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Intelligent Ambience That Can Lead Robot's Actions

—System Design Concept and Experimental Evaluation of Intelligent Ambience—

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Abstract— **In order to execute multiple tasks in offices and houses, robots require a large amount of information. If each item that is part of the ambience is endowed with some intelligence, robots can simply change the state of the item as requested by the item itself. We refer to such an ambience as "intelligent ambience (IA)." This paper describes a constitution method for designing an IA. We constructed two IA models — one comprised a drawer and a mobile robot and the other comprised two types of doors and a drawer, a device developed specially for this IA, and a humanoid robot. We also verified the effectiveness of the IA experimentally.**

I. INTRODUCTION

In the future, we expect robots to carry out various tasks in our daily environment. This means that robots will have to be able to handle almost every object in the environment, such as doors, windows, furniture, and home electronics (Fig. 1). It is almost impossible to define all models of these objects and the related task information for a single robot. To overcome this problem, previous studies have proposed structuring methods for ambient intelligence [1] and interactive human-space design and intelligence [2]. Such ambient intelligence can enable robots to adopt ubiquitous computing technologies by using sensor network systems and radio-frequency identification (RFID) tags and thus acquire the information necessary for carrying out their tasks in offices and residences.

Some researches have endeavored to provide users, both humans and robots, with information about their surroundings by means of data gathered through a network of sensors embedded in those surroundings. For example, Sato et al. [3] proposed a robotic room that measures human actions using sensors and actuators arranged around the room and attempted to apply it in the field of medical welfare. Hashimoto et al. [4] networked ceiling cameras, special sensors, and computers arranged in a particular space and investigated an intelligent space that recognizes human gestures and promotes efficient robot control. Hasegawa et al. [5] suggested a robot town comprising robots with RFID tags, sensors, and street corner cameras arranged in both indoor and outdoor environments. Kodaka et al. [6] described a method for robot movement that employs an environmental map in a model room; in such cases, a large number of RFID tags are embedded in a distributed manner. Manandhar et al. [7] proposed a technology for a seamless positioning system using a GPS signal. They constructed an indoor messaging system (IMES) for mobile users with cellular phones. Further, some researches have focused on facilitating object recognition in a working space. For example, Kurabayashi et al. [8] proposed autonomous robotic systems that communicate with their environments via intelligent data carriers (IDCs). Shibata et al. [9] developed an intelligent mark and the associated recognition system for this mark in order to obtain information about the working space for service robots. Some researches have investigated the enabling of object manipulation using visual marks, RFID tags, and so on. Katsuki et al. [10] prepared a fixed manipulator handle for three objects that were occluded or were close to each other. The robot could select the suitable motion using the object information in 2D codes and signals from proximity sensors. Nagatani et al. [11] developed optical communication marks that allow mobile robots to recognize their environments and handle objects. They developed a mobile robot that could accurately recognize a target in the working space and grasp it. Thus, researchers have focused on a wide variety of approaches for building an "information-structured environment" through ingenuous designs for the robot's working space, the simplification of object recognition, and the facilitation of object manipulation.

In this paper, we propose a new constitution method in which it is not necessary to provide robots with information about all of the tasks in an environment. Further, the environments are consistently maintained at the ideal state. This research is distinct from many conceptual studies that require human beings to give commands to robots. In this study, the responsibility of assigning tasks to the robots is transferred from human beings to the environment itself. The objective of the present study is to design an environment that uses robots and maintains itself at the ideal state by endowing each ambient component with some intelligent features; these components include fixtures, furniture, home electronics, and so on by various manufacturers. Something similar occurs very often in the natural world. For example, consider the

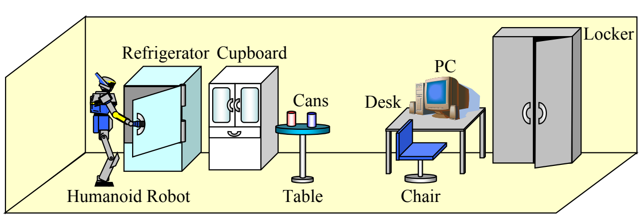

Fig. 1. Various Tasks Performed by Humans in Daily Lives

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relations between flowers and bees (Fig. 2). Since flowers cannot pollinate themselves, they possess nectariferous features, thereby attracting bees. Bees visit flowers for nectar, and in the process, aid the process of flower pollination. These insects have no knowledge of the fact that they are instrumental in the process of pollination. In other words, flowers manipulate bees in order to ensure pollination. If we can realize a structure along similar lines, it would be possible for the environment to exploit the habits of robots to make them carry out their assigned tasks.

Fig. 2. Symbiotic Relationship between Rape Blossoms and Bees

As an example of a robot endowed with "intelligence without representation," in the same way that a bee is without task information, Brooks et al. [12] proposed a robot that uses subsumption architecture to perform reflex actions. Maes [13] proposed a reactive planning system that uses a network based on the correlation between agents; such a network is called a behavior network. Pfifer et al. [14] explained that the issue of perception in the real world can be simplified by considering the interaction between the system and the environment. Ishiguro et al. [15] proposed a new method in which an autonomous mobile robot adopts a behavior arbitration mechanism for the environment that is based on the immune system of organisms; this method involves the use of only the information that the robot obtains from interactions with the environment. In these researches, the environment was merely observed, and the researchers did not assume that the environment actively engaged the robots.

In this research, we aimed to simplify the task information and construct an intelligent ambience (IA) in which we endow the environment with some intelligent features and maintain it in the desired state by its interaction with the robot. Herein, we describe a constitution method for designing an IA. We construct two IA models. One consists of a drawer and a mobile robot, whereas the other consists of two types of doors and a drawer, a device developed for the IA, and a humanoid robot. Further, we verify the effectiveness of the IA experimentally.

The rest of this paper is organized as follows. In Section II, we describe the method used to construct an intelligent ambience. In Section III, we describe an IA model that consists of a drawer and a mobile robot. In Section IV, we describe an IA model that consists of two types of doors and a drawer, a device developed for the IA, and a humanoid robot. Finally, in Section V, we conclude this paper.

II. INTELLIGENT AMBIENCE

A. Definition of Terms

In this research, we refer to the various objects that form a part of our daily lives and working environments as "ambient components." Ambient components have "states" expressed by a position/orientation in the environment, the operating states of moving parts (leaves), and restraint relations with respect to other ambient components. For each ambient component, there is an ideal state that the manufacturer, owner, and user desire. We call this state "the ideal state." The ideal state of each ambient component is defined by the manufacturer, owner, and user. Further, we call the state that is not the ideal state "the non-ideal state."

When an ambient component switches from the ideal state to the non-ideal state, it is returned to the ideal state by humans, robots, mechatronic systems, and so on. We call the entities that perform physical actions on ambient components as "performers." Depending on the situation, there are cases in which a user is the same as a performer and cases in which a user is different from a performer.

For example, when a user wants to pass through a door, the ideal state of the door as an ambient component is "open." The user becomes a performer and performs a physical action on the door (door-opening motion). After the user has passed through the door, the ideal state of the door as an ambient component is "closed." The user performs another physical action on the door (door-closing motion). In many cases related to doors, the performer is the same as the user. However, at an up-market hotel, since a doorkeeper may open/close the door to the building, the performer in this case is not the same as the user. Furthermore, when a performer consists of a mechatronic system such as an automatic door, the ambient component itself senses the ideal state and changes the state.

B. Proposed Intelligent Ambience

If each ambient component can autonomously recognize its own ideal state, the present state, and the difference between these states, and can ask a performer (human being, robot, mechatronic system, and so on) to carry out actions that cause it to transition to the ideal state, it will be possible to realize an environment in which each ambient component can autonomously change to the ideal state. In a previous study, we proposed a robot control method in which various robots acquired common task information from various target objects (ambient components) [16]. However, in this framework, the task information (the position and orientation of target objects, the open angle/distance of the target doors, and so on) was the same as the information that we provided to the robots conventionally. Each robot, which functioned as a performer, still acquired the task information from the environment on demand.

In this research, we designed a system in which the ambient components and robots do not transfer the task information but exhibit reactive behavior in response to certain stimuli. For example, when an ambient component itself recognizes the change in its own state, it emits a stimulus corresponding to a specific reactive behavior. When a robot recognizes the stimulus, it exhibits the particular reactive behavior for that stimulus. Thus, in this research, we propose the realization of simple interactions between the environment and robot and develop an IA in which each ambient component itself returns to the ideal state through such interactions [17].

C. Target Ambient Components

In this research, we focus on various ambient components such as doors, windows, furniture, and home electronics. These components do not change position after the initial setting but have leaves or moving parts. Most of the moving parts (leaves) have only one degree of freedom (DOF), as shown in Fig. 3.

Fig. 3. Examples of Target Objects

If a moving part has only 1 DOF, we can detect its state using a simple sensor. In addition, the physical action required to change the state of the moving part is simple.

Therefore, the objective of this research is determining the structure of an IA with respect to ambient components where each moving part (leaf) has 1 DOF.

D. Target Performer

We intend to use a robot rather than a human as a target performer.

E. Design of Ambient Components and Robot

In order to construct the IA, we design the state transition between an ambient component and a robot, as shown in Fig. 4.

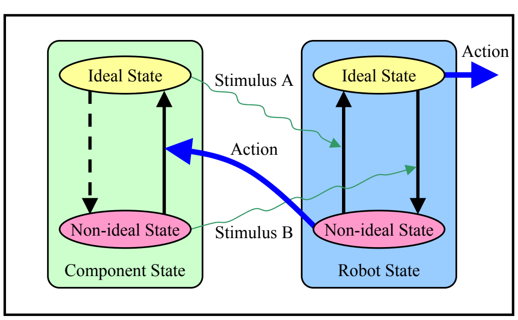


Fig. 4. State Transition Diagram

The ideal state of the ambient component is determined by the manufacturer of the component, the owner, or the user, depending on the situation. The state of the ambient component changes in response to physical actions (performer's actions). We design a component that emits a light stimulus or sound stimulus, depending on the specific situation.

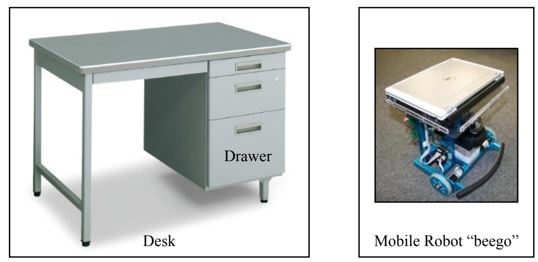
We also design the robot, which functions as a performer, such that it performs physical actions with relation to the ambient component depending on the specific situation and changes its own state on detection of an external stimulus.

Here, we must design the IA such that the ideal states of both the ambient component and the robot are realized at the same time.

III. CONSTITUTION EXAMPLE OF INTELLIGENT AMBIENCE BY DESK AND MOBILE ROBOT

A. Target Ambient Component and Robot

In this study, we used the drawer of an office desk as the target ambient component (Fig. 5 (a)). As the target performer, we selected a mobile robot, "beego [18]," which possesses a locomotion mechanism that allows it to move anywhere (Fig. 5 (b)).



(a) Ambient Components (b) Performer

Fig. 5. Target Ambient Component (Desk) and Target Performer (beego)

We designed a reactive behavior for both of them in accordance with the state and verified that the ambient component operated on the basis of their chain reaction to change it to the ideal state.

The desk had three drawers (350 [mm] in width), but we selected the lowest drawer, located between 150 and 450 [mm] from the floor, so that beego could push it at the 282 [mm] height as the moving part of the ambient component. This drawer can be drawn 400 [mm] from its closed state. A desk drawer is usually closed and is opened only when necessary. Therefore, at the outset, we specified that when the drawer was closed, it was in the ideal state, and when it was left open, it was in the non-ideal state. Transition from the non-ideal state to the ideal state could be implemented by a push on the front of the drawer. To detect whether the drawer was open or closed, we installed a microswitch on the drawer frame. This switch was in the "off" position when the drawer was closed and "on" when it was open. This enabled the ambient component to detect its open or closed state. In addition, we installed an infrared

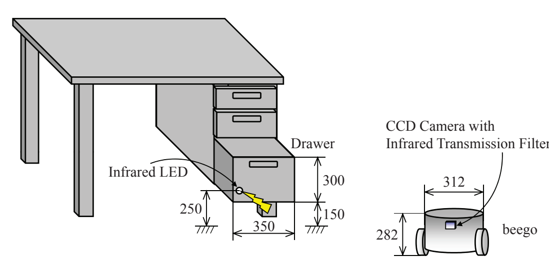


Fig. 6. Architecture of Sample System (Desk Drawer and beego)

LED on the front (at a height of 250 [mm]) of the drawer and connected the microswitch to it. The LED turned off when the drawer was closed (the drawer was in the ideal state) and turned on when the drawer was opened (the drawer was in the non-ideal state). The light emitted by this LED acted as a stimulus to the outside (Fig. 6). As described in the preceding section, the ideal state of the mobile robot was defined by the condition of no light from the infrared LED being detected, so that it could be established concurrently with the ideal state of the ambient component. The non-ideal state was defined by the condition of detecting the light from the infrared LED.

The mobile robot controlled its right and left wheels to generate any speed and to move at will. When it detected a stimulus from the ambient component (light from the infrared LED), the robot changed to the non-ideal state, turned so that the spot of LED light was at the center of its CCD camera, and moved toward the light. Thus, the mobile robot collided with the front of the drawer and continued pushing it until the LED light turned off.

B. Chain Reaction of State Transition and Reflex Action (Desk and beego)

We designed the IA such that the ambient component (drawer) and the performer (mobile robot) executed the state transition by the chain reaction of stimulus and actions, as shown in Fig. 7. The execution procedure is as follows:

1) When the drawer is closed (the ambient component is in the ideal state), its infrared LED is off. When the mobile robot does not detect a stimulus (the performer is in the ideal state), it moves at random (Fig. 7 (a)).
2) If the drawer is left open by some physical action (the ambient component is in the non-ideal state) (Fig. 7 (b) 1), the infrared LED is turned on and emits an external stimulus (Fig. 7 (b) 2). When the robot detects the light stimulus from the infrared LED, it enters the non-ideal state (Fig. 7 (b) 3).
3) The robot advances toward the infrared LED and pushes the drawer (Fig. 7 (c) 4). At the moment when the drawer is closed, the drawer returns to the ideal state (Fig. 7 (c) 5).
4) When the drawer returns to the ideal state, it turns the infrared LED off (Fig. 7 (d) 6). When the robot cannot detect the light stimulus from the infrared LED, the robot returns to the ideal state (Fig. 7 (d) 7).

C. Experimental Evaluation of Intelligent Ambience by Desk and Mobile Robot

In this study, we investigated an IA using a drawer of an office desk as an ambient component and beego as the performer. We arranged for people to open the drawer by a target distance of approximately 0.15 [m]. We kept the drawer in the non-ideal state before starting the experiment. Fig. 8 shows photographs of the experiment. The mobile robot beego moved at random (Fig. 8 (1)(2)). The robot recognized the infrared LED as a stimulus from an ambient component (Fig. 8 (3)), advanced toward the infrared LED

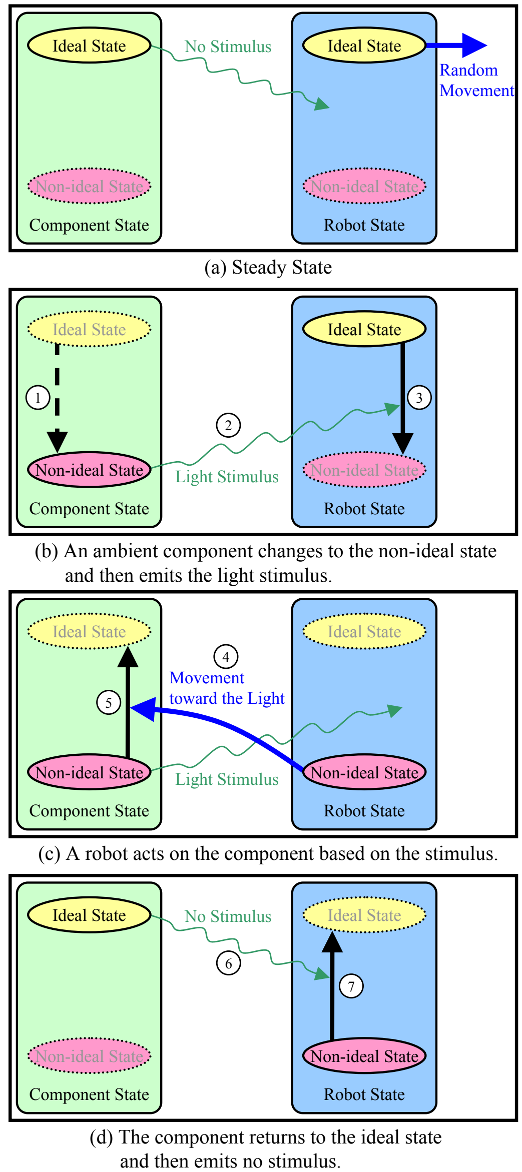


Fig. 7. State Transition Diagram and Chain Reaction (Desk and beego)

(Fig. 8 (4)(5)) and pushed the drawer (Fig. 8 (6)), stopped pushing the drawer when the infrared LED turned off (Fig. 8 (7)) (i.e., when the drawer was closed and returned to the ideal state), and then moved again at random (Fig. 8 (8)). Fig. 6 shows the sizes of the ambient component and the robot used in this experiment. From the experimental results, we confirmed that the IA could cause beego to change its state as requested by the environment itself.

In this experiment, there were some cases when the mobile robot did not quite detect the stimulus from the ambient component, because the robot moved at random in the ideal state. It thus took a long time for the ambient component to return to the ideal state. This is a problem, but there is also another essential problem: it would be difficult to apply this IA model to other ambient components because the robot used as the performer has only a movement function and the action enabling the transition to the ideal state was simply a push.

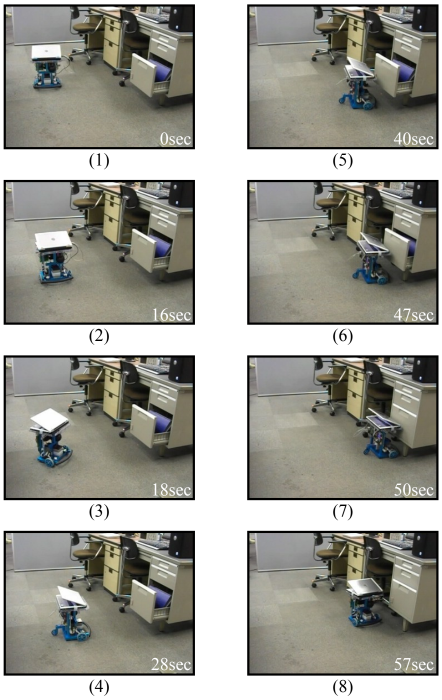


Fig. 8. Desk-Drawer-Closing Experiment Involving Mobile Robot beego

IV. CONSTITUTION EXAMPLE OF INTELLIGENT AMBIENCE BY DOORS AND HUMANOID ROBOT

A. Target Ambient Components and Robot

As another constitution example of the proposed intelligent ambience, we used (A) a drawer of a refrigerator, (B) a hinged door of the same refrigerator, and (C) a sliding door of a cabinet as the target ambient components (Fig. 9 (a)). As the target performer, we selected a humanoid robot, HRP-2 [19], which possesses both a locomotion mechanism that allows it to move anywhere and two manipulators to carry out physical interactions with ambient components (Fig. 9 (b)). HRP-2 is also equipped with a stereo-vision system.

Each door or drawer is normally closed and is only opened when necessary. Therefore, at the outset, we specified that when a door or drawer is closed, it is in the ideal state, and when it left open, it is in the non-ideal state. A sensor is required to detect the state of each component. The details are as follows:

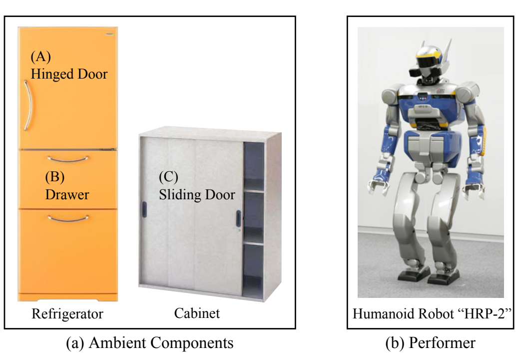


Fig. 9. Target Ambient Components (Doors) and Target Performer (HRP-2)

B. Endowing Ambient Components with Intelligence

1) Function Requirements: We can classify the actions of each leaf along three sets of directions (i.e., a total of six directions): back and forth, right and left, and top and bottom. The circular orbit of a hinged door is equivalent to an arrangement of short straight lines. To endow each ambient component with some intelligence, the following are necessary:

- Setting of the ideal state of the ambient component
- Detection of the state of the ambient component
- Functions to provide an external stimulus with action information (an operational point and a force direction) to return to the ideal state
- Structure that allows a performer (a robot) to manipulate each component

Therefore, we developed a device that satisfied the four abovementioned conditions.

2) Device developed for IA: Fig. 10 (A) shows the device developed for the IA. This device has two hollow balls (diameter: 40 [mm]) that emit light, the color of which can be changed by using a DIP rotary switch, as shown in Fig. 10 (B). We can set the ideal state using a tact switch and define the point of time at which the switch is pushed as the desired ideal state. The device can also detect the present state using a relay switch installed on the door (drawer) frame. We installed a handle on the device so that a performer could manipulate it back and forth and from side to side.

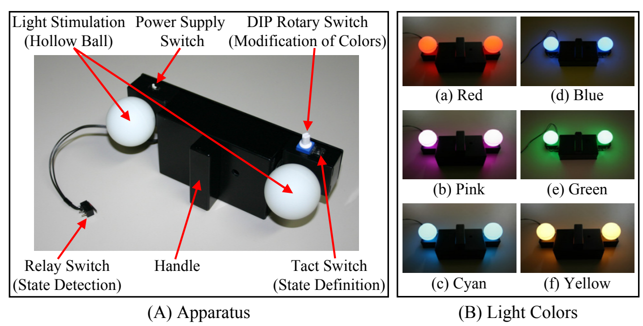


Fig. 10. Device developed for IA

This device can provide a manipulating point and the directions of the acting force to the performer. We set the manipulating point as the position between two lights (emitted from the centers of the hollow balls). The performer manipulates each ambient component with reference to this point. The target direction of the acting force is provided to the performer on the basis of the color of light emitted by the hollow balls. In this study, we set each direction according to six colors, as shown in Fig. 11.

HRP-2 can recognize the two light-emitting balls using its vision system. Prior to the experiment, we programmed HRP-2 to understand the meaning of the light stimulus, to approach the stimulus when it recognized the lights, and to perform an action corresponding to the stimulus.

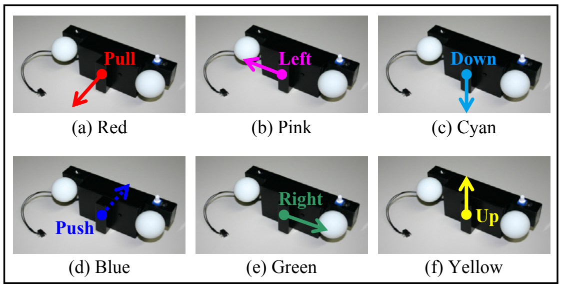


Fig. 11. Directions of Acting Force

C. Motion Generation by External Stimulus

We next describe the motion generated by HRP-2 when it recognizes the light stimulus from an ambient component. There are two phases when HRP-2 performs actions for the ambient component. One phase involves moving toward a target position and orientation that allows HRP-2 to manipulate the ambient component when HRP-2 is standing at a position and orientation that prevents this. The second phase is manipulating the ambient component when it is standing at a position and orientation that allows it to do so.

We first describe the motion generation of the moving phase. When HRP-2 recognizes two lights, it sets the midpoint of the two lights as the origin, the upward vertical direction as the positive z-axis direction, the left-pointing direction that includes the two lights as the positive y-axis direction, and it decides the object frame Σ_{obj} (Fig. 12). Then, HRP-2 sets the origin of Σ_{obj} as the point for the application of force and determines the direction that the force should act on the basis of the color of the two lights.

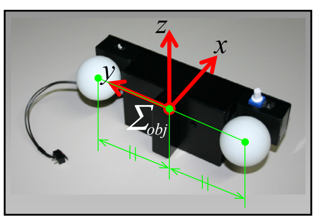


Fig. 12. Object Frame Determined by HRP-2

As shown in Fig. 11, we programmed HRP-2 beforehand with instructions about the relationship between the color of the light and the direction of the acting force. When the light was blue, we set the positive x-axis direction of the object frame, Σ_{obj}, as the direction of the acting force. When the light was green, we set the negative y-axis direction of Σ_{obj} as the direction of the acting force. HRP-2 determined the relative position and orientation from the device developed for the IA, which allowed it to perform the action by acquiring an operational point and a force direction. The operational position and orientation in the present robot frame $T^{robot\_init}_{robot\_goal}$ can be written as follows:

$$T^{robot\_init}_{robot\_goal} = T^{robot\_init}_{obj} \; T^{obj}_{robot\_goal} \tag{1}$$

The motion of HRP-2 is guided by means of information gathered by the internal sensor. This leads to errors by the robot in dead-reckoning of both the distance to be covered and the direction of movement. Therefore, after HRP-2 moves to the target position and orientation that allows it to manipulate the device developed for the IA, HRP-2 recalculates Σ_{obj} by again recognizing the light stimuli and reacquires the operational point and force direction.

Next, we describe the manipulation phase, during which HRP-2 stands at the target position and orientation and manipulates the device developed for the IA. HRP-2 raises its end-effector to a position of -0.10 [m] in the x direction of Σ_{obj} from the point of application of force on the ambient component and performs the necessary movement to bring its end-effector to the point of application of force. After the position and orientation of its end-effector correspond to the point of application of force, HRP-2 performs a physical action on the device developed for the IA by moving its end-effector in the force direction during visual feedback. In addition, HRP-2 performs the reactive behavior of stopping the manipulation in order to prevent itself from falling down when an external stimulus force greater than a constant value acts on the manipulator.

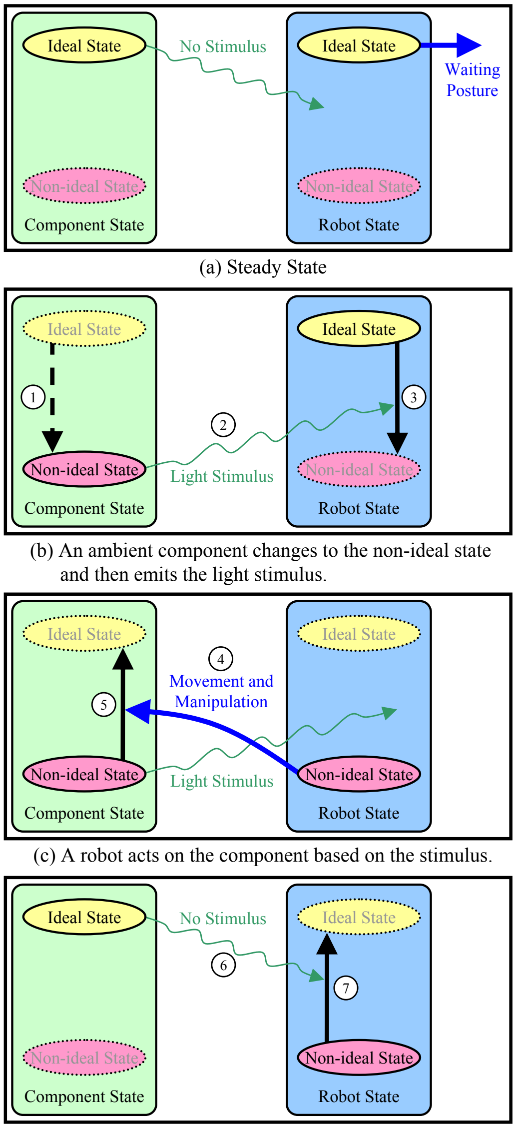
D. Chain Reaction of State Transition and Reflex Action (Each Component and HRP-2)

In this research, we designed the IA such that each ambient component (drawer, hinged door, and sliding door) and the performer (humanoid robot HRP-2) execute a state transition by a chain reaction of stimulus and actions, as shown in Fig. 13. This procedure is as follows:

1) When each door (drawer) is closed (each ambient component is in the ideal state), the device on the component turns off its lights. When the robot does not detect the light stimulus (the performer is in the ideal state), it waits at the initial position (Fig. 13 (a)).
2) If the door is left open by some physical action (the ambient component is in the non-ideal state) (Fig. 13 (b) 1), the abovementioned device emits an external stimulus (Fig. 13 (b) 2). When the robot detects the light stimulus from the device, it enters the non-ideal state (Fig. 13 (b) 3).
3) The robot moves toward the door (drawer) and manipulates the device on the basis of the color of the light (Fig. 13 (c) 4). When the door (drawer) is closed, it is again in the ideal state (Fig. 13 (c) 5).
4) When the door (drawer) returns to the ideal state, the device stops emitting light (Fig. 13 (d) 6). When the robot can no longer detect the light stimulus, it returns to the ideal state (Fig. 13 (d) 7).

E. Experimental Evaluation of Intelligent Ambience by Each Component and Humanoid Robot

In this study, we investigated the IA using two types of doors and a drawer as ambient components and HRP-2 as the performer. We arranged for people to open the drawer by a target distance of approximately 0.15 [m], to open the hinged door at a target angle of approximately 15 [deg], and to open the sliding door by approximately 0.10 [m]. Each case was designed to simulate an occurrence of a user who forgot to close the door (drawer) before leaving.



(a) Steady State

(b) An ambient component changes to the non-ideal state and then emits the light stimulus.

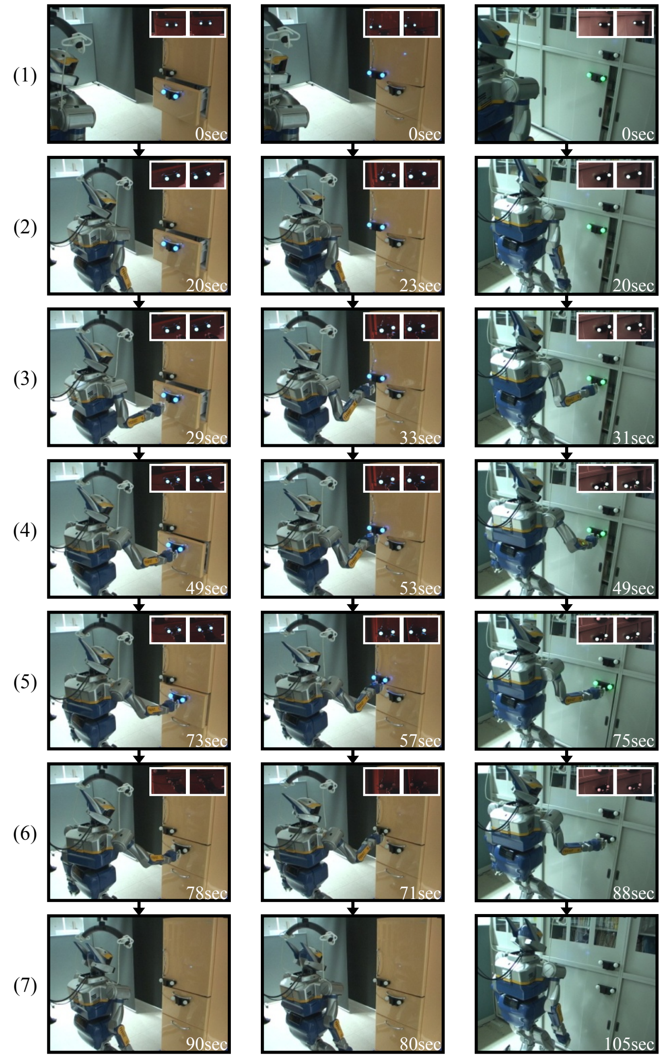
(c) A robot acts on the component based on the stimulus.

(d) The component returns to the ideal state and then emits no stimulus.

Fig. 13. State Transition Diagram and Chain Reaction (Each Component and HRP-2)

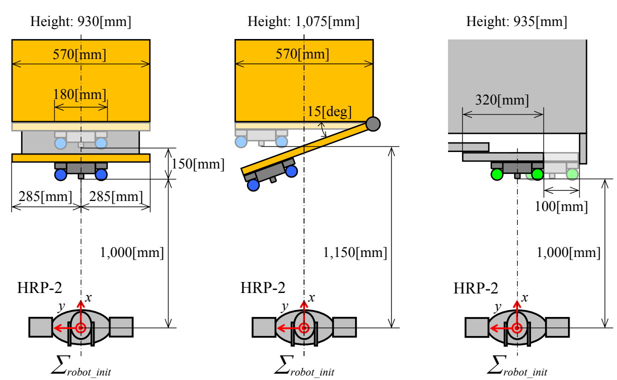
Fig. 14 shows photographs of the experiment for each component. Fig. 15 shows the positions of each ambient component and the robot in these experiments. We installed a device developed for the IA on each door (drawer) using double-faced tape and placed each component in the non-ideal state before starting the experiment. When HRP-2 detected the light stimulus from an ambient component (Fig. 14 (1)), it set the origin of Σ_{obj} as the point of application of force and determined the direction of the acting force from the color of the two lights. Then, HRP-2 calculated the target position and orientation $T^{robot\_init}_{robot\_goal}$ and moved there in order to manipulate the device (Fig. 14 (2)). After HRP-2 was standing at the target position and orientation, it recalculated Σ_{obj} by recognizing the light stimuli and reacquired the operational point and the force direction. Then, HRP-2 raised its right hand toward the device (Fig. 14 (3)), outstretched this hand toward the operational point using its visual feedback (Fig. 14 (4)), and manipulated the device on the basis of the color of the light using the visual feedback (Fig. 14 (5)). If the force acting on the hand exceeded a threshold set by us, HRP-2 stopped the motion. When the light turned off, HRP-2 stopped manipulating the device (Fig. 14 (6)) and returned to its initial posture (Fig. 14 (7)).

From the experimental results, we confirmed that the developed device for the IA could cause HRP-2 to change its state as requested by the environment itself. We showed that



(a) Drawer (b) Hinged Door (c) Sliding Door

Fig. 14. Door-Closing Experiments Involving Humanoid Robot HRP-2



(a) Drawer (b) Hinged Door (c) Sliding Door

Fig. 15. Settings for Each Component and HRP-2

HRP-2 could use its end-effector to perform a physical action on the point of application of force in a direction determined by the color of the two lights and could thus close a drawer or a hinged door by using the same color stimulus. We also showed that HRP-2 could be made to perform different actions simply by changing the color stimulus emitted by the ambient component and could thus close a sliding door. This device could be used to give a robot reflex action by changing the color of the light, thus allowing the robot to perform numerous tasks for ambient components, where each moving part (leaf) has 1 DOF. However, it will be necessary to introduce some kind of metrics to discuss the validity of the target standing positions, initial postures just before starting visual feedback, and reactive behaviors. A statistical analysis of the success rate for tasks will also be necessary. These are important problems for the future.

In this experiment, we did not make HRP-2 walk at random. We assumed that a humanoid robot will work when its owner (user) requires it to. However, if the robot did not stand in front of each ambient component, it could not detect the light stimulus. If each ambient component would use another stimulus such as sound, it might be able to call the robot. Actually, the device developed for IA has a built-in speaker and HRP-2 can detect the direction of speech using a microphone array system [20]. In the future, we intend to perform experiments in situations where the robot cannot find the light stimulus easily.

V. CONCLUSION

In this paper, we described a method for designing an intelligent ambience (IA). As ambient components, we focused on a drawer of an office desk, a drawer of a refrigerator, a hinged door of the same refrigerator, and a sliding door of a cabinet. Each moving part (leaf) of these components had a single degree of freedom. We presented two IA models. One comprised a desk drawer and a mobile robot, whereas the other comprised two types of doors and a drawer, a device developed specially for the IA, and the humanoid robot. Further, we verified the effectiveness of the IA experimentally.

The use of environmental structuralization will make it comparatively easy for us to expand our proposed method and construct an IA where the ideal state of an ambient component changes on the basis of signals emitted by other devices (stimuli from other devices) [21]. For example, we can consider a window as an ambient component. Even if the ideal state of the window is set as the state where the window is closed, the ambient component can be considered to undergo a transition to the non-ideal state when a temperature sensor detects a rise in the room temperature. We can construct the IA such that the ambient component emits an external stimulus indicating that the closed window is in the non-ideal state; the robot opens the window and thus controls the room temperature. Thus, even if the robot performs typical actions, we think that it is possible to increase the extensity of the tasks by actively changing the state of the ambient component.

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