

Disabled people assistance by a semiautonomous robotic system

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ABSTRACT

The primary objective of rehabilitation robotics is to fully or partly restore the disabled user's manipulative function by placing a robot arm between the user and the environment.

Our assistance system is composed of a control-command station for the disabled person and a manipulator arm mounted on a mobile robot. The main constraints of such peculiar systems are flexibility to be adapted to each user's capabilities, modularity to make the system versatile, reliability and cost to be affordable. A good compromise between those constraints is reached by a semiautonomous system in which robotics give the system as autonomy as possible and man-machine co-operation palliates both the deficiencies of the person due to the handicap and the limits of the machine.

The approach consists to determine the autonomy level reachable with an affordable machine using robotic solutions. Taking into account both the capabilities of the person and the robot, the man-machine co-operation defines the best task sharing to do the person a service such as "go and see" or "fetch and bring an object back".

The man machine interface for the perception and the control of the semiautonomous robotic system is based on new remote control approaches: virtual reality or enhanced reality. Enhanced and virtual reality techniques aims at immersing the user into the site where the mission is in progress. The increasing interest of video game firms for the immersion idea contributes to reduce the cost of such technology. An important feature of the MMI is the use of virtual fixtures as perceptual overlays to enhance human operator performances during teleoperating a robot. Virtual fixtures improve accuracy and time for performing a task and may reduce both human operator mental processing and stress.

Keywords : Disabled people assistance, Virtual Reality, Telerobotic, Man Machine Interface.

1. INTRODUCTION

Today's life difficulties of disabled people are more and more taken into account for accessibility, integration into the job market, medical assistance... The primary objective of rehabilitation robotics has been to fully or partly restore the disabled user's manipulative function by placing a robot arm between the user and the environment. Assistance systems currently available on the market require heavy adaptation of the house by means of special building design. On the contrary, mobile robots represent an attractive solution as they could minimize the required degree of adaptation of the house. The success of rehabilitation robotics depends on the respect of two key conditions. The first one is the cost of the assistance. It seems important to admit the robot cannot be completely autonomous. The limitation of the system complexity involves limited perception and computing means. In that case, man-machine co-operation permits to balance machine deficiencies by perception, decision, and to a minor extent action means of the person.

The second condition concerns the very principle of aid.

The system must not "do for" but compensate the action deficiency of disabled people [3]. Disabled person has to participate in the task performed by the system. That also implies to take into account a man-machine co-operation.

The person intervention degree during the task progress is variable. It can begin by taking part in perception or decision functions until a remote control of the system. The partial autonomy of the system completes the field of person abilities either to palliate deficiency due to the handicap or to realize tedious actions.

Among the main today's life functions listed by WHO (World Health Organization), several actions like carrying, grasping, picking up, moving, are "robotisable". Different kinds of project have been presented in [12]. First ones are workstation-based systems. A table-mounted robot arm works in an environment where the position of different objects are known by the system. HANDY1 [16] and DeVAR [17] are two examples. Second kinds of projects are stand-alone manipulator systems where the object position is not known. This allows more flexibility but needs sensors for the environment perception: Tou system [2] and ISAC [13]. Other solutions are wheelchair-based systems. The most well known system is MANUS [10]. Mobile robot systems are also used: WALKY [15], Health Care Robot [5], URMAD [4] and MOVAID [6]. The last kind of systems proposed are collaborative robotic aid systems where multiple robots perform several tasks for the user [11].

The project ARPH is developed in collaboration with AFM (French Association against Myopathies). It belongs to the mobile robot system category. A manipulator arm is mounted on a mobile robot. The mission consists in carrying and manipulating an object in a partially known environment such as a flat. The flat plan is known but table, chairs are not modeled and are considered as obstacles. *The paper focuses on the displacement inside a partly known environment.* First section describes the assistance system and the three main control modes. Second section develops the three functions needed for the displacement of the robot: planning, navigation and localization. The third section presents the Man-Machine Interface based on virtual and enhanced reality techniques.

2. ASSISTANCE SYSTEM ARCHITECTURE

ARPH (Assistance Robotics to Handicapped Person) system is composed of a control station and a manipulator arm mounted on a mobile robot (Figure 1). The mission is divided into two steps: move to the target and then manipulate object.

Mobile robot

In order to "not cost too much" the robot has limited and poor perception means, an odometer and an ultrasonic ring. Odometer gives the position and the orientation versus angular rotation of the wheels. The method is simple and cost effective but presents a systematic error which depends on the distance and a non-systematic error mainly due to wheel spin and sliding. The ultrasonic ring measures the distance between the robot and obstacles all around the robot. Generally ultrasonic technology is limited to proximity because of poor measurement characteristics and a high rate of erroneous measures. Algorithms must operate in those difficult conditions.

The camera mounted on a pan and tilt base is a commercial device dedicated to general surveillance applications. It presents a smart feature: the auto-tracking mode. Camera automatically follows the movement of an object. Camera plays two roles: i) a perception device which provides video feedback during the robot displacement, ii) a control device which provides robot the direction to follow or the object to reach or follow (auto-tracking mode of the camera).

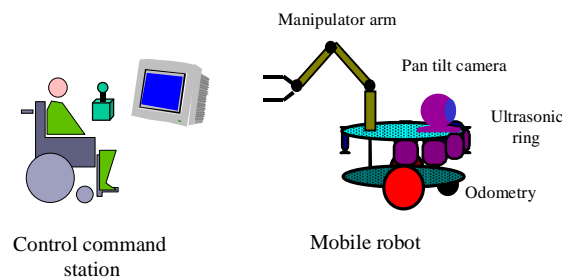


Figure 1 : System architecture.

Control station

The Control station is composed of :

- i) control devices well adapted to the handicap of the disabled person
- ii) a screen which displays different types of information via enhanced reality techniques, such as video image of what is seen by the robot, virtual aids superimposed onto the video image, robot position on a 2D flat plan, virtual camera point of view, robot operating indicators...

Control Modes

There are three main mode types to control of the robot displacement: automatic , manual and a so called "mixed" mode. In the automatic mode , the person points out the destination on a 2D flat plan displayed on a screen. The robot automatically reaches the destination avoiding obstacles. In the manual mode, the person teleoperates the robot "manually" via a joystick or any control device. In "mixed" modes – we can build different combination - the control of the degrees of freedom of the machine is shared between man and machine. For instance, the person points out a direction or an interesting object on the video image provided by the camera. The user defines the goal driving the tilt and pan base of the camera. The auto-tracking function of the camera is used to pilot the robot to the goal. The manual mode can become a "mixed" mode if the user is assisted by the robot to avoid obstacles automatically. In order to realize a mission the person builds strategies based on a succession of control modes.

3. MOBILE ROBOT AUTONOMY

A displacement of a mobile robot requires three functions: planning, navigation and localization. Planning determines the best path to go from one point to another. Navigation ensures the robot follows the planned path avoiding obstacles. Localization gives the position and the orientation of the robot in the flat at any time. The description of control modes has shown that some tasks can be performed by using both different skills of user and robot. It is important the person understands robot behaviors in those cases. A natural approach is to give human-like behaviors to robot functions needed for the robot move.

Planning

The problem is to reach a goal. A person uses different strategies of planning. For a far destination a plan is used to find a way to go from one point to another. If the destination is within sight the person reaches the interest point following the direction he looks at. In our application the system has the same human behavior. In a classical robotic approach the robot computes a path through the flat to reach the goal using the known flat plan [1].

The second way to plan a trajectory is to use the camera in auto tracking mode. The person points out a goal with the camera. The goal must be within sight of the camera. The camera tracks the goal, for example object, automatically. The robot moves in the direction pointed out by the camera. This is a human like behavior. The object is considered as a target which can be mobile. The remaining issue is only to avoid obstacles on the path. This is a navigation problem.

Navigation

The problem is to follow the planned trajectory. A person divides navigation into two behaviors: goal-seeking and obstacle avoidance. A fusion of the two behaviors is performed during the displacement. The orientation of the head defines the direction for goal seeking. If an obstacle is on the way, the trajectory is deviated locally to avoid it. Usually people try to walk as far as possible from obstacles, for example in the middle of corridors.

Automatic navigation imitates the human behavior making the fusion of goal-seeking and obstacle avoidance. For goal-seeking direction is defined by relative positions of the robot and the goal. If a non modeled obstacle stands on the robot path, it must be avoided. Ultrasonic sensors detect these obstacles and fuzzy logic manages obstacle avoidance. As human like behavior, the robot goes in the middle of the free space.

The fusion of two behaviors takes into account only obstacle avoidance when an obstacle is near the robot. When the distance between obstacles and the robot grows up, goal-seeking behavior takes more importance in the robot command. Figure shows a trajectory followed by the robot with a non modeled obstacle in the room. All these results are detailed in [7].

Localization

Cost effective constraint due to the field of application implies the use of a poor perception system as seen before. Three levels of behavior are used in the localization function. They are well suited to possible situations. Each level uses specific algorithms, little sensitive to high rate of wrong measurements and to presence of obstacles (by definition not modeled).

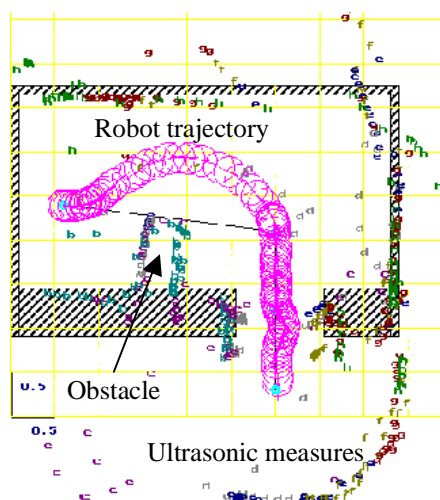


Figure 2 : Fusion of two behaviour, obstacle avoiding and goal-seeking for robot navigation.

In the first level, the robot knows approximately its position and orientation. They are updated on-line by the odometer under the control of the ultrasonic sensors. When the robot

notice it is lost (the decision can be taken in collaboration with the human operator), the off-line localization level is activated. The third behavior level corresponds to the human intervention. The supervisor analyses the situation thanks to two kinds of information: sensor measurements displayed on a 2D plan of the environment and an indicator of the quality of the position given by the algorithm running on the mobile base.

On-line localization system is completely presented in [8]. Off-line localization uses human like behavior techniques. The problem is to find the robot position in a partially known environment. Dead-reckoning system (odometry) is supposed wrong and provides erroneous data. In that case, off-line localization aims at initializing odometry correctly. Only ultrasonic measures are available. As people lost in a town, the robot looks for landmarks in the room. If some landmarks are recognized, the robot is able to compute its location with the help of the flat plan. The main problem is the landmark recognition. Two kinds of landmark are interesting in an indoor environment: walls and doors. Walls are detected with classical techniques (ultrasonic image segmentation). Door detection is a typical pattern recognition problem. Literature proposes several approaches to solve the classification problem particularly neural networks and statistical methods. It depends on the application constraints and on the a priori knowledge on the input data and physical phenomena. Neural networks are more effective and economic than the statistical methods when natural data are not describable by low-order statistical parameters, their distribution are non-Gaussian, their statistic are non stationary and the functional relations between natural data elements are non-linear [14]. The results, detailed in [9], shows the efficiency of neural networks methods in comparison with two statistical ones, Linear Discriminant Analysis, Quadratic Discriminant Analysis.

4. Man Machine Interface (MMI)

Following the control mode, the man machine interface assists the person during the progress of the mission for :

- supervision in automatic mode.
- perception assistance in manual mode.
- sharing of degrees of freedom of the robot in mixed mode.

Virtual Reality (VR) is intended to assist both human operator and robot in teleoperation and telerobotic tasks. VR brings lots of software and hardware tools [24]. These tools are useful to perform teleoperation tasks. Augmented Reality (AR) is another approach obtained by superimposing on the on line video feedback some graphics related to a task. Some systems apply AR [23] [22]. In this paper, we present a system based on both VR and AR.

Description

ARIT (Augmented Reality Interface for Telerobotic) is aimed at providing Human Operator (HO) the possibility of achieving complex telerobotic operations in remote environments [18]. What matters is to supply an interface to the HO which is in a supervisory/control situation. Robot teleoperation is a difficult task. So, HO needs an assistance and a friendly MMI. A first experiment of robot telemanipulation shows that HO reacts faster and better when he is given three kinds of visual assistance [19] devoted to :

- Environment perception.
- Robot control.
- Robot supervision .

Three fourths of the display is devoted to the perception of the telerobotic environment. The HO perceives, on the one hand, the remote environment through a real view of the remote scene (see window up to the left in figure 3), and on the other hand, he can perceive virtual scenes corresponding to several virtual view points (figure 3). In order to help the HO to control the robot and achieve a navigation task, an interactive assistance is given to him. It is the interactive intervention of Virtual Fixtures (VF) in the operation area [19]. These VFs appear and disappear as the mobile robot comes close or gets away from the door, for instance. The type of the virtual fixture appears according to the kind of tasks that had already been achieved.

The MMI is composed of three windows and one control panel : - The top left window concerns the on line video feedback of the real robot on which graphical display can be overlaid. - The bottom left window represents the virtual point of view of the real camera mounted on the robot. - The top right window displays a global point of view of the virtual scene. - The control panel is composed of camera and robot controls...

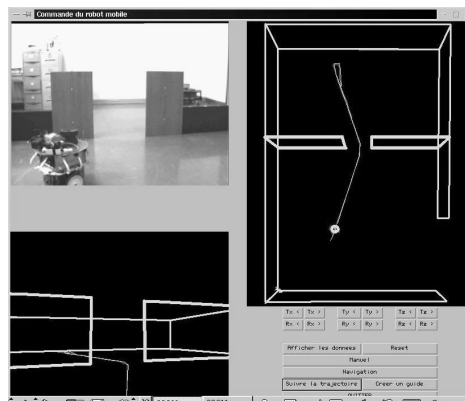


Figure 3. : The ARIT Display

In the next section virtual fixtures concept is presented.

Virtual Fixtures

Concepts and approaches : The work proposed by Rosenberg [20] and by Sayers [21], explores the design and the implementation of computer generated entities known as virtual fixtures. To highlight this concept Rosenberg gives the following example, "When asking one to draw a straight line segment in the real world, human performance can be greatly enhanced by using a simple tool such as a ruler. The use of a ruler reduces the amount of mental processing required to perform the task, and increases operator's performance and ability during the drawing process. Most of all this allows one to draw a correct line segment that if no ruler had been used". It is easy to note that without a ruler, line segment drawing is a manual task which requires a continuous visual concentration and a high hand/eye coordination. In the same way, one can easily imagine that for many tasks, simple tools such as a ruler, can so greatly enhance the performance, it seems that similar perceptual overlays could be developed to enhance performance of complex three dimensional tasks in a telerobotic environment.

Computer generated fixtures, when overlaid onto the workspace video image, interact only with the user and not with the workspace itself. Thus according to Rosenberg "fixtures can occupy the same physical space as objects in the workspace, imposing no constraints upon the placement or the configuration of fixtures". Moreover, such computer generated fixtures has no mass, no physical or mechanical constraints.

Virtual fixtures formalism : The flexibility, that offers a synthetic computer generated fixtures, constitutes certainly a considerable advantage. Yet this flexibility constitutes a drawback somehow since it is difficult to derive a unified approach. Because of their task-dependency properties one can imagine easily the huge possible variety of fixtures. This makes the design of virtual fixture interface a difficult problem. Table 1 attempts to give a unified formalism to the virtual fixtures metaphor and names it passive/active virtual guide. Virtual guides are split into three categories: pure operator assistance, pure remote robot control and, operator and robot shared assistance .

Virtual fixture leads then to a unified structure composed of the following fields which can be operational according to the nature and the context related to the use of the associated virtual fixtures:

Name	Identify the fixture
Type	Simple or complex and active or passive. If complex, it contains the different links to the combined fixtures
Referential	Contains position and orientation of the fixture on X, Y and Z axis
Attachment	Static or dynamic and contains the coordinates of the virtual point or object
Effect zone	Contains the equation of the volumetric form, surface or other any known geometric shape may be associated to the VF
Pre-condition	Contains the activation condition of fixture
Fixture function	Contains a set of actions to be performed inside the virtual guide either by the robot, by the HO or by both actors
Post-condition	Contains the inactivation condition of fixture

Table 1 : *Virtual fixtures structure*

The active VF is a graphic display which improves the robot control. This kind of VF acts on the robot motion control. This concept has been implemented in the control telerobotic architecture defined in ARIT system.

Simple virtual fixtures : A simple virtual fixture is represented by a simple geometric primitive. It can be a line segment, a plan or any arbitrary volume (figure 4). This "canonical" fixture is generally used for achieving a simple task such as follow a line segment path, obstacle avoidance (repulsive field within virtual fixture) or reach an object in the virtual environment (attractive field within virtual fixture).

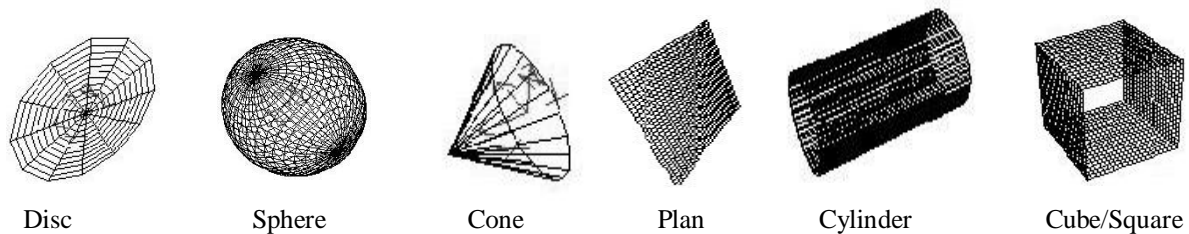


Figure 4 : *Simple Virtual Fixtures.*

Complex virtual fixtures : A complex virtual fixture is composed with several canonical fixtures (a set of line segments defining a path trajectory, a set of plans, or a set of any unified shapes of object, as showing in figure 5, 6, 7). The ARIT system allows HO to create different simple fixtures and gives him the possibility to make a link between fixtures to complete a complex fixture. This type of fixture is generally used to achieve a complex telemanipulation task or to fulfill complex environment constraints such as following any trajectory path or assembling/disassembling tasks, etc.

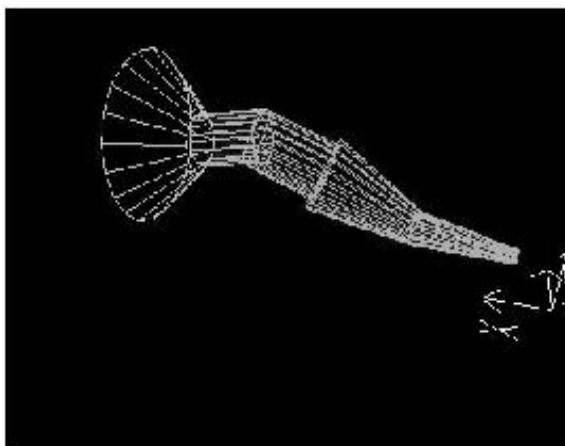


Figure 5 : *Complex Virtual Fixture to reach a target with a robot end tool*

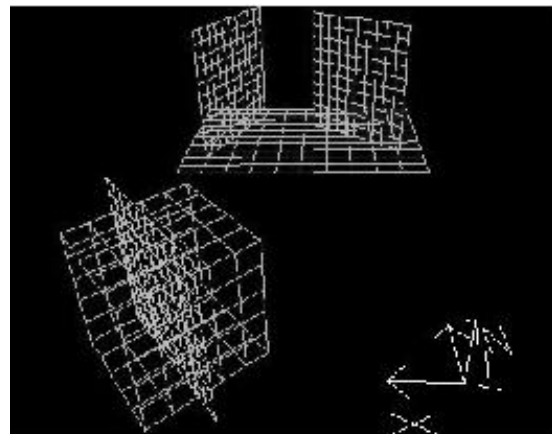


Figure 6 : *Complex Virtual Fixture for Delimiting the workspace between two robots in cooperation*

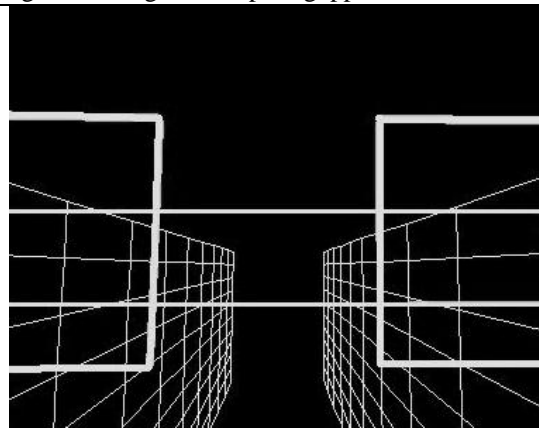


Figure 7 : *Complex Virtual Fixture (two parallel plans) to cross the door by the mobile robot.*

Virtual fixtures for a navigation task : The robot described in section 2 is used to perform navigation tasks in a partly known environment. One of the main difficulties of the robot is to go through the door. So the ARIT system is intended to assist the mobile robot to cross the door, thanks to the use of virtual fixtures as shown in figure 3.

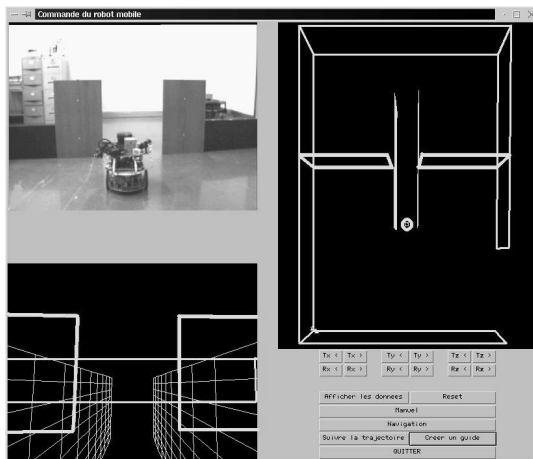


Figure 8 : *ARIT display with complex virtual fixture to cross the door*

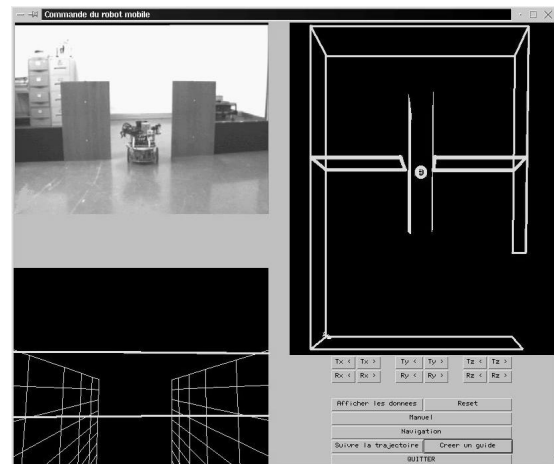


Figure 9 : *The virtual and real robot are going to cross the door*

A first example for the use of virtual fixtures is given as a path intended to guide the mobile robot to cross the door as shown in figure 3.

A second example of virtual fixture to assist the mobile robot to go through the door is represented in figures 8 and 9. These VFs are applied in the mixed mode defined in the section 2. The second VF is active because it constraints the lateral robot motion.

5. CONCLUSION AND PERSPECTIVES

At term, ARPH system aims at restoring manipulative functions of disabled people. Our assistance system is composed of a control-command station and a manipulator arm mounted on a mobile robot. The paper focuses on the displacement of the robot in an indoor environment. In order to respect the constraints "not do for " and "not cost too much" a very close co-operation between user and robot must be put in place.

The person builds strategies to succeed a mission. A strategy can be seen as a succession of control modes which are of three types: automatic, manual and "mixed" mode. In a "mixed" mode the execution of a task is shared between man and machine. That requires a well suited co-operation based on a correct understanding of how the robot operates – robot human-like behaviors- and an efficient man machine interface which adopts virtual reality concepts such as fixtures and virtual cameras.

Following control modes, a task execution can be shared by the person and the robot. For example, the person pilots the robot direction manually and at the same time the robot avoids obstacles. For a well-suited co-operation the user must understand the robot behavior. The main functions: planning, navigation and localization, needed for the displacement of the robot, integrates human like behaviors. This approach makes the co-operation easier for the user. This co-operation is carried out thanks our Man Machine Interface ARIT

S. Otmane, E. Colle, M. Mallem, P. Hoppenot: "Disabled people assistance by a semiautonomous robotic system" - SCI'2000, Vol 3 - Virtual Engineering and Emergent Computing, pp.684-689, Orlando, Florida, USA, 23-26 July 2000. (Augmented Reality Interface for Telerobotics). An important feature of ARIT is the use of virtual fixtures. These graphics improve human operator perception of the remote scene and its ability to telecontrol the robot.

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