Using Adjustable Autonomy to Extend the Independence of the Elderly

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Abstract

We have investigated using the 3T layered software architecture to control an Elder Care Robot. This robot is to provide support to humans who suffer some loss of ambulatory or fine motor skills, such as the elderly, or prematurely arthritic. The main problem with such a robot is the lack of technology for fully autonomous operations in the given environment. This paper describes changes made to the architecture which allow for semi-autonomous operation with present state of the art, and an increasing level of autonomy as sensor and actuator technology advance.

Introduction

The proportion of people over age 65 is the fastest growing component of the US population [TRC 94]. The annual cost of a live-in nurse ranges from $25000 to $40000, depending on the extensiveness of the care needed [ISRA 95]. By using an intelligent robot to provide simple ambulatory assists, take care of tasks requiring fine motor movement of the hands, and limiting the amount of time the elderly person must remain standing, we estimate that a significant portion of that population segment can function without live-in care. The savings in health care will total several billion dollars per year.

To this end, we investigated the development of an Elder Care robot to be used in conjunction with a "smart home" agent to assist the elderly and thus allow them to be more independent for a longer period of time late in life. The robot would be affordable, viable in a range of apartment settings and cooperate with smart home technology to support such functions as: ambulation assistance (i.e., "lean on me"), monitoring of vital signs, taking emergency action, clean up of minor spills, fetch & carry of simple objects (e.g., a remote control), microwave meal preparation, and monitoring and control of the environment (smart home agent). All functions would be supported by spoken language commands/requests from the elder person.

The 3T architecture [Bonasso *et al*, 1996] was to be used to plan for and execute the actions of the smart home and robot agents, as well as to coordinate them with the requested needs of the elder person. The architecture is depicted in Figure 1.

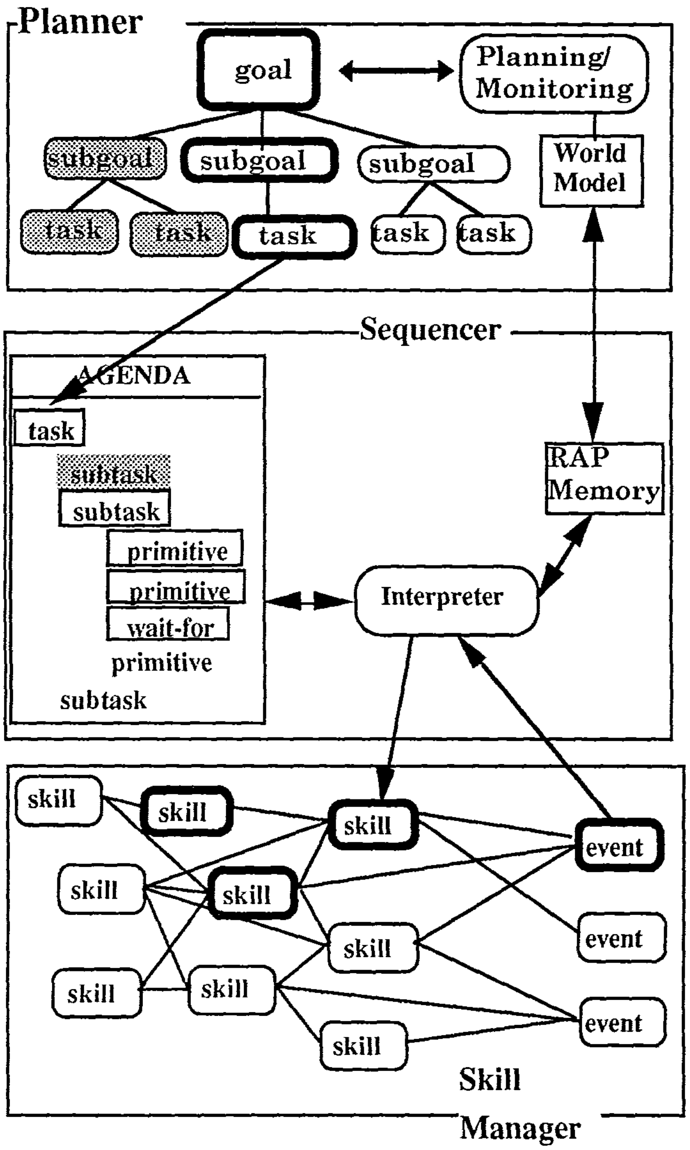

Figure 1 The Three-Tiered (3T) Robot Control Architecture

Essentially, for any agent, there are a set of software skills -- tight sense-act loops which achieve or maintain states in the world -- which command the agent and obtain state data from its actions. Such skills might be obstacle avoidance, navigation to a point, tracking an item with stereo vision, and opening a door using a manipulator. A conditional sequencing layer enables and disables groups of these skills to accomplish a local goal. For example, to go from room A to room B through a portal, the sequence might be to navigate with obstacle avoidance toward the portal while looking for the door. If the door is found to be open, the same set of skills will be continued to go to room B, except for those concerned with tracking the door. If the door is closed, the open door skill will be enabled and the navigation skill disabled while the robot opens the door. The top tier is a conventional hierarchical, non-linear conjunctive goal planner which interfaces with the middle layer to plan for and reason about the long term implications of local actions.

A depiction of this application of the architecture to the elder care problem is shown in Figure 2.

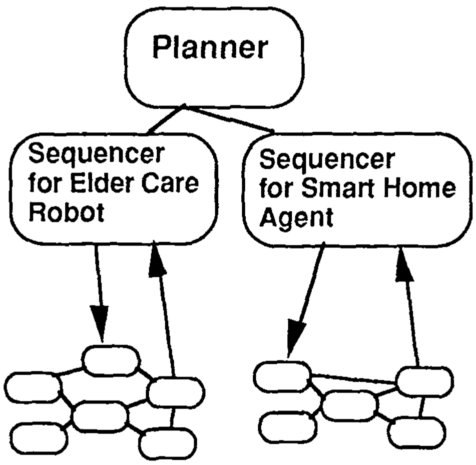

Figure 2: 3T As Configured for Elder Care Application

The smart home and the Elder Care Robot (ECR) would be agents coordinated by the planner. A typical support function might be that the planner is keeping track of the schedule of medication for the elder person, call her Mary. At the next scheduled medication time, the smart home locates Mary using cameras and motion or body heat sensors throughout the house (or perhaps asks Mary where she is and listens for a response), and informs Mary that it's time to take her pills. Mary agrees, and the ECR prepares a glass of water, fetches the pill tray from a counter in the kitchen, and takes them to Mary's location. If Mary also suffers from arthritis, the ECR could select the appropriate pill and place it in her mouth, as well as lift the glass for her to drink. Then the ECR would put away the glass and pill tray.

The Need for Adjustable Autonomy

The difficulty with the above scenario is that a number of technologies are needed to support the ECR that have yet to be developed; e.g., general spoken language understanding, general object recognition, flexible manipulation in proximity of humans, etc. Most researchers in mobile field robots realize this and would finesse some of the technological shortcomings by involving the elder person as much as possible. For example, the person would designate the object to be fetched with an infrared device, or the robot would drop the pill into her outstretched hand, or the human-robot dialogue would involve a limited vocabulary command.

But when the more general technologies become available and the robot becomes more autonomous, how do we extend or modify the elder care control architecture to accommodate these changes? Moreover, even with advanced sensing and acting, the elder person may have good days when she can do -- indeed wants to do -- many of the above tasks unaided. This calls for an architecture which supports *traded control* [Sheridan 89] -- traded control which can be adjusted based on the day to day preference or capability of the supported person. The situation with the elderly is not unlike that of a suited, gloved astronaut which has lost a certain flexibility and degree of mobility due to the need for life support and bodily protection during extra-vehicular activity.

We have recently concluded some investigations which show that the 3T architecture is ready made to implement the needed adjustable autonomy.

Simple Changes to Effect Adjustable Autonomy

Because of the limitations of space for this paper, I will describe some basic enhancements to the sequencing layer of 3T to illustrate the adjustable autonomy concepts. We use the Reactive Action Packages (RAPs) [Firby 95] system to implement our sequencing layer. An example RAP for fetching an item is shown below.

```
(define-rap (fetch-for ?item ?elder-person)
  (succeed (at ?item ?elder-person))
  (method m1
   (task-net
    (sequence
     (parallel
      (t1 (locate-item ?item))
      (t2 (locate-human ?elder-person)))
     (t3 (fetch-to ?item ?elder-person))))))
```

This RAP plan shows the need to locate both the item and the person, before bringing the item to the person. This is straightforward, but the capability to adjust the autonomy lies in the lower level RAPs. The RAP for locating an item is shown below.

```
(define-rap (locate-item ?item)
 (succeed (coords ?item ?x ?y ?z))
 (method autonomous
  (context
   (or (desired-level-of-autonomy autonomous)
       (and
        (unable-to-detect ?elder-person ?item)
        (class-of ?item ?item-class)
        (can-detect ?robot ?item-class))))
  (task-net
   (primitive
    (enable (detect-item ?robot ?item))
     (wait-for
      (item-detected ?robot ?item ?x ?y ?z)))))
 (method teleoperate
  (context
    (or (desired-level-of-autonomy teleoperate)
        (and
         (class-of ?item ?item-class)
         (unable-to-detect ?robot ?item-class)
         (able-to-designate
                ?elder-person ?item-class))))
  (task-net
   (primitive
    (enable
     (designate-item ?elder-person ?item)
     (track-designation ?robot ?item))
    (wait-for
     (item-detected ?robot ?item ?x ?y ?z))))))
```

Though we will not cover it's operation, assume for this discussion that a memory rule will trigger on the item-detected event and will assert the item's coordinates in the RAP memory, thereby making the succeed clause true.

This RAP points out the two augmentations to the RAPs system which provide for adjustable autonomy: 1) the use of agent variables in RAP clauses, and 2) the use of a level of autonomy context cue. We have augmented our current version of RAPs to look for an agent designation in the first variable position for all primitives, i.e., actions and events that are enabled and disabled in the skill layer. Thus if two agents have the same skill, the appropriate agent will have its skill set updated (no agent designation will cause the skill to be enabled in the first agent to have it defined). The level of autonomy can be set by the planning level or by the user at the sequencing level.

So, the above RAP plan indicates that if the elder person desires it and the robot is capable of detecting the class of the item in question, the robot will autonomously detect the item. Alternatively, if the elder person desires it or the robot is not capable of detecting the item, the elder person will point out the item to be fetched.

The locate-human RAP would have similar methods to deal with the human and smart home abilities to locate the elder care person. Specifically, if the home (or robot) did not have the requisite sensing capabilities, the home would query the human, otherwise, the home would locate the human and pass those coordinates to the robot, via the planner. As well the fetch-to could be done by the robot or human using the same mechanism.

Now reconsider the fetch-for RAP. Suppose that the level of autonomy was set by a memory function (RAPs supports such functions) which queried the user as to the level of autonomy desired at each step. Then the human could participate in as much or in as little of the task as she desired. As an example, in particular, if the robot was capable of locating Mary's glasses, Mary might invoke the fetch-for RAP, and specify the autonomous mode until after the detection task, after which she would fetch-to her own glasses.

Robot Monitoring vs. Robot Control

A key notion of this approach is that *it is more efficient to use an architecture designed for autonomous operations than one used for teleoperation.* This is because explicit monitoring for key events in the world is fundamental to autonomous robots. So if the state of the art in robotics does not allow for an autonomous primitive, the monitoring of the associated event will be still done by the robot as the human is carrying out the task (especially if the human is using the robot's limbs as when a human teleoperates a manipulator). Even if the robot is not capable of monitoring the specific event, the robot can ask the human to inform it when the event has occurred. The point is that the requisite monitoring serves as a check on the progress of the task, whether the task is done autonomously or not. And as the robot become more capable (and the elder person presumably less capable), the basic RAPs will remain unchanged -- only the primitives will need re implementing.

Preliminary Results

While we have not applied these ideas to the elder care arena, we have implemented them on a simulation of a robot working in cooperation with a human around a space station [Metrica 96]. The robot is to navigate to various places around the station to carry out a plan of routine maintenance. A human supervisor inside the station as well as humans working with the robot at a site (e.g., the robot preps the site for maintenance only the human can do), can direct that they execute any part of the related navigation, inspection or manipulator tasks. We have been able to demonstrate with this simulation that the human has complete flexibility in specifying which part or parts of the task he or she wishes to execute, complete with the ability to specify that the human or the robot "finish up" the remainder of the tasks in the given operation.

In this effort we have encountered a related point that has to do with the way the human does a task in full teleoperation. Humans are of course more adept than robots at getting several things done at once. Thus a human may not carry out the task in exactly the same manner as the RAP specified for the robot. How does the robot know what has changed, given it has not been able to detect the specific intermediate events it was expecting, even though it has detected the end goal being achieved? This is essentially a different view of the frame problem. The robot could solve it exhaustively by using its sensors to scan (or to ask questions about) the state of every object in its environment. While that environment is finite, such an enumeration would significantly effect the efficiency of the robot operations, to say nothing of the frustrating effect it would have on the human co-workers.

We have tackled this problem in a preliminary manner by using the context of the type of task to limit the search. For example, if the human was involved in picking and placing replacement parts at a site, the robot will periodically scan for the state of only those parts and their associated tools. We have added these scanning actions in all primitives wherein the human can take control; thus having a variable binding environment for the items that are being affected. While effective in most cases, this technique is incomplete and we are investigating better approaches.

Summary

I have argued that intelligent robots can be useful for extending the independence of the elderly, even with current technology, if an appropriate software control architecture is used. Such an architecture must based on robot autonomy and yet must allow humans to do what they can to help the robot wherever the technology is lacking. I have shown how the 3T system -- particularly the sequencing layer-- can serve as that architecture with only slight modifications. We have demonstrated the plausibility of the above statement through a space station simulation. The frame problem is still giving us headaches.

References

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