Remote Food Shopping Robot System in a Supermarket –Realization of the shopping task from remote places–

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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. This system attempts to answer the challenge of extending mobile robot potentials and usage in human daily life. The specific task we set up in this research is to help people buy fresh food in a supermarket from a remote location using the Internet. We built the prototype system by integrating custom designed components: the mobile manipulator, the sucker gripper, the shape scanner using a small laser range finder, and the communication interface. With this system, the selection of the food item by the remote user from the supermarket showcase, its close examination using the gripper, and final placement into the shopping basket were realized. This paper describes the hardware and software of this system, and shows the experimental result performed with the integrated system.**

Index Terms*— Remote shopping, Foods handling, Human dailylifeRemote shopping, Foods handling, Human dailylife

I. Introduction

In this research we focused on developing a system able to offer a service by performing a determined task. Specifically, the task of remotely manipulating a real object as desired by the user. Such an approach was proposed and developed in "Development of a Remote Book Browsing Robot System [1]," and another systems[2]–[4]. This successful implementation shows how robots are slowly making their way into society by performing useful functions. In a new but similar approach, the necessary human task of procuring food, particularly from the supermarket is addressed; thus, in this research, we propose "A Remote Food Shopping Robot System" as a concrete application. This system would greatly contribute to society by helping people who are not able to go by themselves to the supermarket (such as the elderly and disabled) in order to buy necessities.

In order to perform the remote shopping function, the robot has to pick up objects with different textures and irregular shapes such as fruits and vegetables. Also, the robot has to find, identify and put the object into a shopping basket. This paper describes the development of the robotic mechanism for picking up objects with different characteristics, the technique of scanning and measuring the food item's shape, and the user interface for remote shopping; it also shows the complete operation of the system.

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II. The Concept of the Remote Food Shopping Robot System

Industrial products commonly have regular shapes and characteristics, however, in the case of perishable food, each item has slightly different features such as size, shape, weight, softness etc. Therefore, when buying perishable food, the buyer will often need to examine the goods visually to choose the best one. In this research, our purpose is the realization of a system which allows the remote user to examine and choose fresh food items, without going to the supermarket. The system consists of a mobile robot with a manipulator able to pick up different kinds of objects and a user computer connected by a network. The robot is stationed in the supermarket. The user accesses the robot through the Internet from home. The user can examine images of supermarket items captured and sent by the robot and choose one. The concept of our system is explained below and illustrated in Fig. 1.

1) The user selects the desired product.
2) The robot moves in front of the target supermarket showcase and sends an image of the goods in the showcase.
3) The user chooses one object from the displayed image.
4) The robot picks up the selected object.
5) The user examines the object held by the robot.
6) The object to be purchased, is put into the basket and carried for checkout.

Conventional shopping catalogs and Internet shopping sites can only provide sample photographs of products, however, for perishable goods, the size and condition of each item is different, making it indispensable for the buyer to examine the goods first and then choose.

III. Specifications of Targeted Showcases and Food Items

Characteristics of perishable foods such as size, weight, and shape are different for each kind. Also slight variations

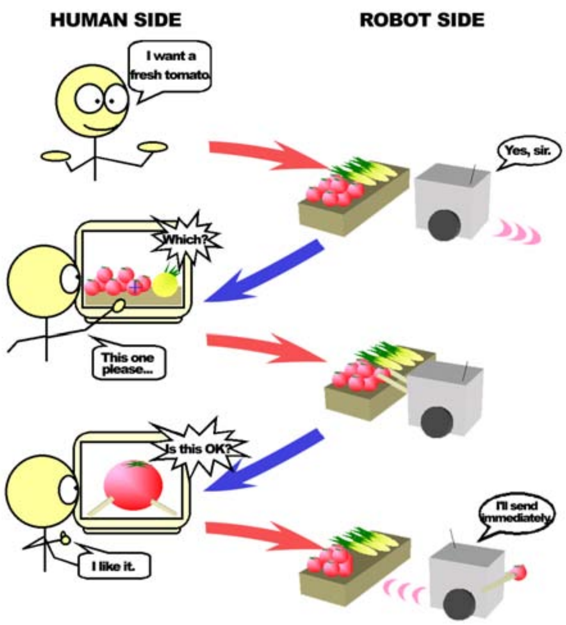

Fig. 1. The Concept of the Remote Food Shopping System

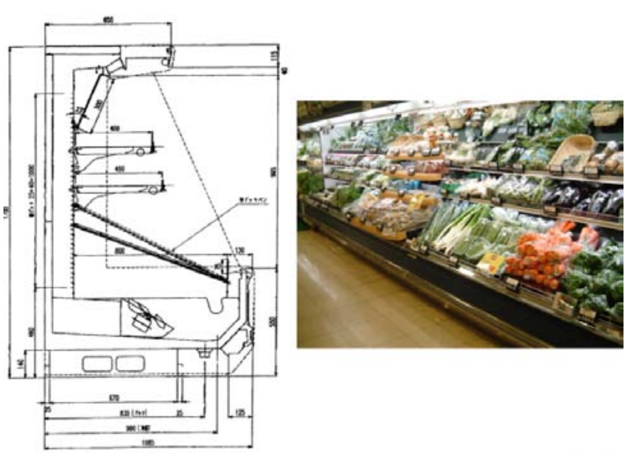

Fig. 2. Dimensions of a Standard Supermarket Showcase

such as color and texture occur even for the same kind of food items. Moreover, the choice of the qualities of perishable goods vary for each person. For these reasons, the system must be able to grasp a wide range of objects and also be able to show the object to the user for inspection.In this research, we assume that the products are placed on a supermarket showcase shelf. As shown in Fig.2, standard showcases have considerable depth, about 800mm, and have a height of approximately 1500mm, the length of the manipulator must be at least of 1500mm in order to reach objects at the top.

Next, we surveyed the characteristics of the target fresh food items. Excluding considerably heavy products such as watermelons, most of the perishable goods in a supermarket weigh between 100g to 500g. The food items can be divided into spherical, cylindrical, rectangular and ellipsoid shaped

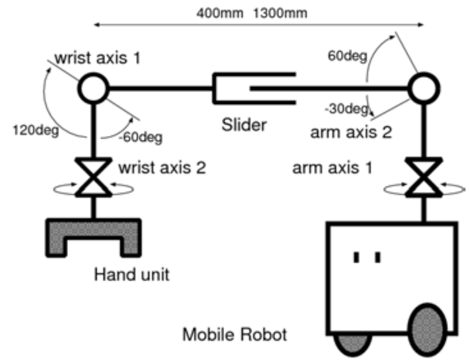

Fig. 3. Hardware Diagram of the Manipulator

objects. Using this information, in order to handle the target objects, the manipulator must have sufficient length to cover the work area, capacity to carry heavy objects, and smooth grasping control in order to avoid damaging the perishables. As this research aims to develop a useful mobile manipulator in a practical situation, the following assumptions about the target objects were considered for implementation:

- The object can be spherical, cylindrical, rectangular or ellipsoid in shape
- The object surface can be attached to a suction device (rubber suction cups from our manipulator)
- The front face of the object can be directly observed
- The object does not separate or divide into pieces

IV. Robotic Hardware

The mobile robot platform used by this research as a mobile base is a nonholonomic system and has two degrees of freedom. The manipulator is placed on top of the mobile robot. Generally, when handling objects in three-dimensional space a robotic arm with 6 degrees of freedom is needed. In many cases, robot arms are implemented similar to the human arm. In this system the manipulator is composed of a turntable base, an expandable sliding arm, and a multi-finger gripper. It has five moving joints for the whole arm. By combining the manipulator and the mobile robot displacements, the tip of the arm can reach any arbitrary point in 3D space.

A. Expandable Sliding Arm

To be able to handle objects in the target work area, the mechanical arm is required to have a large range of motion at the same time it must be of small size. In order to achieve this functionality, we developed a compact expandable sliding arm. The greatest advantage of a sliding arm is its ability to directly and simply reach a target linear with its tip in the shortest distance possible. This also means that mechanical bending and stress, such as in a revolute joint arm, are minimized. Moreover, when approaching an object, the space which the arm occupies is lessened. Other advantages of a sliding arm are:

- The range of motion is very wide

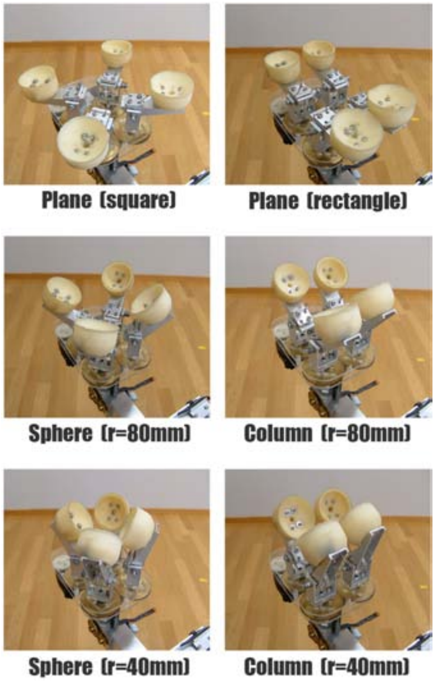

Fig. 4. Motion of the Developed Robot Hand

- Since there are fewer joints, motors, weight and cost are reduced
- Simple calculation of inverse kinematics
- Parallel translation of the hand is easier without changing its posture

The expandable arm which we designed consists of a four-stage sliding joint for translation, similar to a telescopic crane arm. For this joint, slide rails [1] were used. The rails have minimal friction and its structure is built for high momentum movement. Each adjoining stage is connected by a timing-belt and the whole expandable-contractable mechanism has only one motor as an actuator. When the motor pushes or pulls the 1st stage slider, the rest of the sliders also move synchronously. Because of this, the mechanism can be regarded as one actuator for the controller. This arm has a length of 700mm when contracted, and a total length of 1560mm when fully expanded. In order to make a slider expand and contract, high torque is needed. Furthermore, the backlash of the gears or belts which influence the robot hand's accuracy is a cause for concern. In this system, the harmonic-drive was adopted in the actuator. Backlash is minimized while maintaining a high reduction ratio.

B. Robot Hand

In order to perform shopping tasks, the most difficult problem is to pick up objects with different textures, softness and irregular shapes such as fruits and vegetables. Although there have been previous research about techniques for grasping objects with a robotic hand[5], in this research, we designed and manufactured an original mechanism which consists of 4 fingers with small suction cups at each finger tip[6]. This mechanical hand can grip and secure objects of various shapes such as spheres, cylinders, ellipsoids, and planar shapes. The advantages of the developed manipulator using soft suction cups are:

- Flexibility, which increases the resilience of the manipulator's motion controller to small errors and at the same time reduces the sensing cost
- Large contact surface allows for better distribution of the pressure applied to the object
- The vacuum force between the hand and object results in a steady grasp
- The hand can grasp objects bigger than itself
- By regulating the power of suction pumps, pressure applied to the object is controlled

C. Integrated Robot System

The YAMABICO[7] was used as the platform for the robot system stationed inside of the supermarket. The manipulator described above and a basket for carrying the selected goods are placed on the robot. The robot's fundamental

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

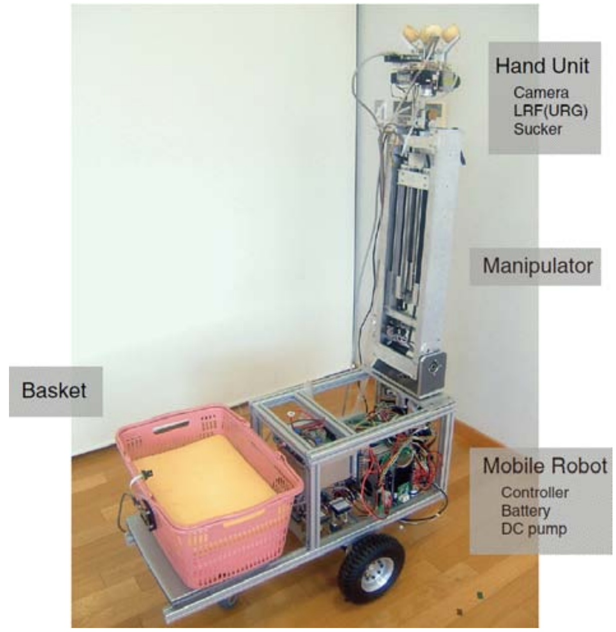

Fig. 5. The Integrated Shopping Robot

TABLE I
SPECIFICATIONS OF THE DEVELOPED ROBOT SYSTEM

Size(moving)	45cm(W)×91cm(D)×155cm(H)
Weight	30kg
Moving Velocity	30cm/sec
Reaschable Height of the Hand	2400mm
Weight Capacity of the Hand	5000g
Resolution of Robot Camera	1024picel(H)×768picel(V)

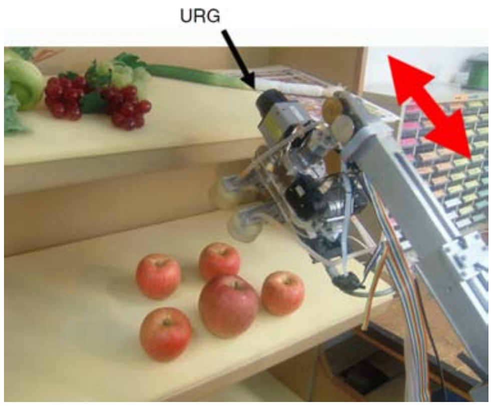

Fig. 6. Small LRF (URG) Attached to the Robot Hand.

specifications are shown in Table I, and Fig.5 shows the integrated robot. The robot has a DELL notebook PC as its main controller. The PC has the following functions: motion planning of arm and hand, information processing for the cameras and sensors, and communication interface with the remote user.

V. Shape Recognition

It is essential to recognize the three-dimensional shape of the object in order to grasp it. In this system, a small laser range finder (LRF) to scan the shape of the object is used. This LRF (Hokuyo Automatioc Co., LTD, URG-X002S[8]) is much smaller than those previously available, and can easily be mounted on the wrist of the robot hand. The sensor is attached to the robot hand as shown in Fig.6.

The object of interest is scanned to acquire the 3D shape data with the robot hand above the object and facing the showcase. Fig.7 shows an example of the shape of an apple measured using this sensor. The shape of the object is approximated to a globe by the least squares method, after which the posture of the manipulator for pick up is calculated. If the calculated position of the robot arm for pick up is within the limits of the hardware, the object is grasped by the hand mechanism. The following chapter describes the interface shown to the user, and the selection method of an object.

VI. User Interface for Remote Shopping

In this section, the interface between the robot in the supermarket and the user in a remote location is described.

A. Information Displayed to the User

When supermarket customers chooses perishable goods, color, size, presence of cracks, weight, softness and other physical properties serve as criterion for selection. Visual information is most important for choosing these kind of goods. Thus, in this prototype system, two cameras were mounted on the robot, and each camera is connected to the robot's notebook PC via IEEE1394. One camera is attached

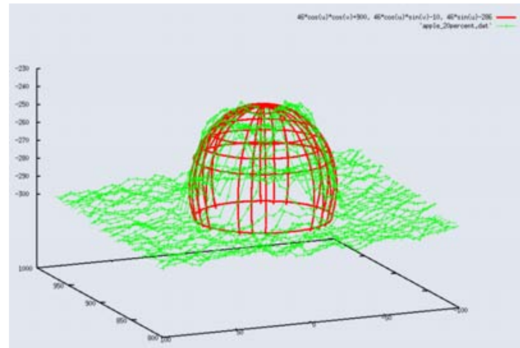

Fig. 7. Estimated Position and Radius of an Apple

Fig. 8. Camera Attached to the Hand (left), and An Image Captured by the Hand-Camera (right)

to the center of the robot hand, Fig.8. This camera provides the view from the robot hand's palm and can be used for up close images of the goods on the showcase. The other camera is attached to the robot's basket, Fig.9. The goods grasped by the robot hand are held up in front of this camera, and are observed from various angles for close examination.

B. Graphical User Interface

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 specific actions from robot. Behaviors to perform commands by the user are actually a combination of executable actions by the robot. With such a software system, the robot is able to be flexible in its behavior towards the user requests. An appropriate robot motion can be specified easily by selecting with the pointer an object from the image displayed on the graphic user interface on the user PC. The overview of GUI is shown in Fig. 10. The GUI is programmed with OpenCV, and consists of 2 live image windows which display the image captured by the robot's cameras. A message window for sending directions and commands to the robot is also part of the interface.

1) Message Window: This window shows messages from the robot to the user. Specifically, it is used for the following: 1. Display a list of goods for selection by the user 2.

Fig. 9. Camera Attached to the Basket (left), and An Image Captured by the Basket-Camera (right)

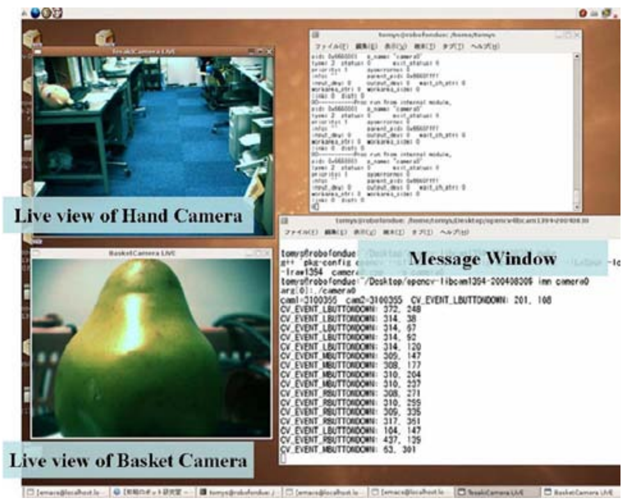

Fig. 10. User Interface of the Remote Shopping System

Display the status of the robot 3. Ask for user commands and confirmation 4. Request input by keyboard or mouse

2) Hand Camera Window: Live images from the hand camera is displayed in this window. As the robot moves to the target showcase, the camera angle is turned toward the front of the robot at about human eye level. Thus, the user can see the environment of the inside of the supermarket. When the robot is in front of a showcase, the camera is turned toward the goods. The user chooses an object to be taken by the robot hand.

3) Basket Camera Window: Live images from the basket camera is displayed in this window. This screen shows the close up image of the object in order to examine its color, its texture, and existence of imperfections. When the user drags the mouse cursor on this screen, the grasped object will be rotated vertically and horizontally by the robot hand.

VII. Motion Planning

Various motion modes are implemented beforehand for this robot. There are three kinds of motion modes: shape measurement of the selected area, grasping a target object, and examination of the picked object. These are described as follows.

A. Shape Measurement of the Selected Area

The target position and height of the showcase are given beforehand, and then the sequence for scanning the shape of the food items is shown below:

1) The turntable of the arm is rotated and the hand is turned toward the showcase
2) The slide arm is lengthened to the target position, at the same time, the object shape is scanned by the LRF attached to the hand
3) The robot transmits the image of the hand-camera to the user, and requests her to select an a object with a mouse click

It is assumed that the scanned arrangement will not change until the robot hand actually grasps the object. Also since the LRF is nearer to the object than the camera, once the object is within the camera view, the object scan has already been performed.

B. Grasping a Targeted Object

After the user clicks one object in the hand camera window, the grasping mode is commenced.

1) The user's gaze vector in real space is calculated from the clicked coordinate on the screen and the position/posture of the camera
2) The nearest 3d-point from the vector is defined as the user's view point
3) By the least-squares method, the measured data near the gaze points is approximated to a sphere
4) The hand is moved to a position to approach the object
5) Fingers are bent until they fit the estimated sphere form while suction is performed by the suction pumps
6) The grasp will be successful if any suction cup attaches to the object. When no suction cup attaches, it means a failure of operation
7) The arm draws out the hand from a showcase, continuing suction grip.

C. Examination of the Picked Object

When the object is picked up, the robot will change to examination mode.

1) The hand carries the picked object from the showcase to the front of the basket.
2) The robot holds up the object in front of the basket camera, and transmits the images to the user's computer
3) The User drags the mouse cursor vertically and horizontally on the close-up image of the object
4) The robot hand rotates its hand vertically and horizontally according to the motion of the mouse
5) If the user decides to purchase it, the object is placed in the basket, and suction is stopped and hand grasp is opened

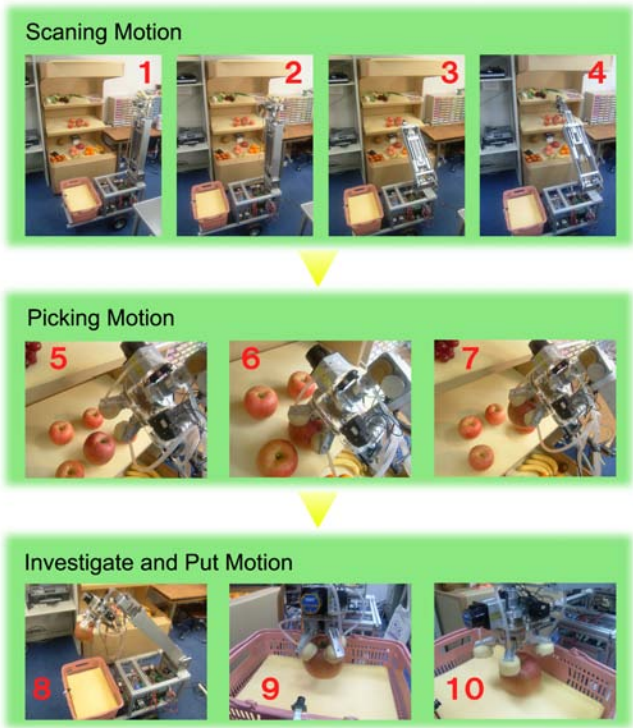

Fig. 11. Demonstration of an Apple Purchase

VIII. Verification Experiments

A. Demonstration of an Apple Purchase

We performed a demonstration in which the user located in a remote place purchases an apple using the built system. The showcase used in this experiment is the same size as what is used at actual stores. The images from the demonstration are shown in Fig.11.

1) The robot moves to the front of the showcase of apples and stops (Fig.11-(1),(2))
2) Robot hand is turned toward the direction of the apple (Fig.11-(3))
3) The contents of the showcase are scanned using the URG LRF sensor for measuring 3D shape (Fig.11-(4))
4) Arrangement of the hand sucker grippers is changed according to the position and shape of the selected apple. (Fig.11-(5))
5) The apple is grasped by a sucker hand (Fig.11-(6),(7))
6) The selected apple is carried to the basket (Fig.11-(8))
7) User examines the picked apple carefully (Fig.11-(9))
8) The apple which is chosen for purchase is put in the basket (Fig.11-(10))

B. Evaluation

In this experiment, the operator can examine and put food items into the basket by only clicking and dragging the mouse cursor. As an idea of the overall time performance of the system, it takes about 30 seconds to scan the 3D shape of an object, and picking the selected object is about 30 seconds. In addition, it takes 20 seconds to grasp an object by the robot hand and carry it to the front of the basket camera. It should be noted that if the system response time is very slow, users may get impatient. The URG used for shape measurement of objects was very effective for the planning of manipulation because of its lightweight and it could measure distance directly. On the other hand, some objects which do not reflect laser beams properly (such as wrapped goods, waxed fruits, and black objects) were not able to be correctly scanned. One of the features of this system is that the item in the robot's hand can be seen by the user in detail from various angles. In order to improve this feature, the function to change grasping position, and functions to provide users not only with visual information but also tactile, olfactory, and taste information should also be considered.

IX. Conclusions

This paper proposed "A Remote Shopping System" as an example of everyday life support which can be done effectively by robots. We built a mobile manipulator, a sucker gripper, a shape scanner using a small laser range finder, and communication interface. The integrated system was implemented, a remote user was able to select a fresh food item located in a supermarket showcase. Furthermore, close examination of the object, and its placement into the shopping basket were realized. Finally, the demonstration of the integrated system was performed and evaluation of the experiment was discussed. Although the shopping demonstration shown here is only an example, the possibilities of robot systems supporting human lives is extended.

References

[1] T. Tomizawa, A. Ohya, S. Yuta: "Remote Book Browsing System using a Mobile Manipulator", Proc. of 2003 Int'l Conf. on Robotics and Automation.

[2] S. Maeyama, S. Yuta, A. Harada: "Remote Viewing on the Web using Multiple Mobile Robotic Avatars", Proc. of 2001 Int'l Conf. on Intelligent Robots and Systems. pp.637-642.

[3] J.Suthakorn, S.Lee, Y.Zhou, T.Thomas, S.Choudhury, G.S.Chirikjian: "A Robotic Libarary System for an Off-Site Shelving Facility", Proc. of 2001 Int'l Conf. on Robotics and Automation, pp.3589-3594.

[4] Prats M, Ramos-Garijo R, Sanz PJ Del Pobil AP: "Autonomous Localization and Extraction of Book in a Library", The 8th Int'l Conf. on Intelligent Autonomous Systems, 2003.

[5] Kouji Murakami and Tsutomu Hasegawa, "Novel Fingertip Equipped with Soft Skin and Hard Nail for Dexterous Multi-fingered Robotic Manipulation", Proc. of 2003 Int'l Conf. on Robotics and Automation.

[6] T. Tomizawa, A. Ohya, S. Yuta: "Remote Shopping Robot System -Development of a hand mechanism for grasping fresh foods in a supermarket", Proc. of 2006 Int'l Conf. on Intelligent Robots and Systems.

[7] `http://www.roboken.esys.tsukuba.ac.jp/english/Yamabico/robot/`

[8] H. Kawata, W. Santosh, T. Mori, A. Ohya and S. Yuta : "Development of ultra-small lightweight optical range sensor system", Proceedings of 2005 International Conference on Intelligent Robots and Systems.