Remote Shopping Robot System

-Development of a hand mechanism for grasping fresh foods in a supermarket–

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***Abstract*— The purpose of this research is to develop a robot system which helps humans to remotely accomplish a daily given task such as shopping. This teleoperated system is based on simple mutual human-robot cooperation where the person remotely communicates with the mobile robot. We define the specific task of buying FRESH foods in a supermarket from a remote location. In order to do shopping operations, the robot has to be able of grasping a large amount of objects with different textures, shapes and weights which include fruits and vegetables with soft and irregular forms.**

After the user chooses the product to buy, the process is the next, firstly the robot has to find the object, then grasp it and then place it into a shopping basket. In this work, we built a system according to the previously explained requirements which involves autonomous navigation, environment perception, object manipulation and teleoperation. In this paper, we present the developed suction hand for picking fresh foods and evaluate its operating performance through experimental results.

I. Introduction

Due to the rapid development of mechatronics, recent systems, are more intelligent, present high level of integration and are more human centric. However, despite of many efforts, robots still have not spread to humans everyday life. On one hand, ordinary people do not have the opportunity to know in detail the limits of robot technology, so for people in general the idea of robot support in everyday life is ambiguous. On the other hand, for robotics researchers is difficult to know what kind of service robots should provide. In order to overcome this vicious spiral, researchers must devise the scene of using robots for everyday life support and build helpful, practical and convenient systems in order to show society robots possibilities.

In this research we focused on developing a system able of offering a service by performing a determined task. Concretely the task of remotely manipulate a real object as desired by the user. Such an approach was proposed and developed at "development of a remote book browsing robot system [1] [2]." This successful approach showed how robots are opening its way through society.

In a different but similar approach, as humans have the necessity of consuming perishable products which are commonly found in common supermarkets, in this research, we propose "remote shopping robot system" as a concrete application. This system would greatly contribute socially for helping people who are not able to go by their selves to the supermarket (such as elderly and disabled people) in order to buy first necessity articles.

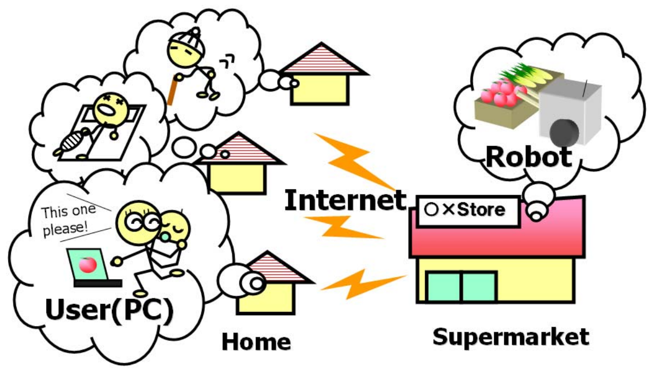


Fig. 1. The concept of Remote Shopping Robot System.

In order to do shopping operations, the robot has to pick up objects with different textures and irregular shapes such as fruits and vegetables. Also, the robot has to search, find and put an object into a shopping basket. This paper describes the development of a mechanism for picking up objects with different characteristics, also shows its performance and operating efficiency.

II. Remote Shopping Robot System

A. Concept

In the case of industrial products, objects have similar characteristics, however, in the case of perishable foods, each object has slightly different features such as size, shape, weight, softness etc. Therefore, when perishable foods are bought in a shop, the buyer will often examine goods by her/his own eyes, and will choose the best one. In this research, our purpose is the realization of a system which allows the user to examine and choose fresh foods from a remote location, without going to a supermarket.

This system consists of a mobile robot which contains a manipulator able of picking up different kinds of objects and computers connected to a network. As shown in Fig.1, the robot is stationed in the supermarket. The user accesses the robot through the Internet from her/his home. Then, user can examine supermarket products captured and sent

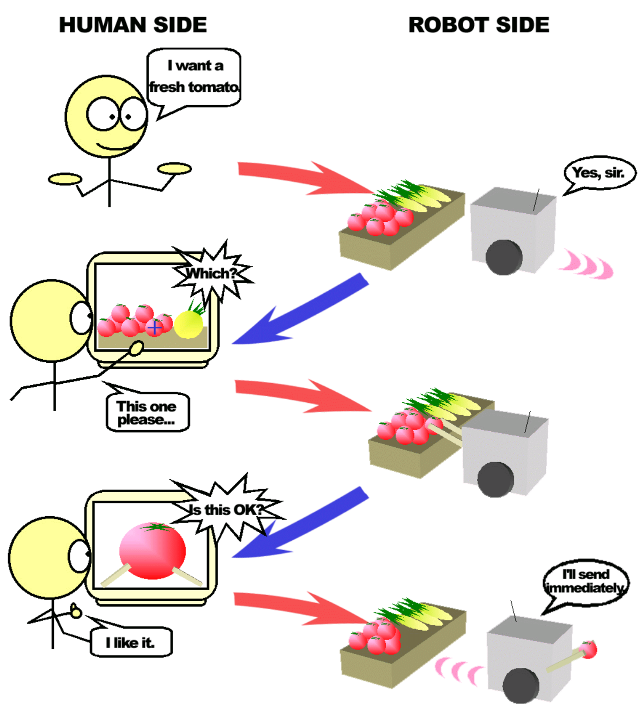


Fig. 2. The Usage of the Remote Shopping System.

by the robot and choose one. The concept of our system is explained below and illustrated in Fig.2.

1) The user selects the desired product.
2) The robot moves to the front of the target 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 which was picked up by the robot.
6) The object to be purchased, is put into the basket and carried to the register.

Conventional sale catalogues and internet mail orders can only provide products sample photographs, however, in the case of perishable products, the size and state of each one is different, making indispensable to personally choose them.

B. Problem Definition

For a robot operating in a supermarket, the next elements are necessary in order to be able to grasp a determined product:

- A mobile robot able to navigate autonomously in the supermarket
- A basket to collect the selected products
- A manipulator able to grasp objects of different sizes, weights, textures and softness.
- A manipulator able to reach products in supermarket's showcases.
- Sensors to find and recognize different products

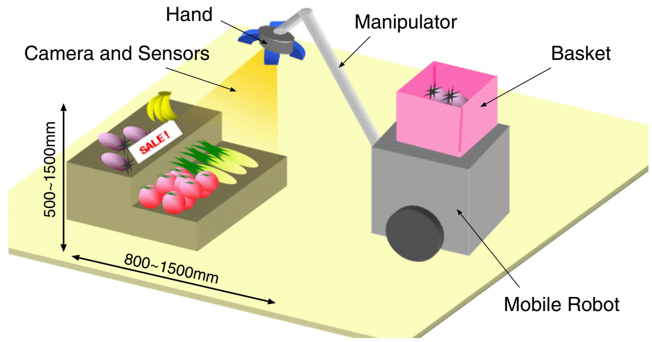


Fig. 3. Elements of the Shopping Robot.

Fig. 4. Samples of Target Object.

Because the difficulty it implies, on this research, we put special attention in soft object grasping (perishable products such as fruits and vegetables).

Characteristics of each perishable product vary from each other. Moreover, perishable product choosing varies from each person. For these reasons, the system must be able to grasp a wide variety of objects and show them to the user. In this research, we assume that products are placed in showcases. As shown in Fig.3, normal showcases havr considerable depth (800mm), and have a height of approximately 1500 mm, the length of the manipulator must be at least of 1500mm in order to reach objects at the top.

An image of target objectbis shown in Fig.4 and Table I shows some common products with its characteristic shape and weight. Excluding considerably heavy products such as watermelons, most of the perishable products in a supermarket weight between 100g to 500g. Considering the shape, products can be divided in to spherical, cylindrical, rectangular and ellipsoid objects. With this previous knowledge, in order to manipulate the mentioned objects, the manipulator must have length to increase work area, capacity for carrying heavy objects and smooth grasping control in order to avoid damaging the grasped products.

As this research aims to demonstrate the usefulness of mobile manipulators in daily life scenes, the following conditions concerning objects were established:

TABLE I

SHAPE AND WEIGHT OF PRINCIPAL FRESH FOODS.

Object	Shape	Weight
Apple	Spherical	250g
Radish	Cylindrical	500g
Package	Rectangular	200g
Kiwi	Ellipsoid	100g

- Object shape can be spherical, cylindrical, rectangular or ellipsoid shapes.
- Objects which can bare contact from an outside interacting body (rubber suction cups from our manipulator)
- The front face of the object can be directly observed. [1]
- The object does not separate or divide into pieces.

III. GRASPING MECHANISM

One of the major problems for object grasping is the fact that the softness of the object to be manipulated is unknown. Object grasping has caught the interest of a great number of researchers, where the fundamental principle is that when the gripper closes its fingers on the object and applies a light pressure on it, the friction force between the two elements makes possible to pick the object up. However, when the two objects have different hardness, at mutual interaction, the softer object tends to be changed or transformed. Moreover, when the object to be grabbed has a narrow surface in comparison to the size of the manipulator, a steady grasp can not be done, and the object tends to be damaged.

In order to solve these difficulties, research has been made in finger coating material. If the manipulator is covered with a soft material, contact surface increases and a stable grasp can be achieved.

Most of the research approaches manage the problem of solid object grasping. However, as this research aims to grasp a wide variety of products in a supermarket, not all the objects have solid bodies. On the contrary, perishable goods tend to be soft which increases the difficulty of stable grasping. Precise measurement of deformation of the object and contact surface between object and hand, is complicated, as is difficult to construct object models in advance. Moreover, mechanical hands cannot handle objects bigger than the surface of the hand. For these reasons, we propose and designed a mobile mechanical manipulator system with few degrees of freedom, with relatively simple sensors that can grasp a large amount of different objects without taking into consideration its softness.

A. Suction Cup Usefulness

For our mechanical hand, instead of the commonly used end effectors or fingers, we propose a manipulator with soft polyurethane made suction cups. By using this kind

[1]This system cannot handle objects which are partially viewed or affected by occlusion.

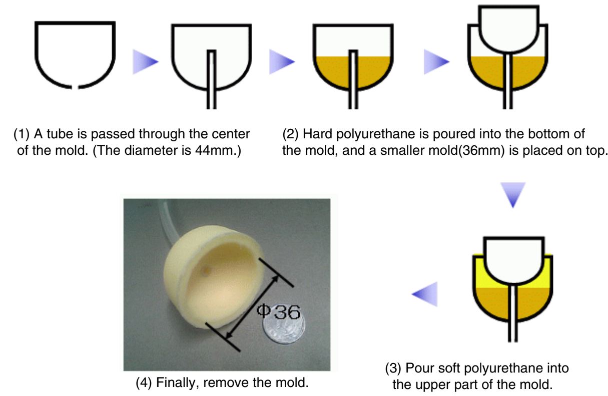
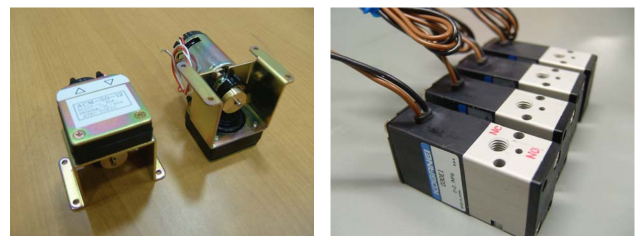


Fig. 5. How to Make an Urethane Sucker Cup.



(a) diaphragm pump (b) Electromagnetic valve

Fig. 6. Pump and Valve.

of soft material, the manipulator can steadily grab delicate perishable goods such as meat packages. Polyurethane is a very soft adhesive material which changes its shape at contact with other bodies adopting their shape. Furthermore, this material can be handled easily and can be molded to the user requirements. As result, the manipulator with four suction cups made of polyurethane and coupled with suction pumps, produces a mechanism able to grasp a large variety of different objects.

The advantages of the manipulator with soft suction cups are as follows:

- It has a big compliance, which increases the range of error of the manipulator's moving control and at the same time reduces the sensing cost.
- A bigger contact surface allows a better distribution of the pressure applied to the object.
- As the friction between the hand and object is big, it allows a steady grasp.
- It can grasp objects bigger than the hand itself.
- By regulating the power of suction pumps, allows to change the surface contact and the pressure applied to the object.

B. Suction Cups molding Process

The process for polyurethane suction cup fabrication is shown in Fig.5. The sucker cup has a two layer structure, the contact part with the object is made from very soft polyurethane and the bottom suction other parts were made

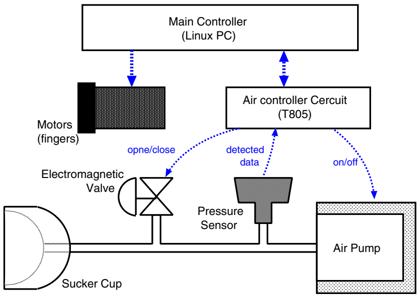


Fig. 7. Hand Mechanism System Structre.

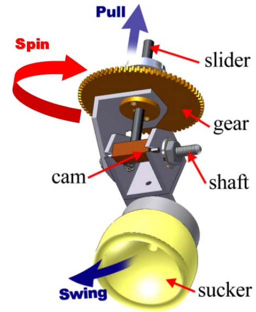


Fig. 8. The Finger Unit Attached the Urethane Sucker.

from a hard polyurethane. The inner radius of the mold is 36mm. In the bottom part of the mold there is an orifice for a 4mm tube that connects the suction cup with the suction pump.

C. Suction and Releasing

Fig.6(a) shows the diaphragm pump used as actuator connected to the suction cups. The actuator is a 12V pump with a flow quantity of $5l/min$, and a decompression of $250mmHg$. When this pump suctions air, it can produce a maximum aspiration force of 30N.

The diaphragm pump has the characteristic that after absorbing air, when stopped, it can maintain a constant pressure on the suction cups avoiding air to escape. Consequently, after the object has been grasped using the diaphragm suction pump, in order to liberate the constant pressure between the suction cups and the object and release it, electromagnetic valves were placed in one suction of the tubes (Fig. 6(b)). This electromagnetic valves are usually closed, however, when it is necessary to release the object, the valves are opened releasing the pressure generated by the diaphragm pumps.

Until now, the grasping and releasing mechanism has been explained. Now as measuring the pressure between suction cups and object is necessary for stable object grasping, we use a pressure semiconductor sensor (ADP1101). This sensor is a semiconductor strain gauge, which can measure air pressure with a high degree of accuracy and a linear output. The system structure is illustrated in Fig.7.

D. Pressure Restrictions

Special attention has to be paid when grasping soft objects. If there is an excessive use of suction force and the load the suction cups or the soft object can bear is over passed, one of the two elements can suffer deformations and be damaged. To avoid this, observation of air pressure sensor measurements is necessary. If a previously determined pressure value is over passed, then suction pumps are temporarily stopped.

In addition, attraction force between suction cup and object is proportional to the contact area between the two bodies. When the object is suctioned deeply into the cup, the contact area decreases reducing attraction force. so, when attraction force decreases, the object naturally separates from the suntion cup bottom increasing contact area and incrementing attraction force. This phenomenon allow our system to steadily suctioning and grasping objects.

E. Structure of the hand with suction cups

In order to be able of grasping a wide variety of different objects, we developed a hand unit with multiple mobile parts with four suction cups. Having multiple mobile parts allows the hand to adapt itself to grab many kinds of different shapes such as spherical, cylindrical, rectangular and ellipsoidal. Moreover, even objects which cannot be suctioned can be grabbed, using the soft suction cups fingers properties to adapt themselves to the object and grab it.

An outline of one finger with a suction cup at the end is showed in Fig. 8. As it can be seen, in the center there is a slider which if pulled or pushed generates a swinging movement of the fingers. Also, in this mechanism, when the gear is rotated, the finger with suction cup rotates.

The hand unit has four polyurethane suction cups and is a 2 degree of freedom mechanism. Each suction cup has its own pump and air pressure sensor. Figure 9 shows the structure and mobility of our mechanical hand unit.

One degree of freedom is defined by the rotation movement in different directions of the four suction cups. Each finger has a gear connected to the gears of the two fingers next to it. As all four fingers are controlled by a single motor, their rotation movement is synchronous. This synchronous rotational movement of the fingers and its arrangement is shown on Fig. 9(a).

The second degree of freedom is defined by the swing down movement of the four suction cups. All four fingers are synchronously controlled by a single motor connected to the slider. This movement and the arrangement of the fingers is presented in Fig. 9(b). As can be seen in this figure the first configuration is for suctioning plane objects and the last one for spherical ones. This hand unit can adapt itself for grabbing objects of different shapes.

With the combination of these two degrees of freedom, the arm unit can: (1) Rearrange the position of suction cups to the object shape, spherical/cylindrical/rectangular/ellipsoidal and suction it, or

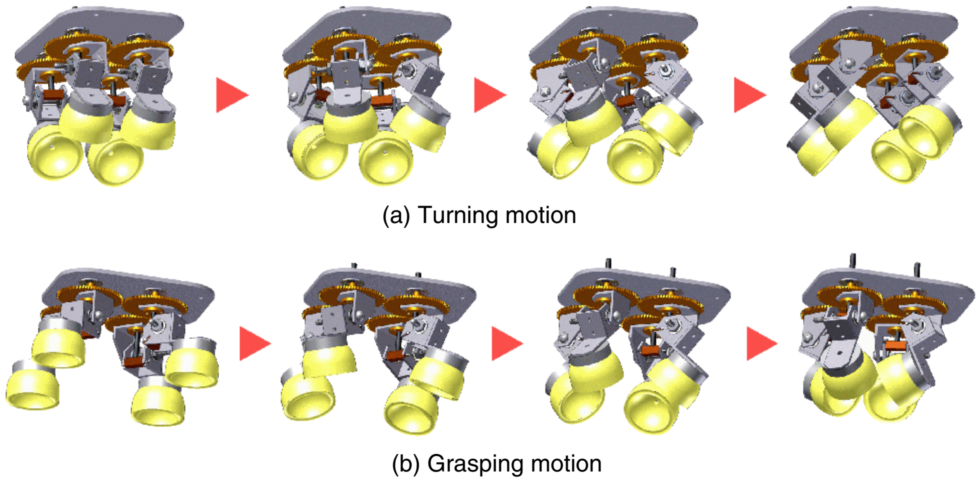


Fig. 9. Motion of the Hand Mechanism.

(2)move the four fingers of the hand to grasp the object. Therefore, if the manipulator can approach to the proximity of the target object, the hand can steadily suction and grasp it.

F. Hand Controller

To change the formation of sucker cups, two small servo motors(Robotis, Dynamixel Dx-117) are used as actuators. The target position and the passing speed of these motors can be controlled directly from linux PC. Moreover, the pressure control of the suction pumps is done with a special control board.

IV. Verification Experiment

A. Experimental System

To confirm the effectiveness of the developed hand, we mounted it on the tip of a mobile manipulator, and tested it grasping various real objects. The hand is given the position and shape of the target object in advance.

It is indispensable to recognize the three-dimensional shape of the object body to hold it. In this system, a small laser range finder that can observe the three-dimensional shape of the object is used. This sensor is much more smaller than previously available sensors, and can easily be mounted on the minion of the hand. This sensor is fixed to the robot hand as shown in Fig. 10. The object of interest is scanned from the upper part of the showcase, and the shape data is acquired. Figure 11 shows an example of the shape of an apple measured using this sensor. The shape of the object is approximated to globe by the least square method, and posture of the hand is calculated.

The procedure of the experiment is shown below:

1) The hand is moved to the top of the target object.
2) The direction of the sucker cups are changed according to the shape of the object.
3) The pumps starts suctioning.

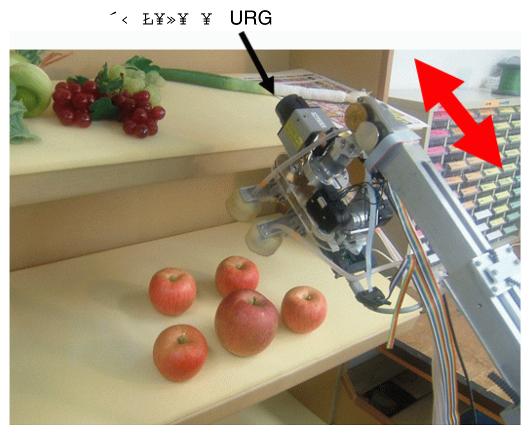


Fig. 10. Developed Hand and Small LRF.

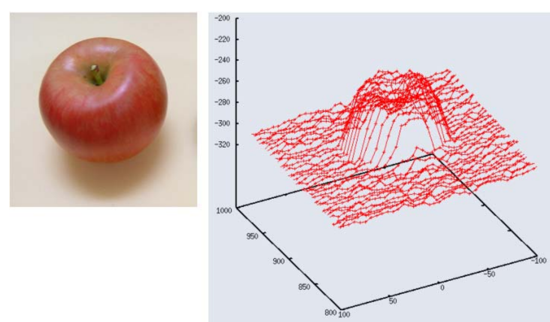


Fig. 11. An Example of the Shape of an Apple.

4) The suction cups are slowly brought close to the object.
5) When one or more suction cups stick fast, it means that the grasp is successful.

A picture of the process of object grabbing is shown in Fig.12.

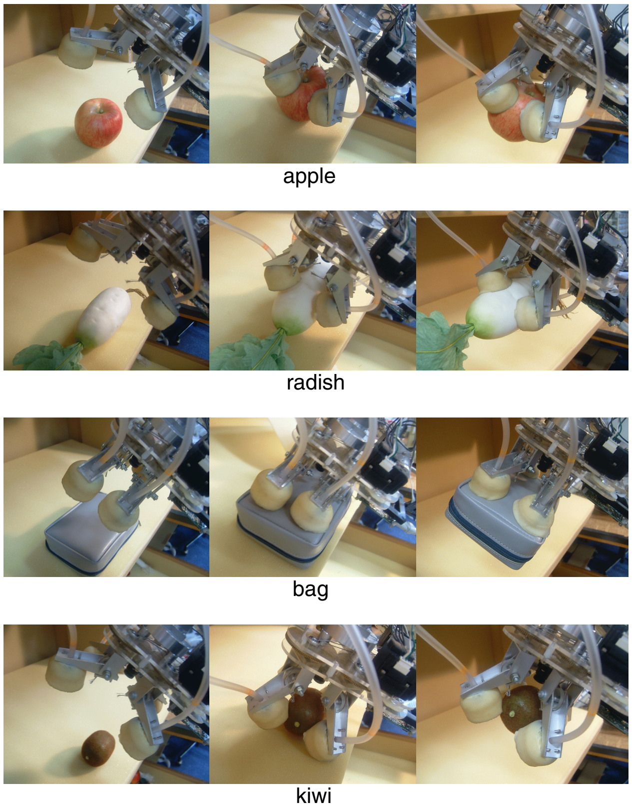


Fig. 12. Objects Grasping Scenes.

B. Experimental Results

As a result of experiments, our manipulator was able to grasp almost all the selected objects. The suctioning status is shown in table II. In the case of box grasping, the experiment was successful. Due to its flat plane surface, the suction cups were placed on the top of it and with just the suction force of the pumps, it could be grasped. Round fruits such as apples or oranges could be picked up. Moreover, a long and slender vegetable such as a Japanese radish was able to be gripped.

Even with a relative position error margin of 15mm between manipulator and object, the hand mechanism could grip the object because when it closes, it pulls the object to its center. When grabbing irregular objects, it is difficult that the four suction cups can stick on it. However, one suction cup alone is able of lifting up a 0.5Kg load which is enough to lift usual perishable foods. In the case of apples and radishes, despite they have irregular shapes, once the suction cup stuck on them, they are picked up. However, in the case of fruits such as peaches covered with cilia (fine hairs), the suctioning was unstable.

This hand could not suction small objects such as kiwis, grapes and bananas. However, these goods could be grasped using the suction cups as soft fingers as shown in Fig. 12.

TABLE II

SUCTIONING STATUS OF REPRESENTATIVE SHOPPING OBJECTS.

Suctioned Objects	Apple, Orange, Peach,Tomato, Poires, Radish, Turnip, Eggplant, Bottle, Can, CD and Packed Foods.
Not suctioned objects	Kiwi, Grape, Banana, Book

V. CONCLUSION

In this paper, the proposed and constructed remote shopping robot system which has soft suction cups on the robot hand enabling it to grasp objects of different textures, shapes and weights was explained. The constructed hand consists of a system of only two degrees of freedom and is made of soft polyurethane suction cups. Despite the simplicity of our developed mechanism, experimental results proved that it could steadily grab objects with irregular shapes, textures and softness.

On the experiments presented on this paper, the object shape and curvature was known in advance. However, as future work, the authors plan to use the sensors placed on the hand for measuring the area and autonomously realize an adequate grasp from the selected object without any previous information. Taking as base the teleoperation interface developed in the “Book Browsing System Teleoperated via the Internet” authors implemented and constructed a remote shopping robot system which proves useful for human’s daily life support, especially for elderly and disabled persons.

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