Paper:

Taxonomy of Atomic Actions for Home-Service Robots

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In household environments, robots are expected to conduct many tasks. It is difficult, however, to write programs for all tasks beforehand due to task diversity and changing environmental conditions. One basic task of developing autonomous multifunctional robots is to define a set of basic robot actions that are executed unambiguously and checked for completion. A task planner then uses these actions to accomplish complex tasks that home-service robots are expected to do. This paper first proposes a set of tasks for first-generation home-service robots, then systematically decomposes them into sequences of smaller but meaningful actions called molecular actions. Molecular actions are then broken down into yet more primitive actions called atomic actions. Because vision, sound, range sensors, and force sensors are the main means of monitoring task progress and completion, atomic actions are classified based on the complexities and frequencies of the sensing algorithms used. The resulting taxonomy of atomic actions serves as a set of basic building blocks for a knowledge-based task planner. Its advantages are verified and demonstrated through experiments.

Keywords: task classification, planning, monitoring

1. Introduction

Robots are expected to conduct a variety of tasks in household environments. Programs conducting all robot tasks are difficult to write beforehand, however, due to the sheer task diversity and changing environments. A basic task of developing multifunctional robots is to define a set of basic robot actions executed unambiguously and checked for completion. A task planner then uses these actions to accomplish more complex tasks expected of home-service robots. This paper takes a set of prototypical tasks for first-generation home-service robots proposed in the literature, analyzes them, then proposes a taxonomy of basic actions called atomic actions. This enables task planners to efficiently plan robot actions to conduct tasks users request.

A taxonomy of atomic actions is equivalent to the standardization of robot actions into primitive units reusable in as many different tasks as possible. For reasons stated below, basic actions are classified into a two-level hierarchy: molecular and atomic actions. No unique way exists to define the number of levels in the hierarchy or the complexity of basic actions, but a well-designed procedure would facilitate more effective task planners. Due to task diversity, we used several principles to define basic actions, then empirically verified their usefulness in experiments. One way we define basic actions is that their completion must be verifiable via sensors.

A steady stream of definition of primitive robot action sets has existed since robots were invented. Industrial robots usually have *joint_move*, *Cartesian_move*, *reset*, and *halt* as their basic motion set. Mobile robots with sensors, vision sensing, or range finding naturally define a set of basic sensing actions [1]. For more complex multifunctional robots such as humanoid robots, a rich set of basic actions is defined including walking, grasping, manipulation, and human interaction algorithms such as face recognition, gesture recognition, voice recognition, speech synthesis, emotion expression, etc. [2]. We focus, however, on a set of tasks for first-generation, commercial, home-service robots, usually involving navigation and object manipulation and dealing little with humans emotionally.

The balance of this paper first reviews previous work in Section 2, and then discusses household tasks, molecular and atomic actions in Section 3. We then propose taxonomy of these actions in Section 4, and Section 5 describes how we evaluate the taxonomy empirically by implementing a household task. Section 6 concludes this paper and describes future work.

2. Previous Work

In research in the taxonomy of primitive robot operations, Cutkosky [3] constructed a taxonomy of grasp and developed an expert system that chooses grasp based on the task requirement and object geometry. His taxonomy is based on the facts that the human hand consists of 25 joints and executes 58 distinct motions [4], and humans tend to use one of two of grips: power and precision [5]. Too many objects exist to be grasped in household environments for robots to be programmed with all grasping rules for each object. Stansfield [6, 7] used vision information to derive object geometry and used a rule-based system to determine grasping configurations. Andrew [8] developed automatic grasp planning that classified the object to grasp as a simplified model – sphere, cylinder, cone, or box. The final grasp configuration was selected based on a hand shape similar to the model. In addition to grasping, research results define a set of basic actions for general task planning and learning. Chen and Hwang [9] developed a natural-language like user interface for a robotic system. It initially has a basic action set that the robot knows how to and learns to conduct complex tasks based on these basic actions through demonstration, memorization, and generalization.

Little research has been done on the taxonomy of actions for general-purpose robots because few robot applications have a wide enough variety of tasks to make systematic taxonomy of robot actions necessary. Home-service robots in ubiquitous computing environments, however, provide a rich set of scenarios for robot tasks. The robots role in ubiquitous computing environments was described by Hwang [10] and divided into servants and companions. Tanie [11], however, suggested five applications of humanoid robots. Two of them, human care and home-security services, are applicable to household robots, while the others are for industrial robots. Other papers suggest scenarios for guide and public-service robots conducting tasks such as collecting trash, going up and down in an elevator [12–16].

The next section analyzes a set of relatively complex tasks to be done by home-service robots. Each task is broken down into a set of atomic actions executed by the robot without future interpretation. They are meaningful chunks of robot algorithms that use sensor information to monitor the progress of actions, and the taxonomy of these enables robots to function effectively in a household environment.

Fig. 1. Eight prototypical tasks for home-service robots.

3. Definition of Molecular and Atomic Actions

We develop taxonomy of atomic actions based on a set of prototypical tasks for home-service robots proposed by governments [18], academia, and industry as tasks for first-generation home-service robots. We wanted to define a set of atomic actions, sequences of which can be used to conduct the prototypical tasks defined below. Atomic actions must be simple enough to be executed by the robot unambiguously and without further interpretation, but must do a meaningful chunk of work. To further enhance the effectiveness of task planners, robot tasks are first broken down into what we call molecular actions, which span a short sequence of atomic actions. This enables task planners to describe actions needed to conduct a task with a fewer steps than without intermediate molecular actions. We next discuss common household tasks and molecular and atomic actions.

3.1. Tasks

A task is defined as a specific piece of work done, whether requested by a human or generated by the robot itself. The number of tasks robots do increases as technologies develop, making it a moving target to define prototypical tasks. In this paper, we select eight tasks proposed in the recent literature [10–18] as follows:

1. Bring me an object
2. Throw an object into a wastebasket
3. Turn on/off a switch
4. Open a door and go through it
5. Pour water into an object
6. Go up and down in the elevator
7. Vacuum the floor
8. Guide a guest

Figure 1 depicts scenes for these eight tasks. Hereafter *task* refers to these eight robot operations alone, which we analyze below to derive the minimal set of molecular and atomic actions required to conduct these tasks. All are multistep tasks and the required sequences of steps are stored in a task planning system we developed. Our ultimate goal is for a sufficient number of molecular and atomic actions enabling the task planner to automatically generate efficient plans to conduct most household tasks.