Book Browsing System using an Autonomous Mobile Robot Teleoperated via the Internet

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Abstract

This paper describes a system which uses a mobile robot as a teleoperated tool for accessing and manipulating remote objects.

The purpose of this study is to develop a robot system which helps humans to accomplish remotely a given task in their daily life, based on simple communication and mutual cooperation between them and a teleoperated mobile robot. The specific task we set up in this research is to help humans browse books of a libraly from a remote location. In this work, we build such a system accordingly to its basic requirements involving autonomous navigation, environment perception, book manipulation and teleoperation.

In this paper, we present the developed book browsing robot system, its teleoperation human interface and evaluate its performance and operating efficiency through experimental results.

1 Introduction

Autonomous mobile robots are still a well-researched topic in robotics and recent progress have been made in this field, particularly in indoor environments, perception navigation and manipulator control. However, concerning applications of mobile robots in real life, their number and variety are very limited and focused essentially on cleaning robots[1], delivery robots[2] and guiding robots[3][4]. One reason might be that many researchers have been focusing on detailed technical and functional aspects of mobile robots, but have not really considered and discussed their final usability.

In order to spread mobile robot use in human daily life, there is an on-going need on researching not only in autonomy and navigation of mobile robots, but also in useful and impactful mobile robots applications helping us in our day-to-day tasks. For this purpose, beside autonomy, interaction with humans is a key function for a robot taking part actively in human life.

By this practical study of developing a book browsing system using an autonomous mobile robot teleoperated via the Internet, we intend to expand mobile robot potentials and usage in human life.

2 Application of Mobile Robot

As a typical remote controlled robot system, one can cite the force feedback based screwing operation[5]. Such a system is strongly task oriented and requires heavy operating skills. Recognizing environment is very difficult with such a method, and an ordinary human cannot master it. Besides, research concerning an appreciating robot in an art museum by considering a web browser as an interface has also been done[6]. In this system a mobile robot equipped with a camera is moving in an art museum, and transmits images of an exhibit to a user. A click in the exhibition image displayed on the screen, enables the robot to move in front of the exhibited target. A more intuitive operation is attained in this system. However, such a robot cannot manipulate remote objects.

In the world, many demands require physical interactions in remote places, and one may consider that realizing them would enlarge considerably their application range in everyday life. This research considers a robot as an access media that can interact physically with objects located in a remote place and that can be used in an everyday life environment. The task consists in perusing a book located in a remote place thanks to a robot. Remote books perusal is illustrated in Figure 1.

The system's environment is a library where the user may not be able to go directly but who can use a robot stationed there as a substitute to himself in order to peruse a book through the Internet. By doing so wherever he may be, the user can pick up the book he wants, have a look at its contents and look for the information he wants to know. Combining this system with a book delivery service would result in an effective way to choose the book to borrow.

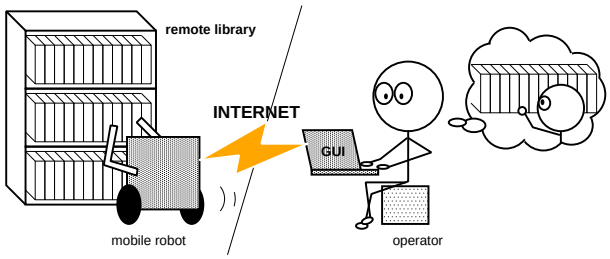


Figure 1: *Concept of book browsing system using an autonomous mobile robot teleoperated via the internet*

Many books have been processed electronically and an Electronic Libraries have also being built in recent years. Electronic book processing focuses on the information importance contained in books. Books can also be considered as the work of their author and as cultural objects, their physical existence has an important meaning. Moreover, since it is hard to imagine that it is possible to process all published books electronically, and that the existence of books may disappear in the near future, one can expect that the significance of the system being build in this research will not be lost immediately.

3 Basic strategy

When considering the behavior of a human looking for a book in a library, the first thing done is moving toward the target bookshelf, then picking up the book which seems to be the most interesting and looking for articles referenced in its table of contents and index.

In conventional remote-controled robot applications, users operate robots using a joystick by observing images or virtual scenes sent from the distant place[5]. Due to communication time that appear with these methods, images and command transfer delays make them difficult to put into practice. In order to facilitate the operation task for the human, the robot should understand the user's will and operate autonomously according to it. For this purpose, determining properly the tasks to be done between the robot and the human can lead to a well defined distributed cooperation work. This determination is obvious once each task is determined concretely.

For humans, the task consisting in picking up the book from the shelf is realized unconsciously since the brain controls muscles directly in this case.

The following points were adopted in this research.

- Human has to specify deliberate behaviors such as choosing a book.
- Robot has to perform autonomously unconscious tasks such as opening the book and turning its pages.

In order to read a book located in a remote place, (1)moving toward the bookshelf, (2)choosing the book and (3)perusing it are the 3 main steps that must be performed. The switching between these 3 behaviors is indicated by the operator.

In the following sections, the system design corresponding to each step is described (Section 4), the robot structure (Section 5), the interface for teleoperation (Section 6) and experimental results (Section 7) are presented.

4 The plan of each operation

4.1 Movement toward the bookshelf

This paragraph describes the robot motion method toward the bookshelf.

The user does not need to know arrangement of the bookshelf in a library. The robot is given in advance the map of the library where it is. When an operator gives the title of a book or its category, the robot has to move by generating a route autonomously and avoiding obstacles. The route generation and path following algorithms were developed in our laboratory[7].

Since only the name of the destination place is given to the robot by this method, the amount of communication data is reduced and no information transmission delay due to images transfer appears with this approach.

4.2 Extraction and return operation

This paragraph presents the book selection method and its picking out operation from the bookshelf.

Although library books area usually arranged on bookshelves according to specific rules such as alphabetical title order, nothing guarantees that a book remains constantly in the same place. Moreover, books often appear in practice to be inclined in such a way that their pose is not fixed. Therefore, there is no meaning in giving the map of the detailed absolute position of each books. After going directly to the specified place, the robot should rather measure the relative position of each book.

The robot shows the user image of the bookshelf, and picks out the book which the user chose from the bookshelf. Moreover, in order to carry out the manipulation of the book, a specific hand was designed and attached to the robot.

4.3 Perusal

Functions required for perusal are "opening a book and turning over pages" and "capturing an image and showing it to the user." Book opening-closing and page turning's equipments are developed independently and equip the robot. Image is captured using a high resolution camera, and the picture is transmitted to the user via LAN.

5 Implementation

This chapter describes the implementation method on a mobile robot. Since this research is aiming at demonstrat-

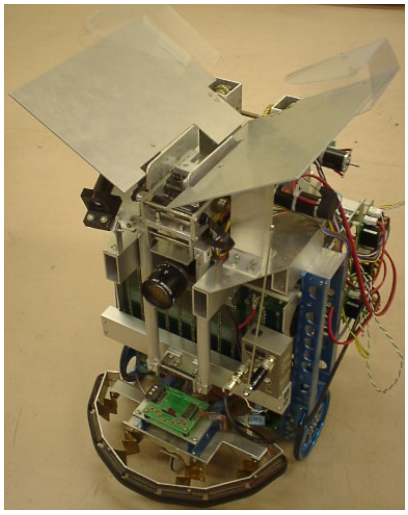


Figure 2: *Mobile robot YAMABICO-LEO*

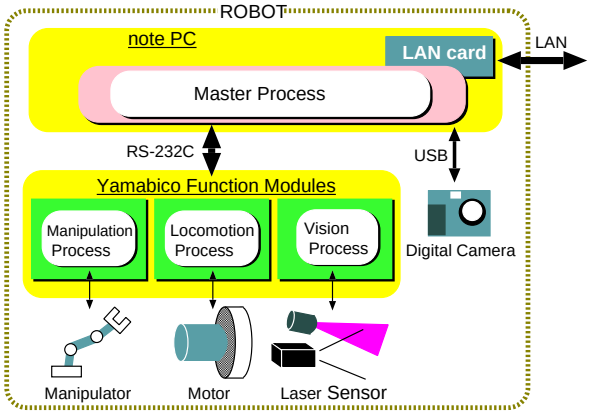


Figure 3: *Controller architecture of the robot*

ing the usefulness of mobile robots in everyday scenes, the following conditions concerning books are established as the first step.

- The book is put on a certain fixed height
- Size is fixed (textbook size)
- The book stands vertically

Under these conditions, the hardware mechanism was simplified and a prototype was constracted. Increasing the manipulator degrees of freedom, would make size and posture problems solvable.

The following elements are required for a mobile robot in order to perform distant perusal task. Each of them have been designed, built and mounted on a mobile robot.

- Autonomous navigation enabling the robot to move to its goal while avoiding obstacles
- Shape recognition of books laying on a bookshelf
- Hand for picking up a book
- Perusal equipment for book browsing
- Communication for teleoperation
- Image transmission of the opened page

5.1 Mobile robot platform

The mobile robot used in this research is a one of the YAMABICO mobile robots series which was developed in our laboratory. YAMABICO is a mobile robot equipped with two independent steering wheels. It's body size is about 40cm(W)*40cm(D)*40cm(H) without actuators and 65cm height including them. By default, it is able to move autonomously along a specified line[8]. Since, typical library has flat floors, wheeled locomotion is enough.

The locomotion platform of the autonomous mobile robot "YAMABICO-LEO" is equipped with a small arm to grasp books and with a vision system for measuring position of books (Figure 2).

5.2 Controllers

The controller architecture of "YAMABICO-LEO" is shown in Figure 3. Each function of the YAMABICO mobile robots series corresponds to a hardware module equipped with a CPU (T805 20MHz). The master control process running on a notebook PC(Pentium 650MHz, Linux) communicates with the locomotion and image processing modules through its serial port. The PCMCIA slot is used by an Ethernet card connected to a wireless LAN module for teleoperating the robot system. Moreover, a USB port is used by a digital camera to take photographs of pages. According to the requests coming from the main PC routine, the digital camera can take images and upload them to the PC.

5.3 Software Structure

The teleoperation interface we provide to users is built based on a selector for applicable behaviors. The robot software system consists of a set of programs for actions of the robot. Each action program is called by a corresponding behavior selected by the user. With such software system, the robot is able to change flexibly its behavior towards the teleoperator requests (Figure 4).

5.4 Sensors

A laser range sensor was adopted as a system to measure the position of a book. This sensor uses a laser to emit an infrared light slit and a camera to capture the reflecting light. The 3-dimensional coordinates of the reflecting points are then computed using triangulation**??**.

When emitting a laser light in the direction of a bookshelf, the light is reflected in the places were books appear to be, therefore making it possible to determine

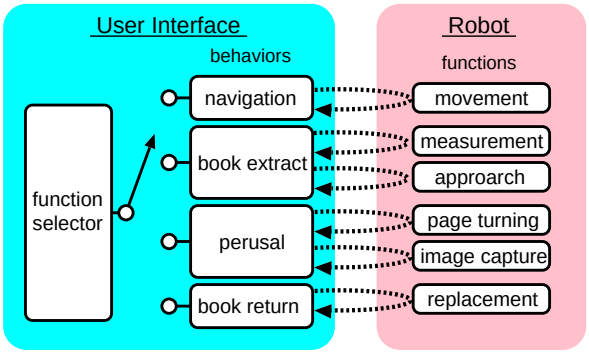


Figure 4: *Structure of software*

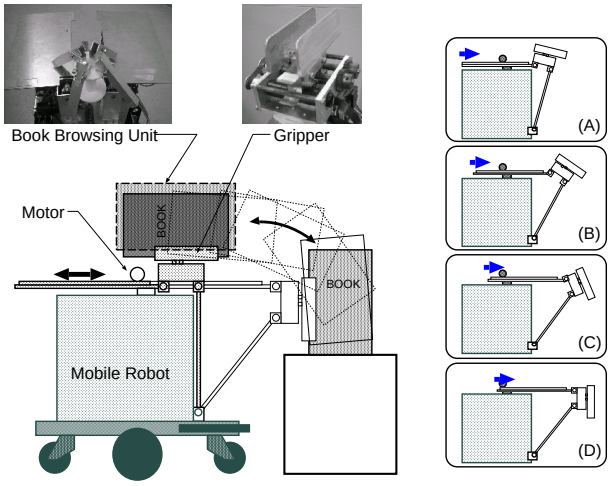


Figure 5: *Movement mechanism of the robot hand*

books position and width. Book position determination accuracy is about 1mm and processing time is about 100msec.

5.5 Actuators

In order to take out and return a book, the hand was attached at the tip of a one DOF link sliding forward and backward. The hand consists of a gripper made of two flat fingers that can slide to right-and-left symmetrically.

The hand movements mechanism is shown in Figure 5. The movement of our gripper combines translation and rotation. Such movement is simply realized by sliding forward the flexible link, activated with a single motor. Since our gripper's orientation is set relatively to the position of the robot which holds it, we therefore enable the gripper to move freely in a given plane, by considering the mobility of the robot as its degree of freedom. This hand can hold the thickness of until it is 50mm, and a book with a weight of 400g.

We explain in the following procedure the way our hand grabs a book.

1. The robot navigates toward the bookshelf and stops in front of the targeted book, at a distance reachable by its hand.
2. Then, the gripper is widen proportionally to the width of the targeted book.
3. Next, the gripper inserts itself between books and grab the targeted one.
4. The hand pulls the gripper out.

Moreover, operation which returns a book is performed as follows.

1. A interval between two books wider than the book width is searched.
2. The robot moves in front of the target space.
3. The book is inserted in the bookshelf.

5.6 Book Browsing Unit

The book which has been dragged out of the shelf, is then placed inside the book browsing unit. The unit consists of a book opening/closing device, several fingers for page turning over and a camera to get an image of the page. A part of mechanism of this equipment is still under development.

6 Human Interfaces

This chapter describes the interface usage. It is based on a basic strategy, that an appropriate robot motion can be easily specified by selecting an object in an image displayed on a PC, and clicking buttons.

6.1 Book selection mode

The interface for "book selection mode" is shown in Figure 6. The main image shows the bookshelf where each book is attributed a label. The button located on the right side of the window enables to modify the viewing area by changing the camera position.

The robot which arrived in front of the bookshelf looks for the position and boundary of each book using a range sensor and at the same time takes an image of the bookshelf. The boundary line of each book is drawn in the books picture, and each book area is marked. Furthermore, after labelling each area with a number displayed on the screen, the user can select a book, by choosing its number.

6.2 Browsing mode

The interface in "browsing mode" is shown in Figure 7. In the main screen, the zoom image of an open page is given. If the page turning-over button located on the left of the screen is clicked, the page turning-over equipment

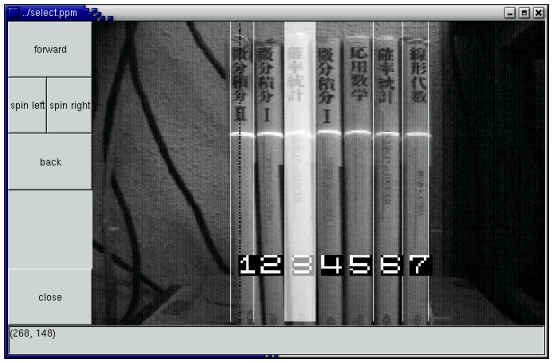


Figure 6: *Display in book selection mode*

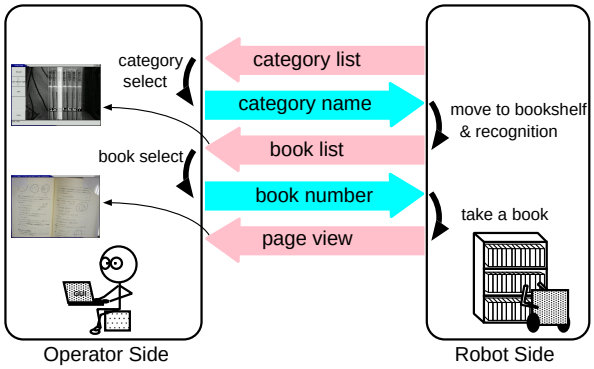


Figure 8: *Flow of experiment*

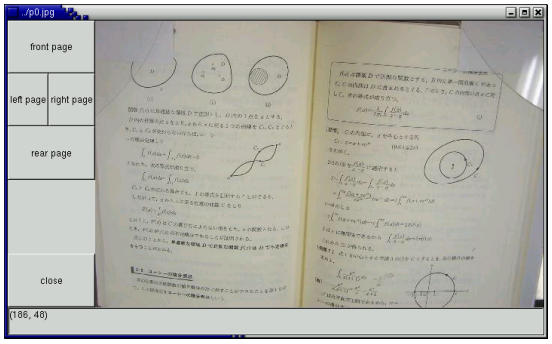


Figure 7: *Display in browsing mode*

will operate and the main screen will update the picture to the one of the following page.

7 Experimental results

The system we developed was used to look at various books located in a specific place. This experiment contains the continuous process flow consisting in picking up the book, opening and closing it, and taking the image of a page. In this experiment, the operator and the robot are located in the same room and the bookshelf is put in a place so that it cannot be directly seen from the operator. The experiment is shown in Figure 8.

1. An operator accesses the robot through a network from his own PC, and selects the target category first.
2. When the robot reaches the bookshelf, it shifts to book selection mode, and the bookshelf image with labeled books is shown to the user.
3. The user chooses a book inside the window, and the robot lengthens its hand and picks up the book.
4. The perusal equipment is used to send an image of the picked up book's page to the user.

The robot motion steps from book extraction until page opening are shown in Figure 9.

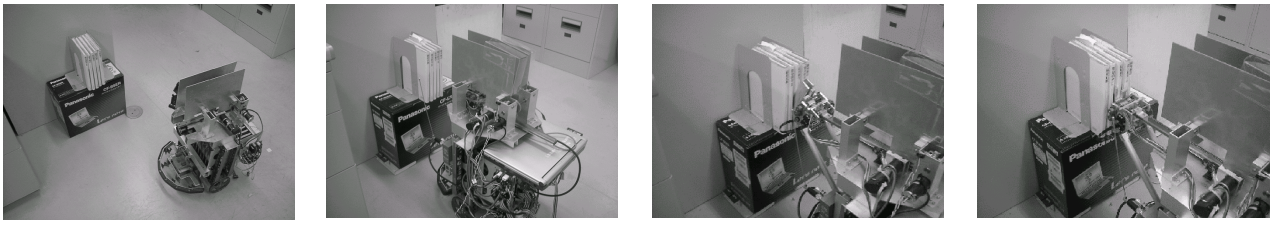
Based on the above experiments, the authors concluded that the gripper should approach a given book within 2mm of accuracy in order to insert itself smoothly to the book. And, since the measurement accuracy of our sensor is 1mm and the developed actuator can operate accurately to a 0.1mm error range, then solving the issue of precise positioning of the mobile base would enable the whole system to grab books from a shelf. However, as our mobile base's maximum positioning error is about 5mm, in our implementation we enable the robot to try repeatedly to position correctly itself untill the grip has a good grab of the book. With such methodology, we obtained a rate of 80 % of success over failures during conducted experiments.

In this experiment, the operator could view the image of a book page only by choosing the book. As an over all performance of the system, the movement speed of the robot in the navigation was 30cm/s and time for picking out a book was about 30 seconds. These values will be improved in the upcoming system.

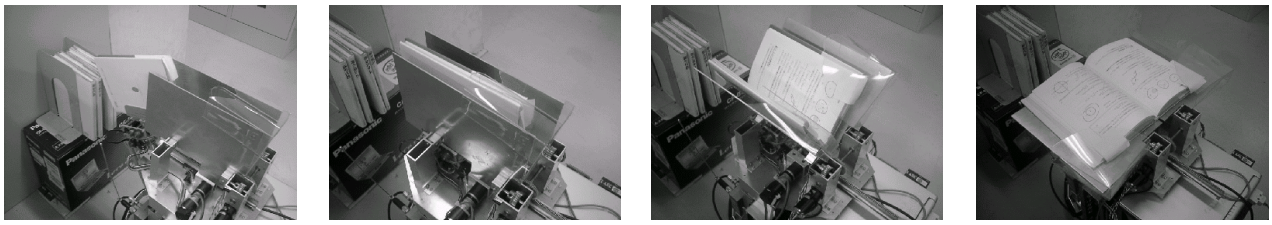
8 Conclusions

In this research, a remote book browsing system was built in order to use a robot as an access media including physical interaction in a remote place. Moreover we aimed showing the usefulness of a robot system which has an active part in everyday living environment. The developed system has capability of picking out the book demanded by a user, opening the book and sending the image of an opened page.

To reconfigure this robot system with the use of a highly flexible manipulator is our future perspective. Also, we intend to build and set with the robot a device to turn over pages in order to enable the reading of an entire book via teleoperation. Finally, to test and evaluate our system in a real library environment is also another future work.



(a) move to the bookshelf (b) books detection (c) approach to a book (d) gripper holding a book



(e) extraction from bookshelf (f) book in the browsing unit (g) book opening (h) reading...

Figure 9: *Scenes of an experiment using the developed robot system*

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