Remote Book Browsing System using a Mobile Manipulator

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Abstract

This paper describes a system which uses a mobile manipulator as a teleoperated tool for accessing and manipulating remote objects, in our challenge to extend mobile robot potentials and usage in human daily life. The specific task we set up in this research is to help humans browse books located in a library from a remote location via the Internet.

This task was decomposed into three major parts which are, the extraction and return of a book from a bookshelf, its browsing, and the teleoperational interface needed for humans to access to this system via a media such as the Internet. We built and realized a robot system which enables remote humans to access and browse books in a library from the Internet.

1 Introduction

For robots, the ability of carrying out successfully human activities in a real-world environment is becoming increasingly important and focused on for their insertion in our daily life milieu and human society. Therefore, it is necessary to consider a mobile robot application which is able to help and serve us usefully on achieving a daily task. In this world, we often need and wish to interact physically with remote humans or objects without displacing ourselves. The realization of such a teleoperational function by a mobile robot would enlarge greatly its applications' range in our everyday life scenes [1][2][3]. For example, a disabled or elderly human could access and observe easily remote objects by using a teleoperated mobile robot designed and built for that purpose, yielding hopefully to decrease their dependency towards helpcare in our dynamic human environment.

This research considers a mobile 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 of browsing a book located in a remote place thanks to a mobile robot. An overview of a remote book browsing is illustrated in Figure 1. The system's environment is a real-world library where remote humans use a mobile robot stationed in the library as their substitute, in order to browse a book through the Internet. The benefit for humans using this system is to enable them to search and find books in a library then, check its contents remotely, as

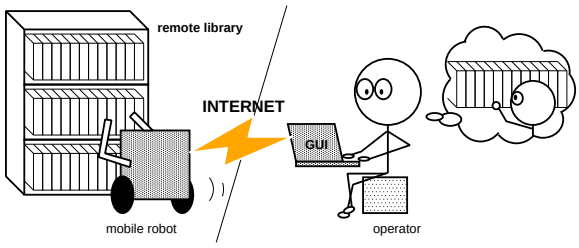

Figure 1: *Concept of remote book browsing system using a mobile robot.*

if there were locally inside the library.

Recently, various books are now processed electronically and Electronic Libraries have also being built. Processing books electronically focuses mainly 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. 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 built in this research will not be lost immediately. Moreover, if such a system is realized, I think that it is applicable also to the automatic electronic processing of ancient documents.

The following functions are required by the robot for performing this remote book browsing task. They are, autonomous navigation, recognition of a book by an appropriate sensor, manipulation for extraction and return of the book by an actuator, page turning over, viewing of a book's contents, communication to/from a remote place.

As related works, we have the CAPM project of the Johns Hopkins University[4] which has built a robot working for a library. In the CAPM project, the robot system is designed and implemented in a friendly library environment; this library was set as books of same size inserted one by one in special cases with constant space between them. In addition, the robot built in the CAPM project, is limited to extract only book from a shelf, but needs another robot system for browsing the selected book.

In our research, we design and implement a robot operat-

ing in a real-world library without any environmental limitations. In a library, in general, books are positioned in unsorted order inside the shelfs with different poses, resulting to a very dynamic environment in which the robot, in our work has to recognize books. Moreover, another difference of our design, here, is to build a mobile robot carrying out the overall operation from extraction of a book, turning over pages and browsing the books in an all-in-one system. Therefore, it becomes unnecessary to carry the selected book to another location, since our all-in-one robot system could browse and teleoperate from the book location, without any time lost or further navigation.

In the process of realizing this system, we first designed and built a prototype [5] using a small size mobile robot with 1 DOF manipulator and a hand. This prototype has the minimum ability to extract and open arbitrary books from a shelf and send images of opened pages of the book to teleoperating humans. However, that prototype was limited to extract only books with a predefined range of size and pose in the shelf. Therefore, the next step in this study was to overcome these restrictions by improving the prototype body and its technical elements in order to enable this robot system to act more robustly and independently in nearly real-world libraries.

We consider the book browsing teleoperation to be a combination of the following key actions.

- Extraction and return of the book
- Browsing of the book
- Remote operation via the Internet

The realization of each of these actions without any environmental limitations by a mobile robot and their integration in an all-in-one system are the difficulties challenged in this study.

In the following sections, each required action is described; Section 2 deals about the extraction from and return of a book to a shelf, the opening, page turning and browsing of a book is elaborated in Section 3, and last Section 4 presents about the teleoperation interface designed for humans. Finally, Section 5 describes the conducted experiments and shows some evaluation results of the integrated system.

2 Extraction and Return of the Book

In this section, the mechanism and the approach method for extracting and inserting books of all size and pose inside the shelf are detailed.

2.1 Manipulator

A robot needs to access the book shelf of various height. We decided to use 7 DOF manipulator of length 1100mm designed and built at our laboratory[6], in order to extract

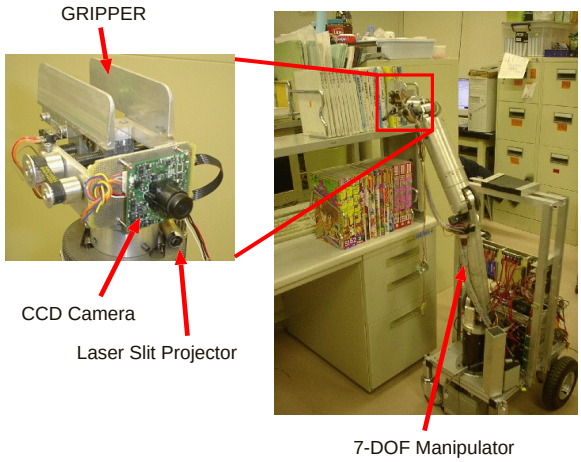

Figure 2: *7 DOF manipulator and hand for the book picking.*

from and return books in a shelf. The height of the manipulator is added by 200mm when fixed within the body of the mobile robot. Then, our manipulator is technically able to position its extremity between 400mm to 1100mm above the ground (Figure 2).

When we, humans, are picking out a book from shelf, our fingers would grab the targeted book and pull it out. This method has a simpler structure than other methods and ways of extracting books with complex multi-fingered hand. The hand designed in order to extract and insert books in a shelf is attached at the extremity of the manipulator. The hand consists of a gripper made of two flat fingers that can move to right-and-left symmetrically; these fingers can technically hold books with a weight up to 400g, meaning, in general, to books with a thickness parameter less than 50mm.

2.2 Target recognition

It is important to measure the position of a book correctly for picking a book. A laser range sensor was adopted to measure the position of a book as a robust and simple sensor. 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 by processing images using the triangulation[7]. When emitting a laser light in the direction of a bookshelf, the light is reflected at the places were books appear to be inserted, therefore making it possible to determine books position and width. Book position determination accuracy is about 1mm and processing time is about 100ms.

2.3 Book picking

We explain in the following procedure the way our hand grabs a book[5]. The robot, once it has arrived in front of the bookshelf, turns the manipulator to the direction of the

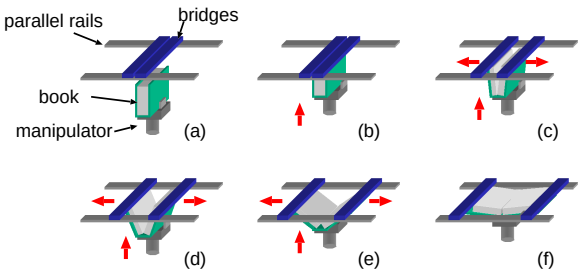

Figure 3: *Structure of book opening/closing device.*

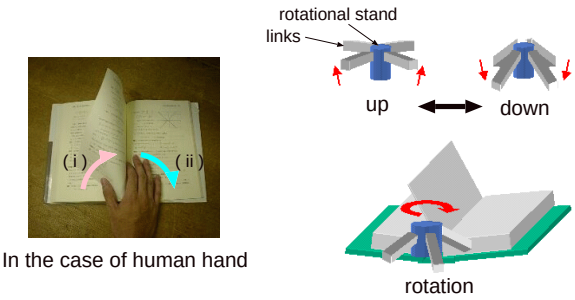

Figure 4: *Structure of page turning device.*

bookshelf. If a user wishes to change the viewpoint, then the hand's position will be moved vertically and horizontally. The robot takes an image of the bookshelf, and looks for the position and boundary of each book using a range sensor. Then, the gripper is widen proportionally to the width of the targeted book. Next, the gripper inserts itself between books and grab the targeted one. Finally, the hand pulls the gripper out.

The gripper should approach a given book within 2mm of accuracy in order to insert itself and grab smoothly the book. And, since the measurement accuracy of our sensor is 1mm and the developed actuator can operate accurately to a 1mm error range, then solving the issue of precise positioning of the mobile manipulator would enable the whole system to grab books from a shelf.

3 Browsing of a Book

The functionalities required for the browsing action of a book are like "Open the book", "Turn over the pages" and "Capture an image of the opened page and send it to the operator." Since the book selected out from the bookshelf is held by the hand, it needs another mechanism in order to be opened and gets its pages turned over. Equipments and devices for an automatic turning over pages of a book have been developed and are sold in the market[8], but they are expensive, big in size and inadequate for dynamically moving systems such as mobile robots. Therefore, in order to turn over efficiently the pages of an opened book by a simple mechanical structure built at low cost, we designed the opening/closing device and page turning over device at our laboratory and set it with the robot. In designing such equipment, the size range of open-able books was set from B5 to A4 size, and its weight range is limited to less than 400g.

3.1 Opening/closing a book

The outline of the book opening/closing device is shown in Figure3. This equipment consists of two parallel bridges set inside and perpendicularly to two parallel rails. The edges of the bridges are softly nailed in a way that once separated they can open a book previously located beneath the nailed parts. These bridges are able to slide from the center to right-and-left and symmetrically to another.

The procedure of opening a book using this device is described below. First, the edges of the book held by the hand are pushed until they reach the intersection of the two bridges in the center of the device (Figure 3 (a)-(b)). The book reaching the bridges is sensed by a touch sensor. The next step is to open the gripper. Then, the hand pushes forwardly the book it holds inside the nailed parts of the bridges while these ones are opening gradually synchronized with the forward movement of the hand (Figure 3 (c)-(f)).

The amount of movements and speed of each bridge will be set in a table accordingly to the size of book measured by calculating inverse kinematics. Using such a device would always open selected books inside the bridges at a constant height, –the height of the bridges–. As we explain in the next section, the page turning-over device can be set at a defined height above the book opening tool.

3.2 Turning over pages

We observed and imitated the motion of a fingertip in the case of a human turning over pages of a book using his hand. As illustrated in the left side of Figure 4, when we are turning over the pages of a book, our hand thumb generally presses down on the surface of the page to turn over and raises it up slowly by sliding fricatively our finger towards the book center. We designed the page turning device imitating the above explained humanly action. The device consists of four free links needed for pressing down vertically on the pages and a rotational stand set for sliding fricatively and horizontally the links on the pages beneath, as shown in the right side of Figure 4. One extremity of each link is fixed to the rotational stand thanks to a pin, and the other extremity is free of motion, hanging downward under gravity exertion. The free extremity of each link can be raised and lowered vertically thanks to an actuator. In addition, these links' extremities are coated by a frictional material to facilitate the sliding of pages.

During the process of turning over a page, all links are low-

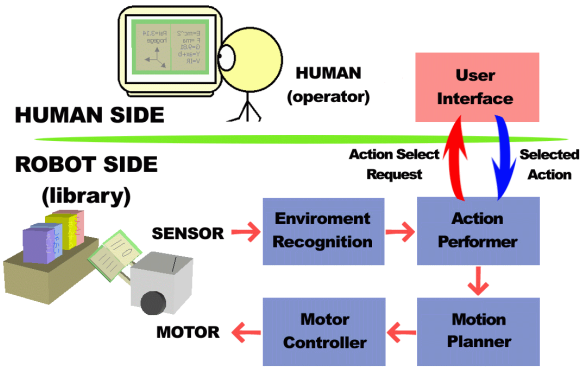

Figure 5: *Control system of teleoperation.*

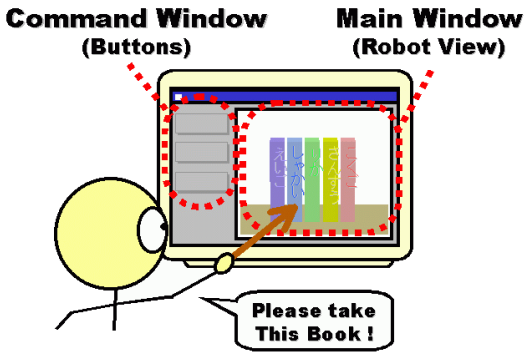

Figure 6: *An overview of GUI.*

ered and only two sided links among the four are pressing down respectively on the left and right pages of the opened book. Then, these links are slided fricatively over the surface of these pages by rotating the stand, yielding to the rise of one page, left one for clockwise rotation or right-sided page during a counter-clockwise rotation. And, as the stand gradually rotates the links, the raised page is sandwiched between one sliding link and a third link, which, in return just starts to landing on the surface of the following page. Hence, rotating by 180 degrees smoothly lowered links on an opened book results to the turning of one page over another depending of the direction of rotation. This action is endlessly repeated untill the device reaches the page targeted by the teleoperator.

3.3 Acquisition of a page image

A targeted page's image is captured by using a high resolution digital camera, and it is transmitted to the teleoperator via a wireless LAN connection. The digital camera used in this system, is a KODAK made digital camera which has an already provided control command library and is easily connectable via a USB port to the notebook PC. The control command library enables the robot system's main process to capture and upload images in the notebook PC, when needed accordingly to the teleoperator requests.

4 Teleoperation via the Internet

4.1 Control system of teleoperation

The teleoperation interface we provide to users is built based on a selection of executable behaviors of the robot. The robot software system consists of a set of programs generating action of the robot. Each action's set of programs is called by the corresponding behavior when selected by the teleoperating user (Figure 5). With such software system, the robot is able to change flexibly its behavior towards the teleoperator requests.

4.2 Tereoperation method

This chapter describes the interface designed for teleoperation by remote humans. An appropriate robot motion can be specified easily by selecting with a pointing device an object from an image displayed in a graphic user interface on the user desktop PC. The overview of GUI is shown in Figure 6. The GUI consists of a main window which displays the image captured by the robot's camera, and a button panel for sending directions and commands to the robot. The teleoperation process of browsing a book located in a remote place is executed in this order, (1) moving towards to the bookshelf, (2) selecting a book and (3) browsing its pages.

Navigation mode. The list and map of book categories in a library are inputted in the robot, and the teleoperator is provided with the environmental map. The teleoperator searches and selects from the bookshelf on the map, the book she wants to read, yielding the robot moving towards the targeted bookshelf.

Book selection mode. The GUI main window shows an image of the reached bookshelf. In this image, each displayed book is attributed a label. The button panel located on the left side of the GUI offers the modification of the viewed area done by changing the camera position. In addition, the boundary line of each book is drawn on the displayed image and each book occupyied area is painted. Furthermore, after labelling each area with a number displayed on the GUI, the teleoperator can select a book, by clicking its area.

Browsing mode. The zoomed image of an opened book's pages is displayed in the GUI main window. If the page turning-over button located on the left side of the GUI is clicked, the page turning-over device will then operate and the main window will update itself with the captured image of the following page.

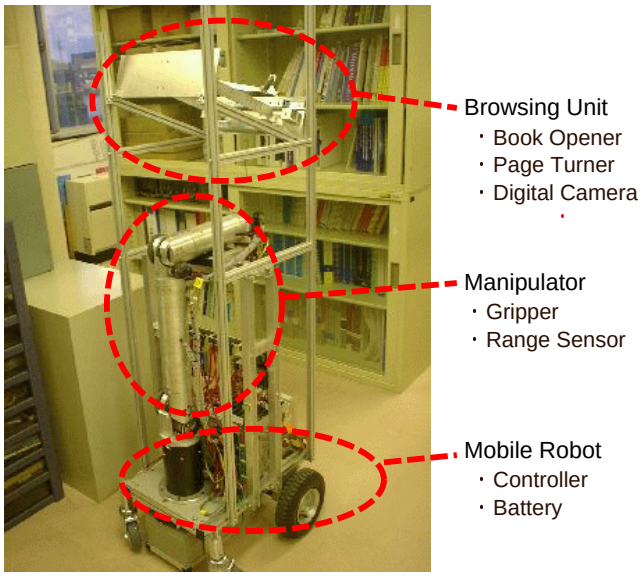

Figure 7: *Integrated book browsing robot "YAMABICO-BOB (BOok Browsing robot)."*

5 Experiment

5.1 Experimental system

We built the experiment system by integrating described 3 functions to a mobile robot. The mobile robot used in this research belongs to the YAMABICO mobile robot series which was developed in our laboratory[6]. YAMABICO is a mobile robot equipped with two independent steering wheels. It's body size is about 45cm(W)×55cm(D)×80cm(H) without the browsing unit and 170cm height when it includes the unit. By default, it is able to move autonomously along a specified line[9]. The locomotion platform of the autonomous mobile robot "YAMABICO-BOB" is equipped with a manipulator to grasp books and with a browsing unit for opening the book and viewing its contents (Figure 7).

Each function of the YAMABICO mobile robot series corresponds to a hardware module equipped with a CPU (T805 20MHz). The master control process running within 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.

5.2 Experimental results

The system we developed, was used to browse various books located in a specific place inside our laboratory. In this experiment, the teleoperator and the robot are located in different parts of the laboratory and the bookshelf is put in a place so that it cannot be directly seen from the teleoperator. The experimental scenes are shown in Figure 8.

1. A teleoperator accesses the robot through a network from her desktop PC and selects the target category first.
2. When the robot reaches the bookshelf, it shifts from the navigation mode to the book selection mode and the bookshelf image with labeled books is displayed to the user.
3. The teleoperator chooses a book within the displayed image and the robot lengthens its hand to pick up the book.
4. The browsing equipment is used to send an image of the grabbed book's page to the user.

In this experiment, the user could view the images of a book page only by selecting the category and the book. As an overall performance of the system, the motion speed of the robot during the navigation mode was 30 cm/s and the time for grabbing and opening a selected book was about 30 sec. Moreover, turning over a page requires 4 sec/sheet.

The page turning-over equipment of the experimented system could turn over only one sheet of paper at once. These values are to be improved in the future.

6 Conclusions

We aim to show the usefulness of a mobile robot system taking part actively in an everyday living environment. In this research, a remote book browsing system was built in order to use a robot as an access media for a physical interaction with a remote object. The developed system has the capability of grabbing the book selected by an user, opening it and sending images of its opened pages to the remote user.

In order to improve the operability and reliability of remote book browsing, our future works are to solve the following problems.

- Optimization of the manipulation planning
- Improvement of the book recognition
- Improvement of the page turning over process speed
- Implementation the GUI viewable from the WWW.

Finally, we will test and evaluate our system in a real library environment.

Acknowledgments

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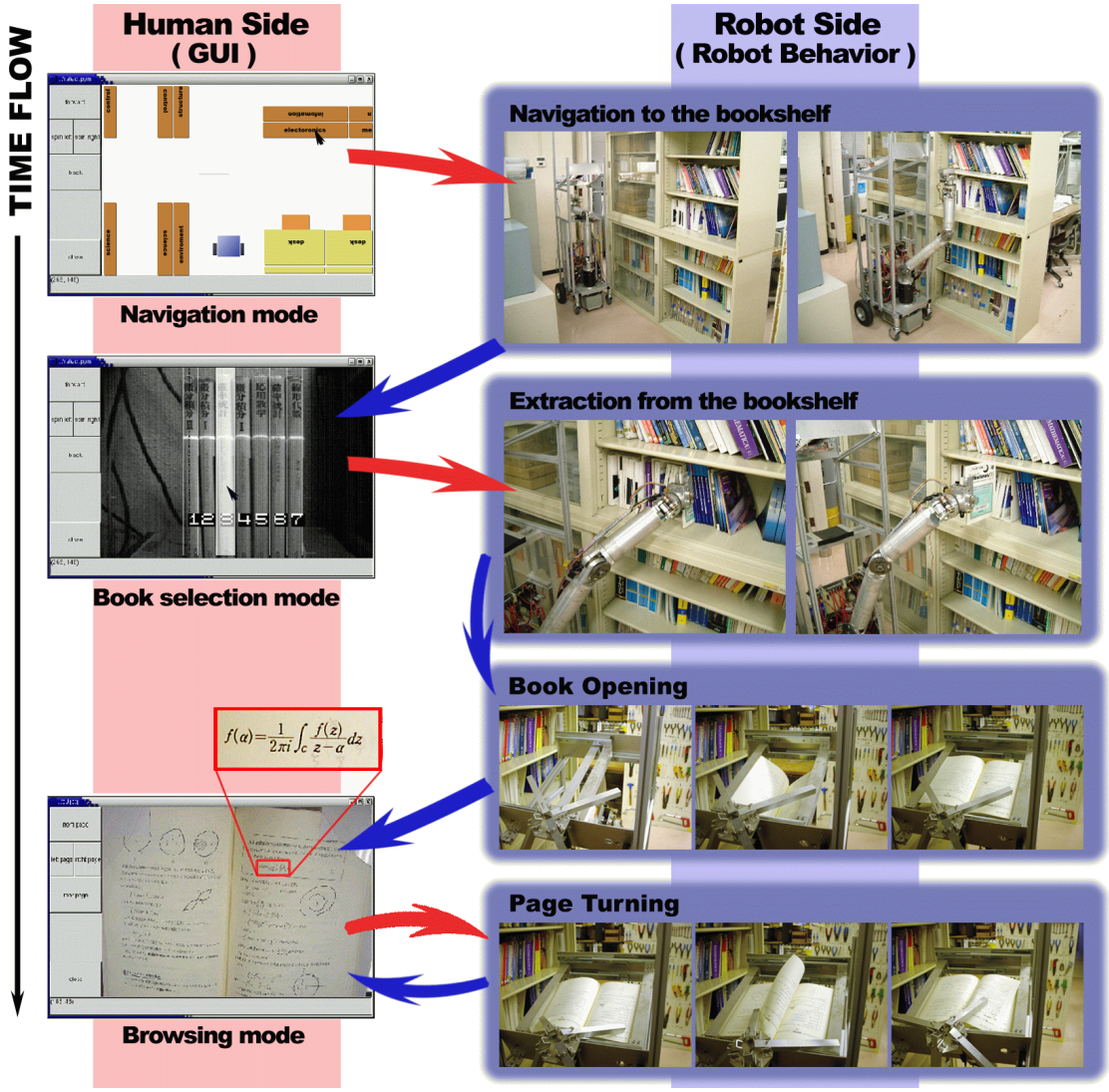

Figure 8: *Scenes of an experiment using the all-in-one integrated robot system.*

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