Development of a General-purpose Expandable Arm for Small Mobile Robots

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Abstract

In this paper we present our developed expandable sliding arm which enables a small sized mobile robot to push and pull objects. The mobile robot arm can manipulate objects such as elevator buttons, light switches and mailbox drawers. The expandable arm has 3 degrees of freedom; a rotary degree of freedom at the base, a stretching degree of freedom and a rotary degree of freedom at the end-effector. The stretching section is composed of 4 links. The length of the contracted arm is 388mm and the expanded total length is 1218mm. Our mechanical arm is composed of linear motion guides in the stretching section, driving DC motors, an harmonic-drive as speed reducer and a solenoid to push switches and buttons at the end-effector.

Keywords: small mobile robot, expandable arm, physical services

1 Introduction

Recently, mobile robots working areas greatly expanded. For instance, home mobile robots with security and entertainment functions already entered our daily life. Small mobile robots are comparatively suitable for operation in tight spaces like home environments; this is why we believe that demand for such robots will rise in the future.

Many of actual home robots have determined functions such as taking pictures of indoor environments and transmitting them to user's mobile phones or terminals while being remotely operated. General home robots are used mostly as information service systems using communication technologies. Moreover, most systems don't target a task which involves physical interaction for modifying its surrounding environment. If robots can achieve real physical manipulation tasks, their utility value would be increased.

As concrete tasks of physical interaction we have grabbing, pushing, and pulling. Grasping is a considerable difficult task that depends in many factors such as grasping object characteristics like size, weight, shape, texture, and volume. Some research has been done about mobile manipulator grasping like in [1] and [2]. However, common grasping systems would be difficult to mount on a small mobile robot because usual devices are large scale. Operations such as pushing/pulling objects can be easily achieved as long as manipulator's position is accurately estimated. Moreover, if movable range and object loads are well defined and limited, it is possible to make a compact mechanism that can be equipped on a small sized mobile robot. Our goal of this research is the development of a general-purpose arm that can achieve the pushing/pulling operations for small mobile robots.

2 Arm Specifications

In this section we describe tasks to achieve with our developed manipulator, mobile robot platform, and general characteristics of expandable arm.

2.1 Concrete Tasks

2.1.1 Pushing Tasks

- Operating an elevator button

  Indoor navigation for small and medium mobile robots has being actively researched, with actual research, mobile robots can move freely at indoor one floor flat environments.

  If a robot could move from one floor to another using an elevator, its working area could be largely expanded. For this reason, robots which can move from one floor to another using an elevator have being developed like in [3]. In our research, a small-sized expandable arm for small sized mobile robots capable of pushing elevator buttons is proposed and described.

- Operating a light switch

  Our mobile robot is capable of operating the light switch of a wall for turning on/off the light. Checking and controlling light switches are very useful tasks for supporting human everyday life, especially for elder or handicapped people.

Figure 1: Mail box.

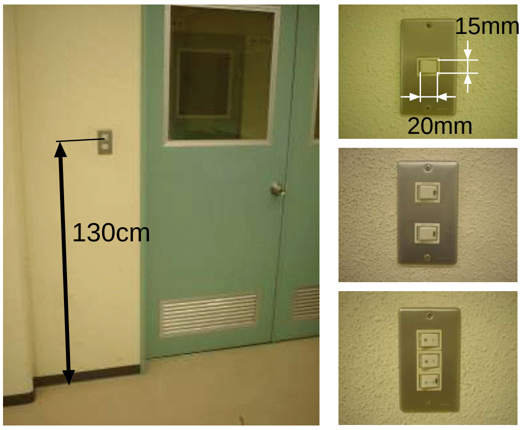

Figure 2: Light switches.

2.1.2 Pulling Task

A small robot can open a drawer by hooking and pulling it with the tip of our expandable mechanical arm. This drawer opening function could be applicable to a system which checks a mail box from a remote places.

2.2 Mobile Robot Platform

The developed arm was mounted on a mobile robot, and evaluation experiments were performed. In this research, YAMABICO is used as mobile robot platform. This robot's body size is 370mm $\times$ 322mm $\times$ 420mm (length $\times$ width $\times$ height), as it is a small sized robot, the arm must be small and lightweight.

For that purpose, structure of the hand and arm should be simplified, where heavy robotic parts must be allocated at the base of the arm. The arm was placed on robot's upper part. Moreover, the arm should be designed according to the size and power of the mobile robot platform.

2.3 The Movable Range of the Arm

In order to decide the movable range of the arm, the environments where target objects exist were investigated. First, the mail box currently used at our laboratory is shown in figure 1. The drawers of this mail box are located at a height of less than 88cm from the floor. Next, the switch panel of electric lights is shown in figure 2. Generally, light switch panels are set at a height of about 130cm from the floor and one to three switches are arranged on the panel. Figure 3 shows an example of the button of an elevator. These buttons are placed at a height of 110 to 150cm.

As mentioned above, our aim in this research is to develop an expandable arm which can operate objects which are located at a maximum height of 150cm from the floor.

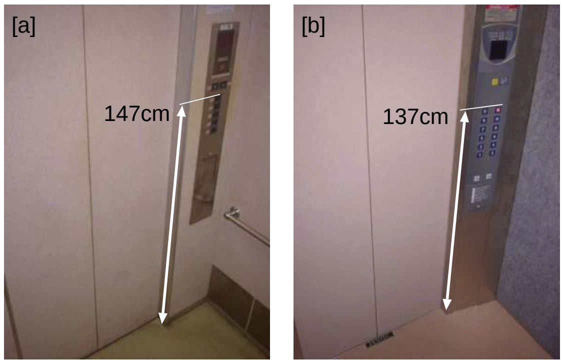

Figure 3: Elevator buttons (a) College of engineering systems and (b) Laboratory of advanced research B, University of Tsukuba.

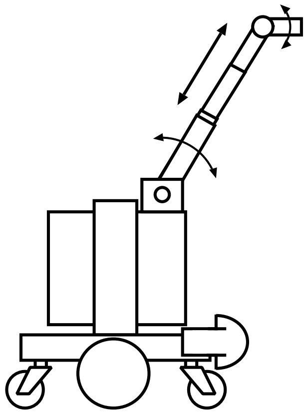

Figure 4: Image of the arm.

2.4 Flexibility of the Arm

The YAMABICO robot platform used on our system is a non-holonomic system and has three degrees of freedom. Generally, when operating objects in three-dimensional space with a robotic hand, 6 degrees of freedom flexibility is needed. However, since only comparatively simple motions were targeted in this research, we decided that the flexibility of yaw posture angle was unnecessary. Therefore, flexibility of the arm was made only into 3 degrees of freedom

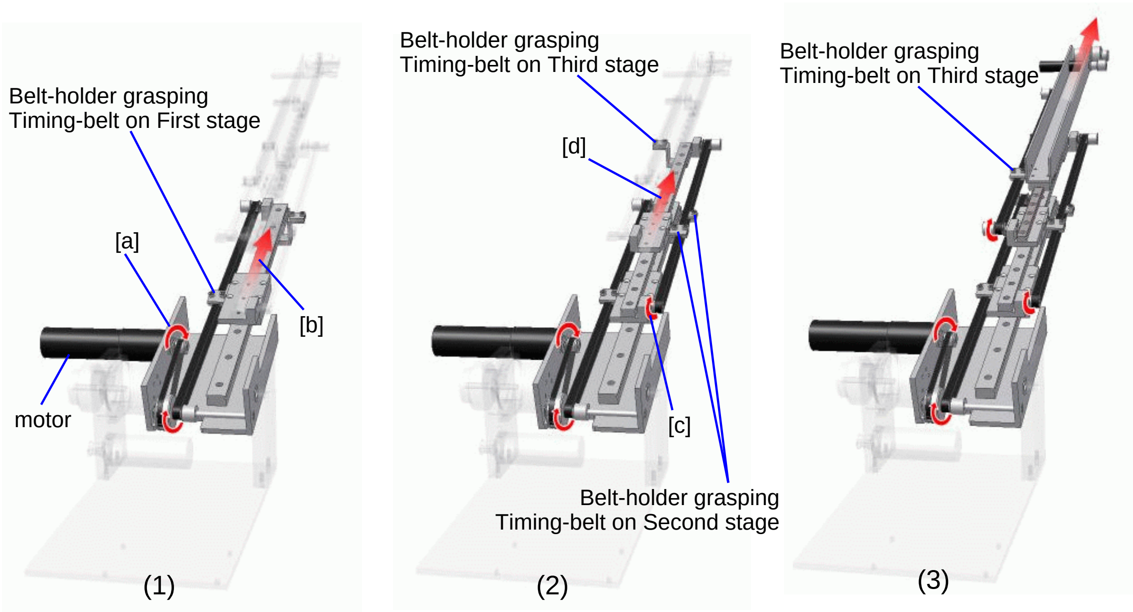

Figure 5: Structure of the stretching section.

flexibility. By these concept, the mechanism of an arm becomes simpler.

2.5 Maximum Load

The power required to operate each object was measured. The measured objects were: the button of an elevator, the switch of electric lights, and the drawer of mail boxes. By using a weight spring, we could arrive to the conclusion that about 500g power was required. [1] Therefore, the robot arm developed in this research was designed under the specification that it could output 500g power.

2.6 Structure of the Arm

Although mechanical arm must be of compact size, simultaneously it is required a large movable range to reach its surroundings. In order to obtain this functionality, we developed a sliding expandable arm which characteristics are mentioned in this section. The advantages of a flexible arm are shown below:

- Reachable range is wide.
- When an arm is not needed, it will slide in and become compact.
- Since there are few motors, arm weight is light.
- Simple calculation of inverse kinematics.

[1] Although the drawer was able to be pulled by about 200g force when it was empty, required power changes according to the weight of the object into which it is put in inside.

The appearance of the arm devised from the above conditions is shown in figure 4. An end-effector is connected at the tip of the arm. This device is used to push a switch, or to hook to the handle of a drawer. In addition to expansion and contraction capabilities, it has a rotational axis at the base and before end-effector, making it a 3DOF system.

2.7 Flexible Mechanism

The outline of flexible mechanism is shown in figure 5. Arm has a length of 40cm when contracted and a total length of 110cm when fully expanded. The arm consists of four slide-rails, the length of each rail is about 40cm. This flexible mechanism has only one motor as an actuator. When the motor pushes or pulls the 1st stage slider, the slider after the 2nd stage also are moved all together. The details of the mechanism which lengthens the arm are described below.

1. The belt is rotated by the motor (figure 5a), the 1st slider fixed to the belt moves along with the 1st rail (figure 5b).
2. The rail of 2nd stage is fixed on the 1st slider. The second belt is attached to the first sliding rail and after first slide rail is totally expanded, second belt starts to rotate as can seeing at figure 5c. This rotation of second belt is used to move the second sliding rail (figure 5d).
3. This mechanism is repeated with the second belt and third slide and third belt and fourth slide respectively until total extension of arm is achieved.

Since all stages move synchronously, this mechanism can be regarded as one actuator from the controller.

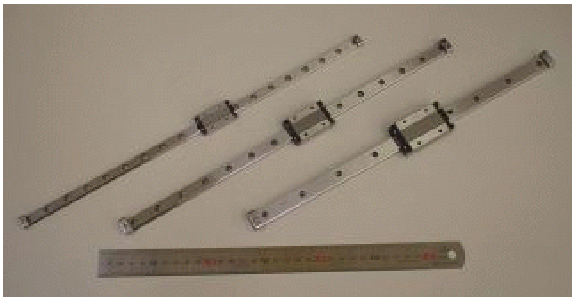

Figure 6: Linear motion guides (RSR9N, RSR12N, RSR15N).

Table 1: Specifications of linear motion guides

	1st stage	2nd stage	3rd stage
Model number	RSR 15N	RSR 12N	RSR 9N
Moment rating	63.1Nm	28.9Nm	18.4Nm
Length of rail	350mm	370mm	375mm
Weight	417g	270g	147g

Table 2: Specifications of developed arm

Length of contracted arm	388mm
Length of expanded arm	1218mm
Movable space of arm	225degrees
Movable space of end-effector	270degrees
Motor	3-DC motors
Max. expanding velocity	25cm/sec
Weight	2.8kg

3 Manufacture of the Arm

Here, the hardware of the developed arm according to specifications stated in Chapter 2 is described.

It is desirable that sliding mechanism has as reduced friction and back-lash as possible. For expandable arm explained in this paper, the slide rail shown in figure 6 was used. This slide rail despite being light and compact is rigid enough to support different loads with accuracy. According to load and stage each slide occupy, each rail was carefully selected. The specification of the slide rails used for each stage is shown in table 1.[2]

As a belt for power transfer, a timing belt (Made by Tsubakimoto Chain Co.) was used. A timing belt has high rigidity compared to normal belts, and fits with high precision which is adequate for position control. Moreover, a harmonic drive was adopted as the reducer of each actuator. This reducer is compact and can obtain high slowdown ratio and it has little back-lash compared with an ordinary gear.

The arm was built using the above parts and aluminum material. The flexible arm carried on the YAMABICO robot is shown in figure 7. And, the specification of the manufactured arm is shown in table 2.

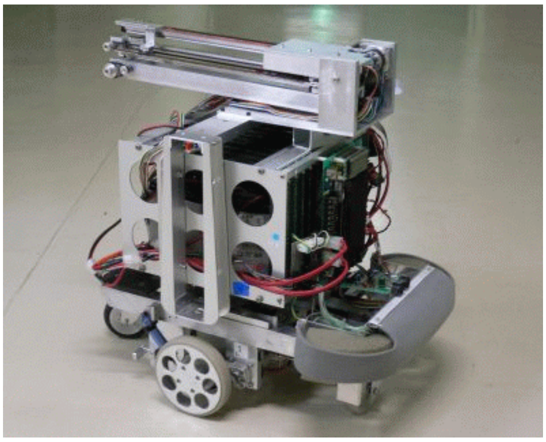

Figure 7: Contracted arm on mobile robot.

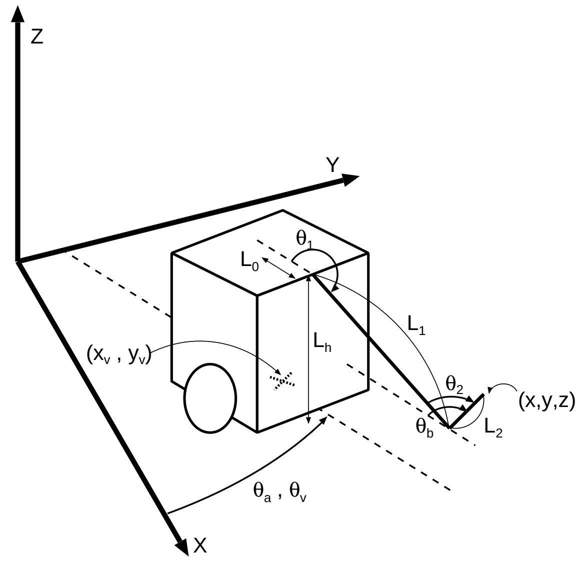

Figure 8: Mobile arm coordinate system.

A solenoid is placed on the tip of the arm as an end-effector and is used in order to push a switch. An end-effector can be stored in the 4th step, when not using it. The developed arm was mounted on a mobile robot with a height of 42cm. So the arm when fully extended can reach a height of 160cm.

4 Control of the Arm

The coordinates of mobile manipulator system are shown in Figure 8. Each joint angle(θ_1, θ_2 and length of the arm(L_1) are calculated with the following expressions:

$$\theta_1 = \arctan \frac{x + L_2 \cos\theta_b}{z - L_2 \sin\theta_b} + \frac{\pi}{2} \tag{1}$$

$$\theta_2 = \theta_b - \arctan \frac{x + L_2 \cos\theta_b}{z - L_2 \sin\theta_b} + \frac{\pi}{2} \tag{2}$$

[2] These slide rails are made by THK Co.,LTD.

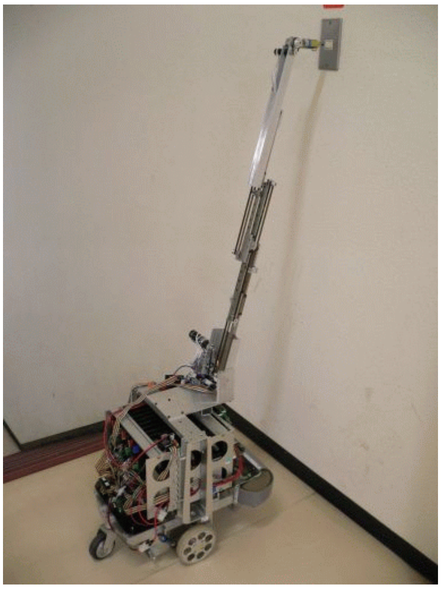

Figure 9: Pushing a light switch.

Figure 10: Pushing an elevator button.

$$L_1 = \sqrt{(x + L_2 \cos\theta_b)^2 + (z - L_2 \sin\theta_b)^2} \quad (3)$$

where, (x, z, θ_b) are position and posture of the hand.

Because of its own weight, when arm is expanded it slightly tends to slack. Therefore, controller estimates the value for slack correction. When it is programmed to reach a determined object, it will reach correct position despite arm slacking effects.

5 Experiments

Operational experiments were conducted using the previously explained expandable arm. Mobile robot has an environmental map and can move to arbitrary places by odometry autonomously. The map has not only the robot's path and obstacles but also the position and height of the buttons of an elevator or drawers.

For pushing light switches and elevator buttons, manipulator is expanded and solenoid at the tip of it performs pushing action as it can be seen in figure 9 and 10.

Figure 11 also shows a scene of pulling a drawer. Drawer opening action was realized with the arm contracted and the end-effector facing up, then mobile robot moves back pulling and opening it, and then content images can be taken after.

6 Conclusion

We have developed a general-purpose expandable arm for small mobile robots. This paper describes the design of the mechanism, and shows some examples of useful applications.

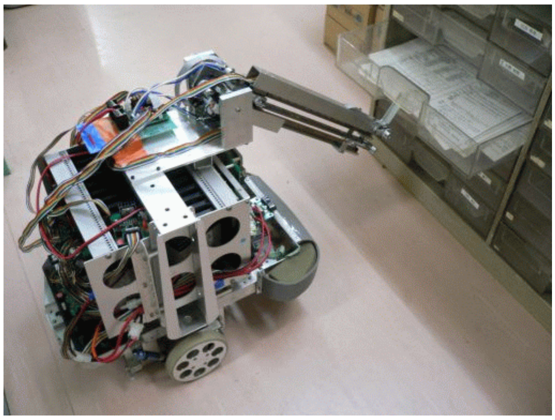

Figure 11: Pulling a mailbox drawer.

7 References

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