# Task Modeling for Intelligent Service Robot using Hierarchical Task Analysis

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## ABSTRACT

This paper is about the research on task modeling for intelligent service robot. HTA(Hierarchical Task Analysis) method is applied for the analysis of three tasks which are selected according to the scenario of service robot, such as 'Fetch and carry' task, 'Greet the human' task and 'Read e-mail or schedule' task. The matters that require attention when HTA is applied to the robot's task analysis are stated and resultant task models are constructed in the consideration of them. Those models will be useful in the design stage of service robot and can be utilized as the guideline for finding problems in the task execution of service robots.

## 1. INTRODUCTION

Many people have dreamed about robots which can service humans in places where humans live their daily lives like house and office. Robotics technology has been developed ceaselessly and service robot is now considered as one of the most promising robot's applications that will make it possible to surpass industrial robots in both market size and social effect.  But, there is still wide difference between what the public want a service robot to do and what a service robot really can do. Therefore, there have been huge efforts to specify robot's task which are most helpful to humans and design the service robot for that purpose. For example, ISR(Intelligent Service Robot) of KTH is designed for fetch and carry task in a domestic setting [1,2] and KARES II of KAIST is designed for serving meal to the handicapped and helping movement of them [3].

Intelligent Robot Research Center is aiming at humanoid service robot in the domestic environment. In addition, information service using Internet is also considered as an important function of this service robot. For this purpose, robot's application scenario was made up and three tasks were selected. The first task is to recognize a human and greet him. The second task is to fetch and carry the object that a human want a robot to pass it to him. The final task is to read e-mail or schedule to humans when they request.

Those tasks are very simple for humans to do, but many things should be concerned carefully for robots to do those tasks at any conditions. Therefore those tasks should be carefully investigated in the design stage about what kinds of functions are necessary, how those functions should work and what is the main bottle-neck to complete those tasks. In this paper, task models that were derived using hierarchical task analysis method are presented and discussion about how to utilize those models in the development of service robot also is presented.

This paper is organized as follows. In chapter 2, short explanation about hierarchical task analysis method is presented. Task models for selected three tasks are presented and their utilization plan will be discussed in chapter 3.

## 2. HIERARCHICAL TASK ANALYSIS

Task analysis is the systematic methodology for investigating characteristics of tasks. It is originated from industrial engineering and widely utilized to analyze tasks which occur in various areas from large and complex plant to personal computer interface. HTA (Hierarchical Task Analysis) is one of various task analysis methods and was developed by John Annett and Keith Duncan [4,5]. It makes describing human activity and understanding the purpose of work possible in the domain of organization and system. The origin of HTA method is systematic thinking. All the systems have their purpose to work, and it is the 'Goal' corresponding to the purpose of systems in HTA. Therefore, goal directed behaviors can only be analyzed with HTA and it is assumed that operators behave with firm recognition of the goal. However, it is risky assumption, because system's own goal and the goal recognized by operators can be different. Therefore, operators' goal should be identified through task analysis process. However, HTA doesn't give an unquestionable truth about analyzed tasks. HTA gives a hypothesis formulation about a task and it reduces an oversight in analysis process. Therefore, the difference between two goals can be recognized after repetitive analysis and it can become to be consistent by various methods such as

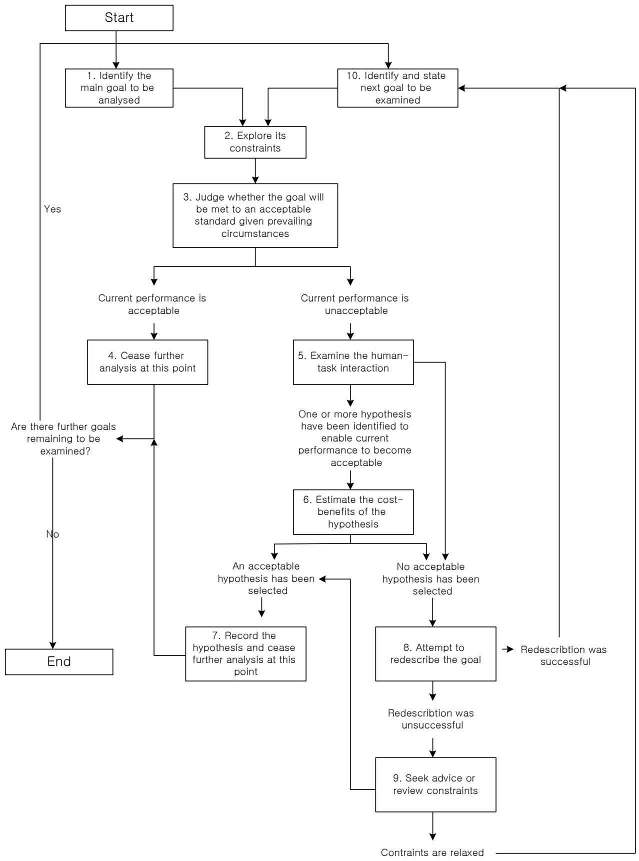


Fig. 1. HTA Framework
(Reprinted from J. Annett and K. Duncan's book)

training, management, and personal selection for operators to work with system correctly and easily.

Detailed process of hierarchical task analysis is shown in Fig. 1 and short explanation about each process will be given in the following. At first, the uppermost goal of the target task is identified (1). After that, given constraints to task is explored (2). There are two types of constraints. One is operating constraint and the other is design constraint. Operating constraints are the constraints given from external environment, such as illumination and noise. Design constraints are the constraints given from system administrator, the management or operators. Therefore, frequency of task, limit of cash and technological limit come under design constraints. Analyst judges whether the task should be analyzed further according to the performance of task accomplishing the identified goal under given constraints (3). In general, performance criterion is frequency of error and cost of replacing faults. If the performance doesn't meet the standard, it is necessary to hypothesize what is the source of performance degradation (5). A hypothesis can be derived by various analysis methods. We can find causes of errors by modeling operators' task execution as input, plan action and carry out action sequence. There are other methods such as referring similar tasks, making up check list about suspicious error sources and videotaping and analyzing task execution. However, all the derived hypotheses aren't just accepted. We must decide whether to accept that hypothesis or to reject in the viewpoint of cost and benefit. If it is decided not to accept the hypothesis, the previous goal should be re-described to subordinate goals (8). This kind of subdivision of goals is attempted in HTA because it is assumed that complexity of the task as one process makes it hard to find cause of errors. This process repeats until all the sub-goals meet the performance standard and it is not necessary for more detailed analysis.

Through these processes, a task can be subdivided into subtasks which describe steps accomplishing a final goal and it will be a tree-like hierarchical model composed of several subtasks. The way to conduct each subtask is called plan. The plan is decided according to the method how to conduct each subtask. There are several types of plan such as 'Fixed sequence', 'Contingent sequence', 'Choices', 'Optional completion', 'Concurrent operations' and 'Cycles'. It is 'Fixed sequence' when an operator starts to do next task after previous task was accomplished. The cue for starting next task is the signal that previous task was done. For example, 'Fixed sequence' plan is applied when one assembles computer parts or uses toaster. 'Contingent sequence' is similar with the 'Fixed sequence'. However, it is identified as 'Contingent sequence' when dynamics exists in system. There is time lag due to dynamics of the system. Therefore, an operator should wait for previous task to have an influence upon system even though he already did the previous task. When an operator should select a task among several subtasks, this plan is called 'Choice'. When an operator conducts according to 'Choice', he needs to make some decisions between several tasks. 'Optional completion' is the plan that an operator can do any subtasks regardless of the order of them. A pilot checks every parts of the plane before the plane takes off. However, the order of checking is not important if all the parts were to be checked. 'Concurrent operation' is applied when several subtasks should be conducted at the same time. Actual execution of this type of plan can be different from every operators or machines. Therefore, it is very hard to analyze characteristics of 'Concurrent operation' with only HTA method. At last, 'Cycle' is applied when subtasks are conducted repeatedly until task completion criterion will be met. This type of plan can be found easily in the plant for mass production. Types of plans can be identified through analyzing decision making process in task execution. When all the plans in each subtasks are identified, the HTA process is completed.

## 3. TASK MODEL FOR INTELLIGENT SERVICE ROBOT

Task which combines complex system and operators can be analyzed with HTA method as explained in chapter 2. The focus of this research is to apply HTA method to the analysis of service robot's task. However, this method can not be applied to service robot's task analysis directly because it is designed for human operator's task. Therefore, it is necessary to consider differences between human operator's task analysis and robot's task analysis in utilization of HTA. At first, human operator sets his goal according to information that he receives and understands while doing his tasks. When the goal in the operator's mind differs from system's own goal, this mismatch can lead to the failure in the completion of tasks. However, we can set robot's goal arbitrarily and make this goal to be same with system's goal. At second, robot's ability to do some tasks is inferior to human in general. For example, human operator can gather necessary information through interaction with other people or machines and estimate surrounding situation through comprehensive information analysis easily. However, it is very hard for robots to do those kinds of things yet because robots have limited interaction capability and intelligence. Finally, human operator can manage unexpected events more easily than robots. And robots will fail in completion of their tasks when such events occur.

Therefore, there are two differences from general HTA method in applying HTA to service robot's tasks analysis. At first, a task is subdivided into subtasks until necessary movement of the robot and information for completion of task are identified, not until cost and benefit meets. At second, the task which requires interaction with human is subdivided into subtasks according to the kind of interaction channel and differences in required information.

Intelligent service robot's tasks are decided as fetch and carry task, greeting human task and reading e-mail or schedule task according to application scenario. HTA method was applied to the analysis of those three tasks and analysis process of fetch and carry task will be explained in the following chapter in detail.

### 3.1 Fetch and Carry Task Model

The ultimate goal for fetch and carry task is to find the object which a user required and deliver it to him. A user uses vision and audio channel to interact with the service robot. Therefore it is the constraint to use natural language and gesture for the user to interact with the robot. The task is considered to be successful when the robot carries the exact object and delivers it to the user. At first, this task is roughly divided into serial subtasks referring to human's same task execution.

(a) Recognize order
(b) Understand object's name
(c) Understand object's location
(d) Route plan
(e) Move to destination
(f) Pick up an object
(g) Return to the user
(h) Certify an object
(i) Pass an object to the user

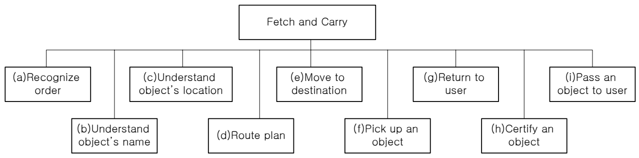

Fig. 2. Initial Task Model for Fetch and Carry Task

Task model can be drawn like Fig. 2. according to above subtasks' sequence. However, there are uncertainties and similarities in each subtask. Therefore, subtasks are identified according to each one's characteristics. Those subtasks are divided into four types of events like Table 1. Identification of event ranges doesn't match to all the subtasks which are subdivided in initial analysis. However, those tasks are refined according to the classification by dividing some subtasks or binding other subtasks.

Table 1. Identification of Event Ranges

| Interaction with Users | Move to Destination | Operate Manipulator | Searching |
|---|---|---|---|
| Recognize user's command (a,b,c) | Move to object's location (d,e) | Pick up an object (f) | Search user's position (g) |
| Request necessary information (b,c) | Move to user's position (g) | Pass an object to user (i) | Search an object (d,e,f) |
| Identify user (i) | | | |

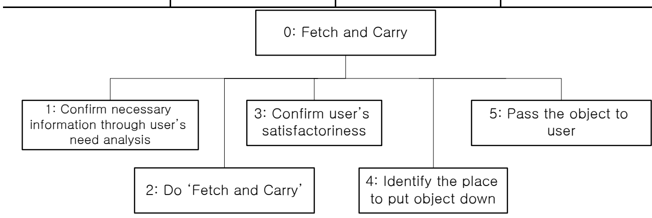

Fig. 3. Refined Task Model by Identification of Event Range

As a result, initial task model in Fig. 2 can be refined into the task model in Fig. 3. Each subtasks in Fig. 3 are not subdivided clearly yet, and they should be subdivided until all the subtasks are identified concretely. Final task model which was obtained through repetitive process is shown in Fig. 4. Preceding three subtasks in Fig. 3 are composed of recognition of order, carrying object and confirmation of task completion. Those subtasks are conducted serially. When the user confirms that the object

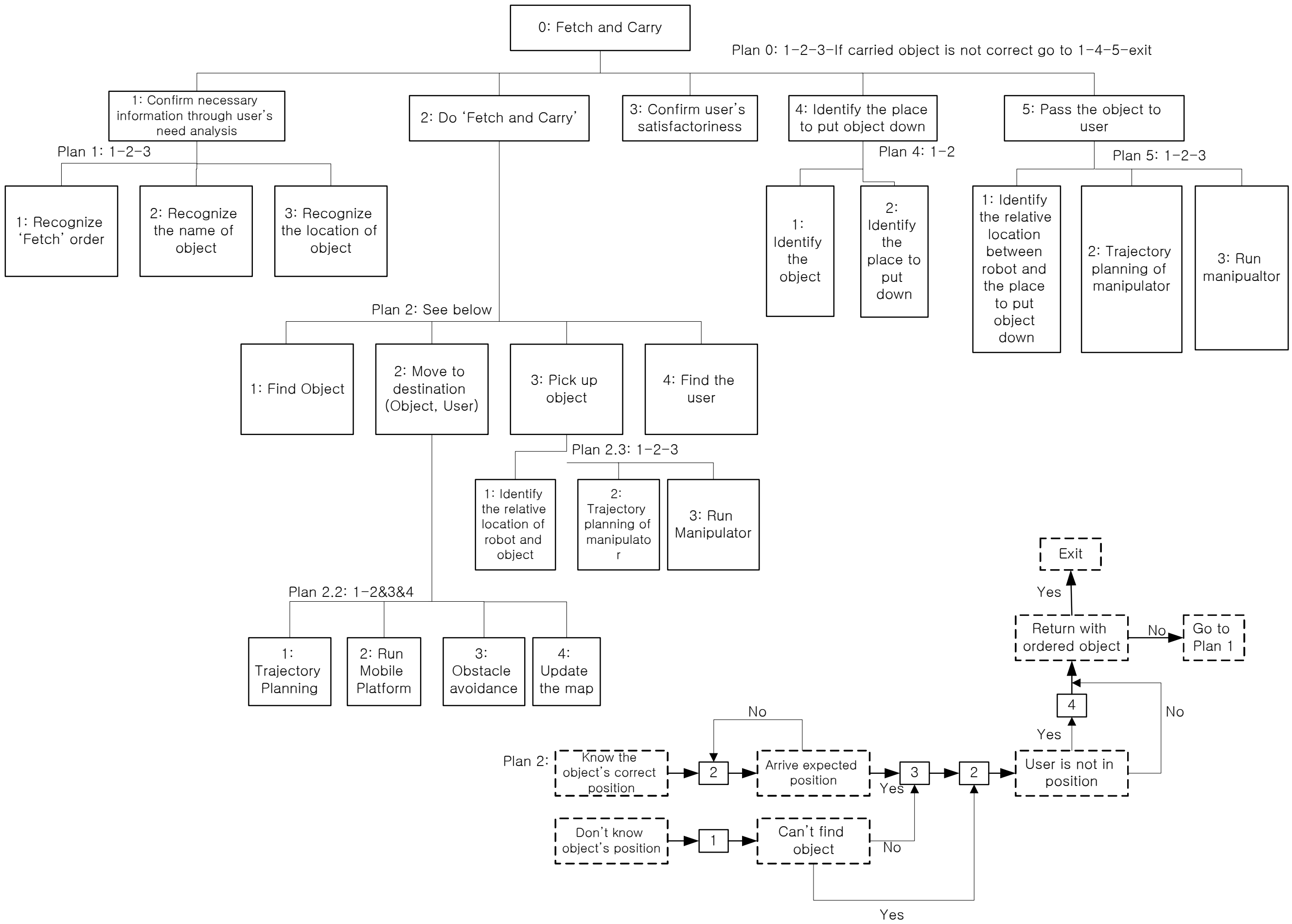

Fig. 4. Hierarchical Task Model about 'Fetch and Carry' Task

which a robot is carrying with is the correct one, the robot proceeds to subsequent tasks. Therefore, the robot finds the place to put on the objects and then it passes the object to the user.

The first subtask which means '*Confirm necessary information through user's needs analysis*' is subdivided into three subtasks, '*Recognize 'Fetch' order*', '*Recognize the name of object*' and '*Recognize the location of object*'. Those three subtasks are conducted serially and following task should be conducted after preceding task is done. Therefore, it is fixed sequence. Second, '*Do 'Fetch and Carry''* task is subdivided into '*Find object*', '*Move to destination (Object, User)*', '*Pick up object*' and '*Find the user*' tasks. Those four subtasks are not serial tasks. Therefore, plan 2 in Fig. 4 describes decision making algorithm for those four tasks. This algorithm starts with the judgment whether the robot knows the exact location of the object or not. If the robot knows the exact location of the object, it conducts '*Move to destination (Object)*' task until the robot arrives the designated destination. When this task is completed, the robot picks up the object by executing '*Pick up object*' task and returns to the user by '*Move to destination (User)*' task. The robot assumes that the user will be on the position where the robot starts to move. However, the robot should find the user by '*Find the user*' task if there is no user near starting position. The robot goes back to the plan 1 in Fig. 4 when it doesn't carry any object, otherwise the '*Do 'Fetch and Carry''* task ends. If the robot doesn't know the exact location of the object in the first judgment, it tries to find the object searching everywhere by doing '*Find Object*' task. After the robot finds the requested object, it continues to do '*Pick up object*' and '*Move to destination (User)*' tasks. If the robot can't find any object after '*Find object*' task, it skips '*Pick up object*' task and goes back to the user directly.

'*Move to destination (Object, User)*' task and '*Pick up object*' task are subdivided into subtasks. '*Move to destination (Object, User)*' task is subdivided into '*Trajectory planning*', '*Run mobile platform*', '*Obstacle avoidance*' and '*Update the map*' task. Those four subtasks are conducted according to the plan 2.2. After the robot plan the trajectory, it conducts subsequent three subtasks concurrently. '*Pick up object*' task is subdivided into '*Identify the relative location of robot and object*', '*Trajectory planning of manipulator*' and '*Run manipulator*' tasks. Those three subtasks are conducted according to the plan 2.3, and it is simple fixed sequence plan. Third, '*Confirm user's satisfactoriness*' task is for confirmation of task execution. Forth, '*Identify the place to object down*' is subdivided into '*Identify object*' and '*Identify the place to put down*' tasks. Finally, '*Pass the object to user*' task is subdivided into '*Identify the relative location between robot and the place to put object down*', '*Trajectory planning of manipulator*' and '*Run manipulator*' tasks. In addition, task models for greeting human task and reading e-mail or schedule task is simpler than that of fetch and carry task. Those models are shown in Fig. 5 and 6.

### 3.2 Application of Task Model

Derived task model in previous chapter for fetch and carry task is the necessary component in the design stage of service robot rather than it is the algorithm for robot's task execution. As previously expressed, task model in Fig. 4 is not the only description of the given task and analyst can overlook some important aspects in task subdivision. However, this result can tell the necessary specification of service robot's component like vision, voice recognition, mobile platform and manipulator. Therefore, all the components would be designed according to those specifications. In addition, the source of error in the execution of the task can be identified easily by comparison of task model and the stage when the error occurred. Therefore, the task model can guide for the service robot designers to fix problems easily.

## 4. CONCLUSION

In this paper, task models about several tasks for service robot have been derived. Because task analysis is originated from necessities for examining human operator's task execution, it is hard to apply task analysis methods directly to robot's task analysis. Therefore, several suggestions which would be considered in robot's task analysis were proposed. These models can work as guideline in the development of service robots. And, it is necessary for them to be verified through actual experiments in real environment.

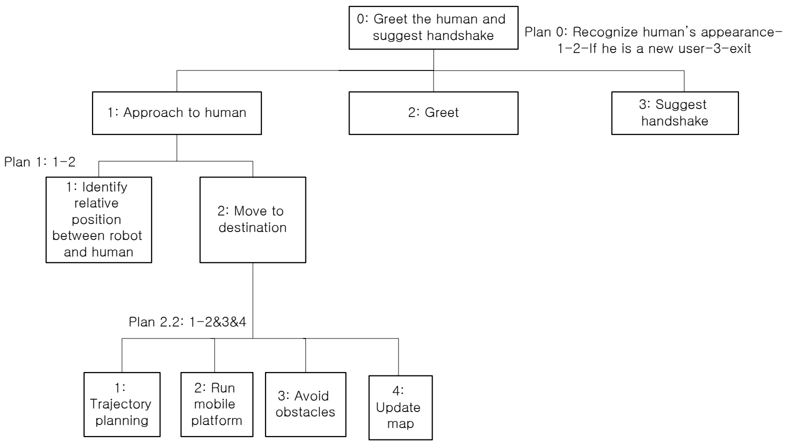

Fig. 5. Hierarchical Task Model about 'Greet the human and suggest handshake' Task

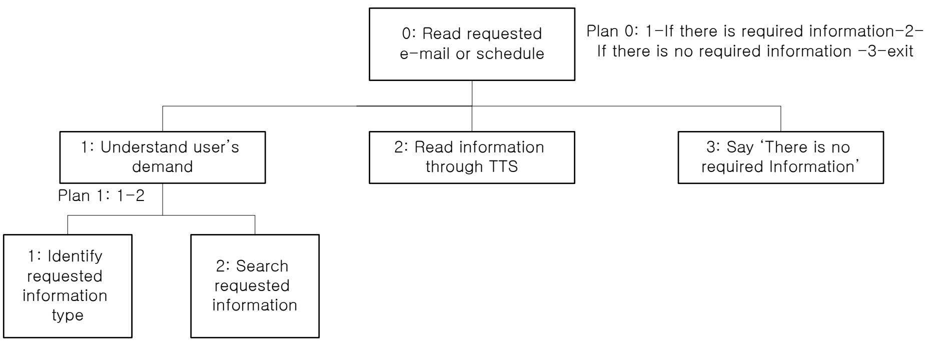

Fig. 6. Hierarchical Task Model about 'Read requested e-mail or schedule' Task

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