, the control method of the robot system is proposed. Finally, the fetch-and-give task experiments are reported.

II. OVERALL SYSTEM

This section introduces the overall system composed of an inflatable robotic arm and a mobile platform. The appearance of the system is shown in Fig. 1.

A. *Inflatable robotic arm*

The robotic arm consists of pneumatic bag actuators, links with an inflatable structure, a robotic gripper with pleated sheet structures. All of them are made of plastic materials which have many advantages such as lightness, softness and safety. The weight of a link is about 50 g and the weight of an actuator is from 90 g to 120 g which depends on the number of bags. The total weight of the robotic arm and

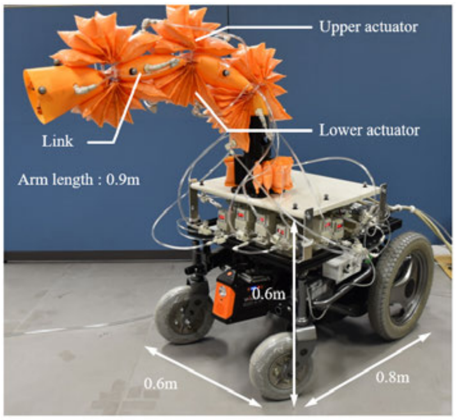


Fig. 2. Inflatable links and actuators, and the robot's size

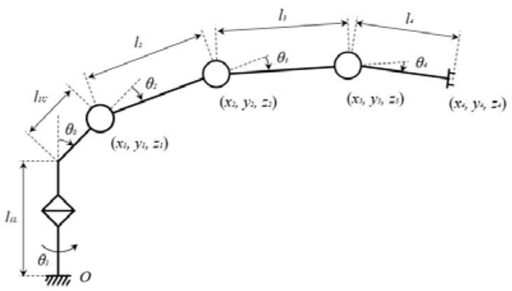


Fig. 3. DOF configuration of the inflatable robotic arm (In this research, θ_0 is constant value $45°$.)

the gripper excluding the pedestal is only 340 g. Significant weight reduction is achieved compared with a conventional robotic arm made of metal.

The actuators and the links are made by welding poly-laminated sheets and low-density polyethylene (LDPE) sheets. The poly-laminated airbag has high-pressure resistance and is laminated outside of a LDPE airbag. The pressure resistance of the overlaid structure is approximately 300 kPa.

The links maintain rigidity by pressurizing in a cylindrical shape. The actuator is constructed by accumulating from 6 to 8 pouch-shaped inflatable bag unit. The joint torque is generated by two actuators arranged antagonistically inside and outside of each joint. **Figure** 2 shows the links and actuators. The DOF configuration of the robotic arm is shown in **Fig.** 3. The robotic gripper is made by using pleated sheet structures. **Figure** 4 shows the gripper. The pleated structure is a bag-like structure, where the back side of the gripper is folded. Different expansion ratio between the flat part and the folded part enables it to grasp objects and release by its own plasticity. The load capacity of the gripper is approximately 700 g. The position of the gripper is measured by a motion capture system Vero (Vicon Motion Systems Ltd.).

B. *Mobile platform*

In this research, a mobile platform, Chairbot (Sustainable Robotics Inc.), is installed. This platform is a two-wheeled

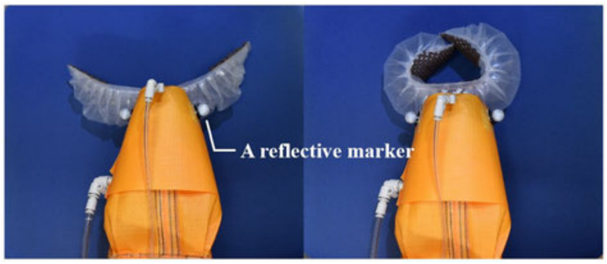


Fig. 4. Robotic gripper using a pleated sheet structure

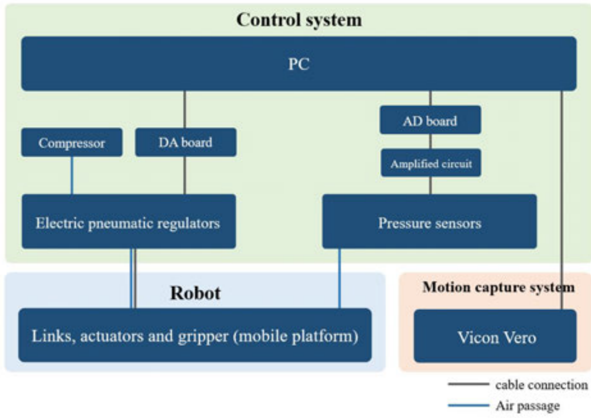


Fig. 5. Whole hardware system

vehicle and controllable by using ROS. The position of the mobile platform is also measured by the motion capture system Vero.

Totally, the overall system architecture is illustrated in **Fig.** 5.

III. CONTROL METHODS

This section shows the control method of the robot system which consists of the inflatable robotic arm and the mobile platform.

A. *Inflatable robotic arm*

The inflatable robotic arm is controlled by the combination of pressure and visual feedback controls. In visual feedback control, the position of the robotic gripper $\boldsymbol{r}$ is controlled using the following equations

$$\boldsymbol{\tau_v} = \boldsymbol{J}^T(\theta)\{K_{Pv}\boldsymbol{e}_v(t)+K_{Iv}\int\boldsymbol{e}_v(t)dt+K_{Dv}\frac{d}{dt}\boldsymbol{e}_v(t)\} \quad (1)$$

$$\boldsymbol{e}_V(t) = \boldsymbol{r}_t - \boldsymbol{r} \quad (2)$$

where
$\boldsymbol{\tau}_v = (\tau_{v1}, \tau_{v2}, \tau_{v3}, \tau_{v4})^T$: Desired torque for visual feedback control
$\boldsymbol{J}^{3\times4}(\theta)$: Jacobian matrix
$\boldsymbol{r}_t = (x_t, y_t, z_t)^T$: Target gripper position
$\boldsymbol{r} = (x_4, y_4, z_4)^T$: Current gripper position
K_{Pv}, K_{Iv}, K_{Dv} : Proportional, integral and differential gain of pressure feedback control.

The gripper position is measured by tracking reflection markers using the motion capture system as shown in Fig. 4.

The desired torque is calculated by adding the gravity compensation torque $\boldsymbol{\tau_g}$ to the PID torque $\boldsymbol{\tau_v}$ as

$$\boldsymbol{\tau} = \boldsymbol{\tau}_v + \boldsymbol{\tau}_g \tag{3}$$

where
$\boldsymbol{\tau} = (\tau_1, \tau_2, \tau_3, \tau_4)$: Desired torque.

Then, the torque-pressure conversion is performed using a conversion function $A(\theta)$ acquired from preliminary experiments. The conversion from desired torque to target pressure is calculated as

$$\boldsymbol{P}_t = \boldsymbol{P}_b \pm \frac{1}{2} A(\theta) \boldsymbol{\tau} \tag{4}$$

where
$\boldsymbol{A}(\theta)$: Conversion function
$\boldsymbol{P}_t$: Target pressure
$\boldsymbol{P}_b$: Base pressure.

Finally, the compensated target pressure by pressure feedback control are given as follows:

$$\boldsymbol{P} = \boldsymbol{P}_t + K_{Pp} \boldsymbol{e}_p(t) + K_{Ip} \int \boldsymbol{e}_p(t) dt + K_{Dp} \frac{d}{dt} \boldsymbol{e}_p(t) \tag{5}$$

$$\boldsymbol{e}_p(t) = \boldsymbol{P}_t - \boldsymbol{P}_s \tag{6}$$

where
$\boldsymbol{P}$: Compensated target pressure
$\boldsymbol{P}_s$: Pressure acquired by a pressure sensor
K_{Pp}, K_{Ip}, K_{Dp} : Proportional, integral and differential gain of pressure feedback control.

B. Mobile platform

The self-position of the mobile platform is acquired by the motion capture system installed in the experimental room imitating living space. The environmental map of the room is obtained previously. The target position of the mobile platform needed for manipulation is calculated using target position for robotic arm $\boldsymbol{r}_t = (x_t, y_t, z_t)^T$ as follows:

$$\begin{pmatrix} x_m \\ y_m \end{pmatrix} = \begin{pmatrix} 1 & 0 & -l_m \cos\theta_m \\ 0 & 1 & -l_m \sin\theta_m \end{pmatrix} \begin{pmatrix} x_t \\ y_t \\ 1 \end{pmatrix} \tag{7}$$

where
$\boldsymbol{r}_m = (x_m, y_m)^T$: Target position for the mobile platform
l_m : Target distance from the center of the mobile platform to the object
θ_m : Target angle for the mobile platform.

In this system, a global path is generated by means of Dijkstra method before moving. When the robot is moving, the local path is generated in real time using Dynamic Window Approach (DWA). This platform is basically operated by using ROS (Robot Operating System).

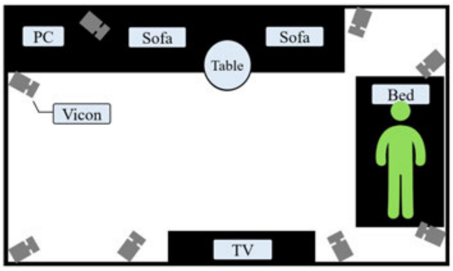
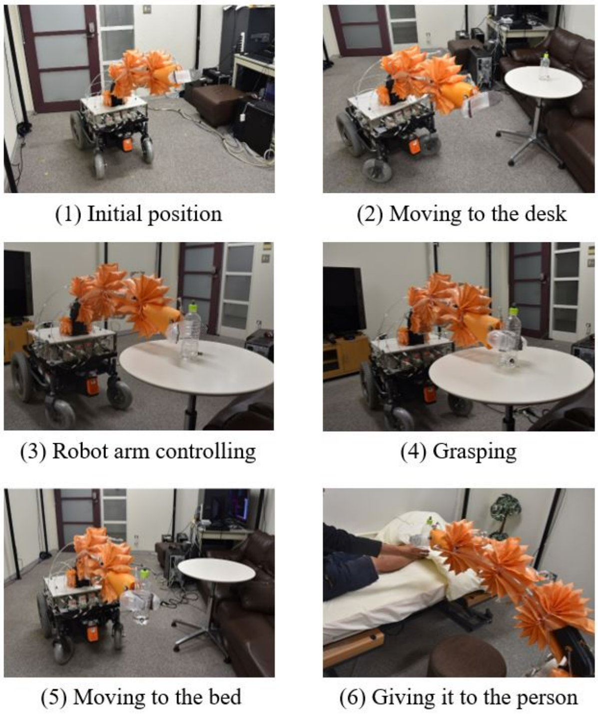


Fig. 6. Experimental environment



(1) Initial position
(2) Moving to the desk
(3) Robot arm controlling
(4) Grasping
(5) Moving to the bed
(6) Giving it to the person

Fig. 7. Snapshot of the fetch-and-give task

IV. EXPERIMENTS

In this section, a fetch-and-give task in living space is performed as an example of daily practical applications. In the experimental environment in **Fig.** 6, eight motion capture camera are mounted up to surround the room. The target object is a plastic bottle whose weight is 100 g, and it is placed on the table. The reflective markers attached to the object is traced by the motion capture system. The robot starts from the initial position, moves to the table, picks the bottle up, moves to the bed and gives it to the target person sitting on the bed, as shown in **Fig.** 7. **Figures** 8 and 9 show the global paths of the mobile platform using Dijkstra method. **Figure** 10 shows the actual trajectory from the initial state to the goal state. In these figures, the red arrows, green lines and black dots represent the target postures, global paths and actual trajectory respectively, which are visualized by RViz. Furthermore, **Fig.** 11 show the time variation of the position of the robotic gripper. The blue lines and the orange lines show the desired position and

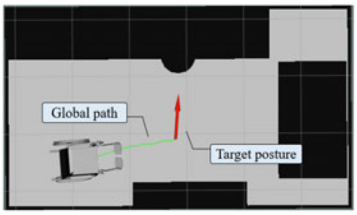


Fig. 8. Global path to the table

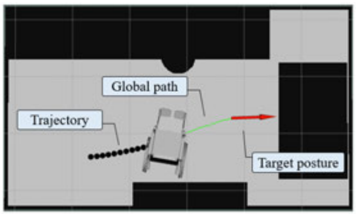


Fig. 9. Global path to the bed

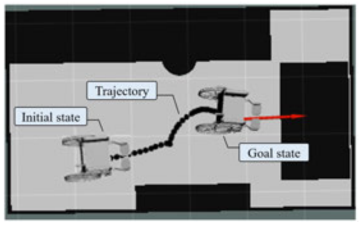


Fig. 10. Trajectory of the mobile platform

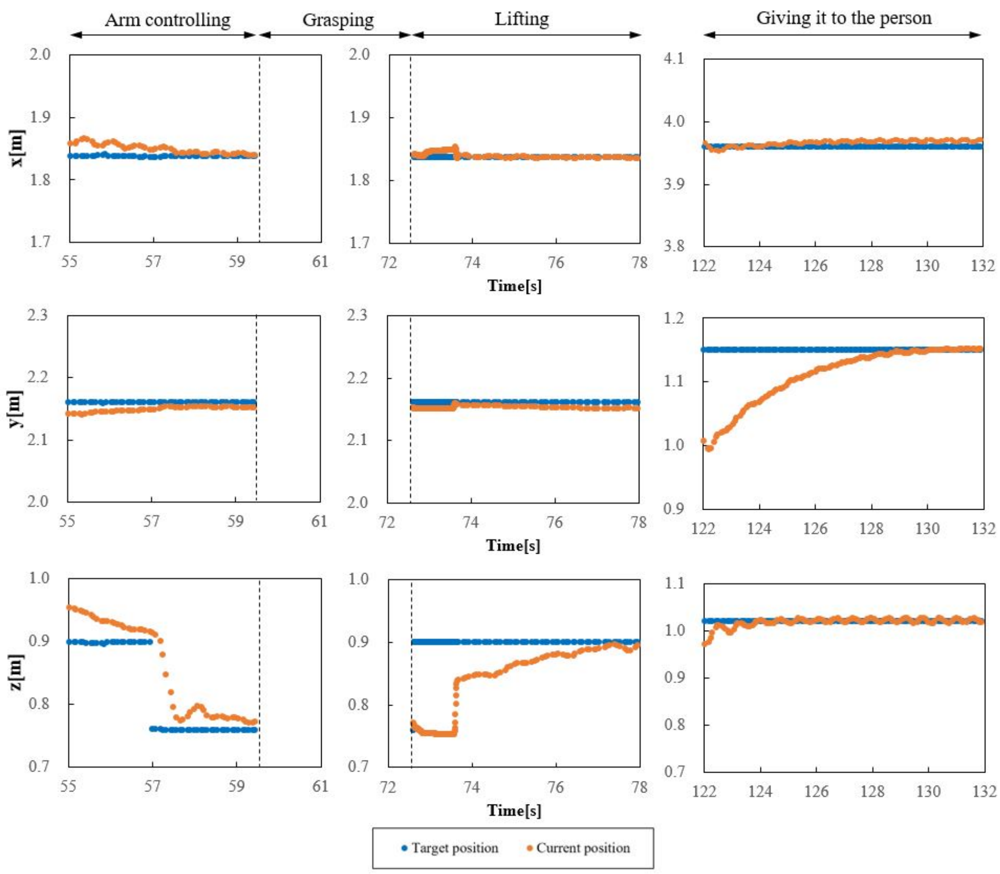


Fig. 11. Time variation of the position of the robotic gripper

the actual trajectory respectively. It is confirmed that the position of the gripper converges to the desired position in each motion. Finally, it is verified that the performance of the newly developed robot is adequate to execute the fetch-and-give task. The experiment is repeatedly executed ten times. As a result, the fetch-and-give task is achieved nine times. The one failure is caused in the moving phase of the mobile platform. Therefore, the usefulness of the inflatable robotic arm to realize manipulation tasks in daily life is verified by the results.

V. CONCLUSIONS

In the paper, we proposed an inflatable robotic arm on a mobile platform. The purpose of this paper is to experimentally verify the performance of the inflatable robotic arm for applications in daily lives. The performance was confirmed by experiments of a practical daily task, fetch and give task. The proposed robot system is able to move and manipulate objects appropriately.

In future work, we will build a self-contained robot system equipped with an air tank and a communication module. Moreover, we will realize more diverse applications such as manipulation of various things and assistance for people with disabilities.

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