EVOLUTION OF THE FLIGHT TELEROBOTIC SERVICER

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ABSTRACT - The Flight Telerobotic Servicer (FTS) is a two-armed manipulator which will be used to build and maintain Space Station Freedom. One of the goals of the project is to be able to upgrade the capabilities of the FTS by incorporating new technology. To achieve this goal the FTS is using the NASA/NIST Standard Reference Model for Telerobot Control System Architecture (NASREM) for its functional architecture. While using NASREM helps integrate new technology into the system, the decisions concerning the precise technology needing development must be addressed. In this paper, an approach to the technological evolution of the FTS will be explored. The approach begins with detailed scripts of representative FTS activities. These scripts are analyzed to determine the generic or common actions performed by the FTS. Then, technological alternatives are described in terms of a decision tree format.

INTRODUCTION

The FTS is unique for NASA because there is a clear attempt to have it evolve with technology. The FTS will initially be operated as a tele-operated device. Astronauts inside the pressurized cabin of the Space Shuttle will manipulate a master device which is used to control the motion of the manipulator in space. In this mode of operation, the astronaut is an integral part of the control loop. Over time, however, crew time could be utilized more efficiently if some of the robotic tasks were done more autonomously. As a result, there is a conscious effort to make the FTS evolve toward autonomous operation.

Teleoperation and autonomy represent states of operation along a continuously decreasing amount of human involvement in task execution. Other operating modes on the path from teleoperation to autonomy include:

1. traded control, where the operator and machine alternate in controlling the FTS,
2. shared control, where the operator and machine simultaneously provide information required for controlling the FTS,
3. human supervised control, where autonomous functions, suggested by the machine, are invoked or rejected by the human,
4. human override, where the operator can interrupt actions generated by the machine.
5. autonomous operation, a desirable but probably unachievable goal where all actions are determined by the machine.

Two activities are required to achieve this evolution. The first is determining what to do. The second is determining how to do it. The problem of how to do it has been approached by requiring that the FTS be designed using NASREM as its functional architecture [1]. NASREM is a three-legged hierarchy where the task decomposition, world modeling, and sensory processing hierarchies are specified from a functional standpoint. For example, a robot moves because of a control algorithm. However, there are many control algorithms available in the technical literature. A place in the functional architecture must be available to provide this function. The crucial factor for evolution is that the proper interfaces are created between the functional modules so that new software or hardware can be inserted into the FTS without a major redesign of the system. Based on the technical literature, several boxes in NASREM architecture have been defined to support all of the algorithms currently available [2,3,4,5].

The issue of what to do to achieve a sensible evolution is the subject of this paper, which is organized as follows. The next section describes a study of representative FTS tasks. From this study, certain actions which would impact crew efficiency are identified. This is followed by tradeoffs between technological sophistication and risk/robustness for various options.

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CANDIDATE TASKS FOR AUTOMATION

The Mission Utilization Team (MUT) on the FTS project has developed a task description methodology and has scripted several representative FTS tasks including the installation of a structural interface adapter, installation of radiator panels, Space Station truss member installation and removal, electrical and fluid connector mating, and several inspection tasks. The method used to ascertain the best candidates for automation is based on these task analyses. The procedure is as follows:

1. Create a generic task -- The generic task consists of: RETRIEVE FTS from storage, TEST FTS, DELIVER FTS to worksite, ORIENT, MOVE ARMS, ATTACH, DO WORK, DETACH, MOVE ARMS. Not all FTS tasks require each step of the generic task, and in that case the null step is used.

2. Map the MUT task scripts into the generic task.

3. Summary of the task steps -- The steps for the complete task were cataloged. The final tally sheet for several tasks is shown in Figure 1 where each task is described on a single line. In order to complete a task, some of the elements of the generic task may need to be repeated, e.g., several orient operations may be needed. Figure 1 shows the percentage of times that each element of the generic task was executed to complete the task. Note that the metric is the number of times a generic task element was executed, not the amount of time it takes to execute.

It is interesting to note that the "Do Work" part was not the major candidate for automation because different functions would be required for each task. Based on the results, it was determined that the best candidates for automation would be moving arms to vicinity of work, attach, and detach. These activities have several elements in common: path planning, non- contact alignment, and contact planning and control.

TASK STATES AND EVOLUTION

In this section, three flowcharts are presented to illustrate the proposed alternative technology paths which meet FTS near term needs. There is an attempt to build a bridge from required capabilities to options of what to work on next. The three task-states are non-contact alignment, path planning, and contact planning.

Figure 2 illustrates the process of non-contact alignment. The purpose of the diagram is to illustrate alternatives and tradeoffs rather than particular algorithms. The initial condition is that the target is in the camera field of view and that the target's orientation is obtainable from the camera image. Once this initial condition is satisfied, the system is capable of moving the sensor with respect to the target until a pre-defined geometric relationship is satisfied. Consequently, non-contact target motion is predominately in orientation rather than in translation. Alignment can be performed using pre-defined targets or can work directly with objects. The alternatives are a trade between greater structuring of the environment and more complex sensory processing.

The path planning task state has several tradeoffs. In path planning, the goal is to move through a large volume of space primarily in translation in order to place a sensor close enough to a target to perform the previously described alignment procedure. First, the operator must designate a goal position. Either the system can achieve the goal position completely autonomously or some combination of man and machine is required.

The last task state is the process of contact planning and control. Whenever contact is made with the environment, the robot or the environment must comply. The simplest way to achieve this compliance is to use passive devices such as a remote center compliance end effector. However, to use such a device effectively implies a certain amount of structuring of the environment. Even if a passive device is used, it is also possible to have other sensors, such as a wrist force/torque sensor, check whether the motion is proceeding normally. This added complexity is compensated by greater safety and reliability.

Based on this analysis, near-term and mid-term technologies were identified. The list of potential technologies include:

NEAR-TERM TECHNOLOGIES (within 2 years)

Non-Contact Alignment
- object labels
- teleoperation/autonomous verification of simple convex geometric shapes
- acquisition/tracking of stationary or slowly moving objects
- proximity/range sensing
- centroid determination using photo-sensitive devices

Contact Planning and Control
- passive compliance devices
- model-driven position control
- teleoperation teach pendant position control
- force/torque sensing with feedback to operator
- autonomous force/torque control
- predetermined autonomous compliance macros
- operator assisted shared control

Path Planning
- pre-taught path plan execution
- off-line human designated spatial planning
- off-line autonomous spatial planning with known environment

model-driven collision detection
operator-derived collision detection by touch

MID-TERM TECHNOLOGIES (within 5 years)

Non-Contact Alignment
object models for concave and convex curved objects
shape sensing with conversion to approximate models
autonomous verification of complex objects
real-time world model updates
autonomous acquisition/tracking of rapidly moving objects
high-resolution full-field zoom cameras
fused vision sensing with uncertainty

Contact Planning and Control
autonomous robust model driven active compliance
real-time dynamic damping of contact induced arm oscillations
contact control with time delay
autonomous compliance with operator shared control

Path Planning
model driven on-line task/spatial planning
on-line knowledge capture of new objects and interface with world model
collision avoidance with known or sensed environment

CONCLUSIONS

This paper describes an approach to determine which technology areas would benefit most from automation to help focus the evolutionary path of the FTS. Some technology exists today but must be space qualified for FTS use while other technology must be developed. In both cases, this study identifies the path for evolution.

ACKNOWLEDGEMENT

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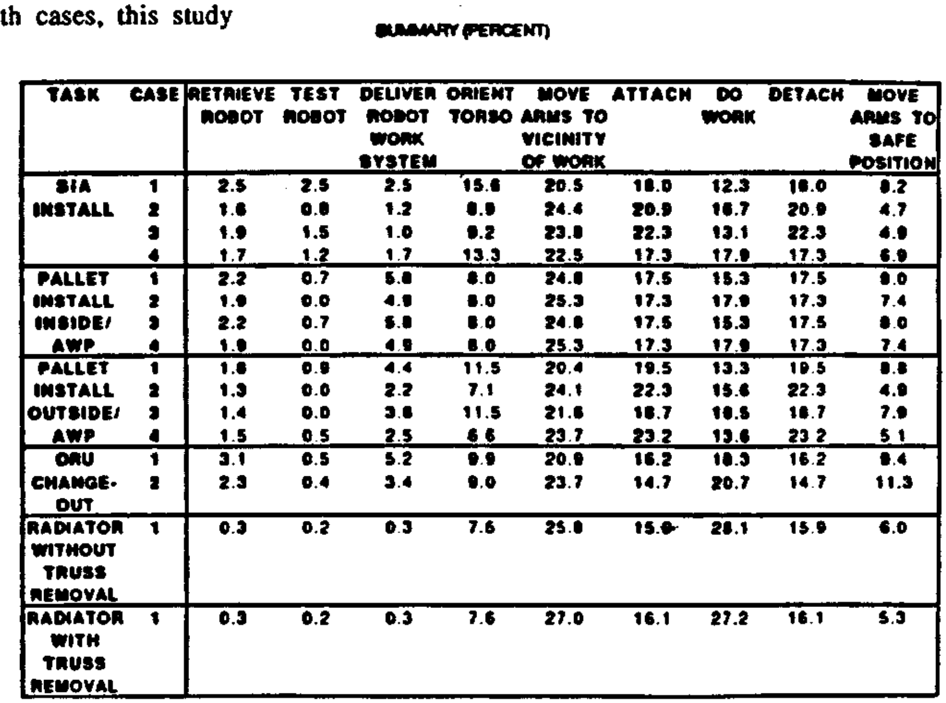

SUMMARY (PERCENT)

TASK	CASE	RETRIEVE ROBOT	TEST ROBOT	DELIVER ROBOT WORK SYSTEM	ORIENT TORSO	MOVE ARMS TO VICINITY OF WORK	ATTACH	DO WORK	DETACH	MOVE ARMS TO SAFE POSITION
SIA	1	2.5	2.5	2.5	15.6	20.5	18.0	12.3	18.0	8.2
INSTALL	2	1.6	0.8	1.2	8.9	24.4	20.9	16.7	20.9	4.7
	3	1.9	1.5	1.0	9.2	23.8	22.3	13.1	22.3	4.9
	4	1.7	1.2	1.7	13.3	22.5	17.3	17.9	17.3	6.9
PALLET	1	2.2	0.7	5.8	8.0	24.8	17.5	15.3	17.5	8.0
INSTALL	2	1.9	0.0	4.9	8.0	25.3	17.3	17.9	17.3	7.4
INSIDE/	3	2.2	0.7	5.8	8.0	24.8	17.5	15.3	17.5	8.0
AWP	4	1.9	0.0	4.9	8.0	25.3	17.3	17.9	17.3	7.4
PALLET	1	1.8	0.9	4.4	11.5	20.4	19.5	13.3	19.5	8.8
INSTALL	2	1.3	0.0	2.2	7.1	24.1	22.3	15.6	22.3	4.9
OUTSIDE/	3	1.4	0.0	3.8	11.5	21.6	18.7	16.5	18.7	7.9
AWP	4	1.5	0.5	2.5	6.6	23.7	23.2	13.6	23.2	5.1
ORU	1	3.1	0.5	5.2	9.9	20.9	16.2	18.3	16.2	9.4
CHANGE-OUT	2	2.3	0.4	3.4	9.0	23.7	14.7	20.7	14.7	11.3
RADIATOR WITHOUT TRUSS REMOVAL	1	0.3	0.2	0.3	7.6	25.8	15.9	28.1	15.9	6.0
RADIATOR WITH TRUSS REMOVAL	1	0.3	0.2	0.3	7.6	27.0	16.1	27.2	16.1	5.3

Figure 1: Task Summary

NON-CONTACT ALIGNMENT

(assumes motion will be within a small volume and primarily in orientation)

(primary source of data is a camera image and a low level vision system exists)

(initial condition is that target is in field of view and sufficiently large for processing)

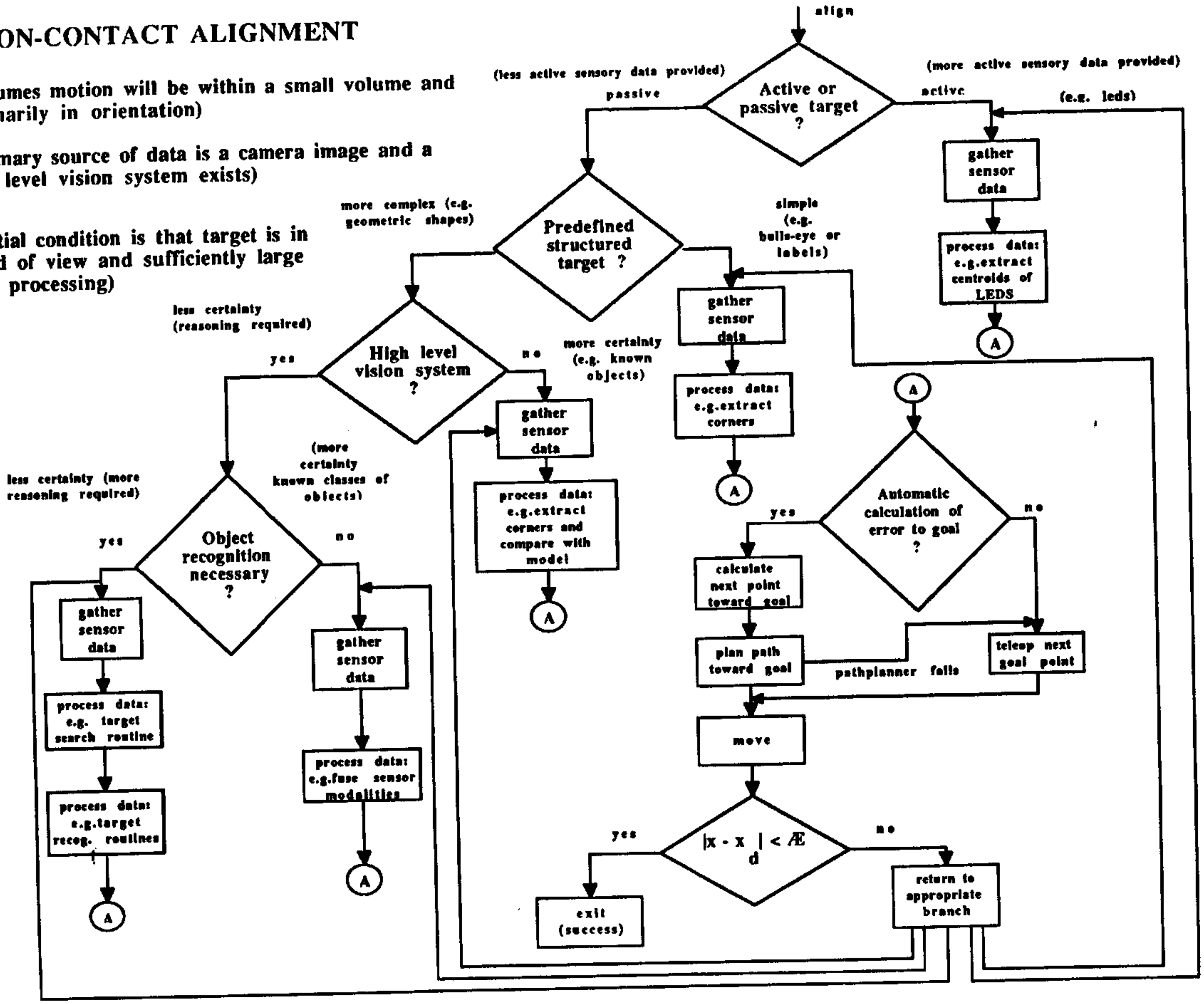
align
Active or passive target ?
(less active sensory data provided)
passive
(more active sensory data provided)
active
(e.g. leds)
gather sensor data
process data: e.g.extract centroids of LEDS
A
Predefined structured target ?
more complex (e.g. geometric shapes)
simple (e.g. bulls-eye or labels)
gather sensor data
process data: e.g.extract corners
A
High level vision system ?
less certainty (reasoning required)
yes
no
more certainty (e.g. known objects)
gather sensor data
process data: e.g.extract corners and compare with model
A
Object recognition necessary ?
less certainty (more reasoning required)
yes
(more certainty known classes of objects)
no
gather sensor data
process data: e.g. target search routine
process data: e.g.target recog. routines
A
gather sensor data
process data: e.g.fuse sensor modalities
A
A
Automatic calculation of error to goal ?
yes
no
calculate next point toward goal
plan path toward goal
pathplanner fails
teleop next goal point
move
$|x - x_d| < Æ$
yes
no
exit (success)
return to appropriate branch

Figure 2: Non-Contact Alignment