Abstract

Visually based control, accumulation and assistance systems are presented as an effective environment for teleoperation. We developed the Bilateral Behavior Media (BBM) paradigm and implemented systems which offer a status driven interface, collection of sampled control behavior, and operator assistance. The paradigm emphasizes a human-intuitive visual specification of task completion states without resorting to image understanding, modeling or extensive calibration. Visually based teleoperation has been effectively applied in a variety of tasks where an operator’s past experience in the macroworld is not applicable to the physics and scenario experienced in the microworld. Experiments of manipulating individual biological cells have shown the success of the visually based BBM paradigm.

1. INTRODUCTION

Teleoperated robots are indispensable in environments where humans cannot perform direct manipulation. In dangerous or distant locations or in the microworld, humans must manipulate the environment through a remotely controlled mechanism. Although teleoperation techniques have been extensively researched and developed, human operators still experience problems with non-intuitive interfaces or require extensive training or experience. Improving the teleoperating worker’s situation is our underlying theme.

Recent work in visually based control methods has laid the foundation for advanced and robust master slave teleoperation. The visually based control methods offer 1) a more intuitive human machine interface and 2) allow for much simpler and robust control algorithms. [1,2,3,4]

Previous generation teleoperation control methods such as “joint-angle correspondence” or “generalized coordinate transform” techniques can offer very good response times or be used with automated control techniques. However, there are also several significant limitations. For example, joint-angle techniques require that the master and slave arms must be of identical mechanical configurations or autonomous control by the robot is not possible. Likewise, for generalized coordinate transform techniques, inclusion of external sensing information such as video or adaptation to dynamic environments has proven to be difficult.

With many control techniques, sensors are merely appended to the system and are not an integral component of the control algorithm. Sensors such as cameras may display the work environment to the operator but cannot be automatically beneficial to the control mechanism. We contend that the control algorithm must be fundamentally based upon sensing and in particular, visual sensing in order to be effective in real world teleoperation applications.

We have developed the bilateral behavior media (BBM) paradigm based upon explicit and intuitive visual communication between human operators, slave manipulators, and teleoperation systems. The bilateral behavior media paradigm comprises three areas: 1) A control methodology for visually specifying tasks and visually controlling machines. The methodology is referred to as status driven control. 2) A data representation and extraction method for accumulation of visually based interactions between humans and tools. This is termed behavior sampling. 3) Functions for assisting and supporting humans through visual mechanisms. Capabilities include visually navigated “redo”, “undo”, or summarization based upon past visual-control sequences. This functionality is expressed as status on demand. Together the three areas encompass the notion of bilateral expression of behavior between humans and machines through a multiplicity of visual media. (Figure 1)
(BBM-CHS). Although applicable in any teleoperation domain, we have concentrated our application of BBM techniques to teleoperation in the microworld. New techniques to analyze individual Mato fluorescent granular perithelial (FGP) cells [5] require the isolation of each cell by removing the tissue surrounding the cell. Figure 2 shows a visually based manipulator with a two micrometer wide scraper made of glass. Further details about the application and system requirements are presented in §3.1.

In the following paper, we will first present and discuss the three main components of the BBM paradigm: status driven control, behavior media, and status on demand in §2. This will be followed by a discussion of the implementation of the subsystems that perform status driven control, behavior sampling, and status on demand in §4. Finally, we review the experiments performed to show the productivity of using BBM techniques.

2. BILATERAL BEHAVIOR MEDIA PARADIGM

2.1 Status Driven Control Method

The main components and information flow of the status driven master slave control method are illustrated in Figure 3(b). The operator interfaces with a computer screen (labeled VCI) instead of a traditional master manipulator. The slave manipulator itself can be any conventional manipulation arm. The implementation of a status driven control method requires and produces different information than conventional teleoperation control methods (e.g. Figure 3(a)). In particular, data from (visual) sensors in the slave environment is essential to the system control and the task specification by the operator.

![Diagram](a) Teleoperation System via Control Coordinate

![Diagram](b) Teleoperation System via Status

Figure 3. Teleoperation System Comparison

2.1.1 Description of Sensing Points

The status driven control method relies on sensor information from the slave environment. The integration of sensor information into the control algorithm is accomplished through *sensing points*. Sensing points are used to describe pertinent features in the workspace. *Target sensing points* are associated with the target object that is to be manipulated. Once designated, the target sensing points remain fixed to the image of the object as the object is moved throughout the task. Likewise, *environmental sensing points* are associated with pertinent features in the manipulation environment. Environmental sensing points are similar to target sensing points in that they also remained fixed to the environmental location they were assigned. If the environment moves with respect to the viewing frame of reference, the sensing points track that movement. Environmental points differ from target sensing points in that the environmental sensing points are also the goal states to which the target sensing points are being made to coincide. In other words, the system controls the manipulator is such a way as to cause the target sensing point(s) and environment sensing point(s) to coincide.

The location of the sensing points should be selected by the operator based on two criteria. First, each sensing point should be placed on a relevant physical attribute of the target or environment objects. For example, sensing points could be placed on edges or vertices. Second, since the system manipulations will eventually cause the target sensing points and the environment sensing points to coincide, the sensing points should be located such that coincidence would indicate the final desired state of the target with respect to the environment.

2.1.2 Task Functions

Although the use of status driven techniques are applicable to a wide range of assembly tasks, in this paper we concentrate on a few exemplary tasks and the functions necessary to execute them. The functions correspond to the relationship between the initial and final locations of the sensing points. When teaching the sensing points to the system, the operator selects one of the task functions so that system knows the relationship to achieve the desired final state of the sensing points. Different task functions require differing numbers of sensing points. The functions defined here should not be considered exhaustive or intrinsic. For more complicated assembly tasks, these functions can be combined or new functions could also be designed.[5]

For typical pick & place and insertion tasks, three task functions are implemented: “point”, “center”, and “arrow” which progressively have more constraints on the movement from initial to final state. These three functions, superimposed on tasks in the slave world, are illustrated in Figure 4 and the point function is described as follows.

![Diagram](a) Positioning by “Point”  
![Diagram](b) Place by “Center”  
![Diagram](c) Insert by “Arrow”

Figure 4. Status Driven Task Functions.

The “point” function operates on two points, moving one point so that it coincides with another point. In general, the initial position of the moving point would represent a sensing point on a target object in its initial state.
This function can be executed with purely translational movement. (See Figure 4(a)).

Descriptions of other status driven task functions and details on the control method can be found in [6].

### 2.1.3 Status Driven Summary

One particular point of the status driven teleoperation input system is that instructions of movement to the slave are operations on the sensing points. The manipulator itself is not being controlled by the master, instead the slave component of the system moves the manipulator in response to the desired status of the sensing points as described by the master. Movement of the manipulator is caused by the relative locations of the sensing points. Although the system will automatically cause the sensing points to coincide once specified by the teleoperator, the system is not considered autonomous since the teleoperator is actively specifying the individual steps of a complete assembly or process.

### 2.2 Behavior Sampling Method

#### 2.2.1 Motivation

The status driven control method described so far is basically a very short term control algorithm. Status driven control is concerned with the immediate task of causing the sensing point to coincide to achieve task completion. However, use of teleoperation tools is much more than a disjoint set of independent short term events or manipulations.

For long term manipulation considerations we believe the following three features are essential:

1) A data representation and storage mechanism is needed for visually based control mechanisms. The herefore described status driven subsystem only displays the instantaneous representation of the control sequence and does not provide a means for displaying past control sequences. The only method of reviewing a past manipulation would be to video tape the combined video image and graphical overlay of the control indications.

2) A means to accumulate the underlying raw data (both object visual representation and control instructions) is needed. While some knowledge based or autonomous robots do have mechanisms for accumulating past experience, they tend to be based purely on image frame data or abstract representations or models.

3) The ability to syntactically organize the visual and control information and allow for the addition of semantic information. A status driven controller purposely does not have an underlying concept of the objects it is manipulating. However, when humans are reviewing the information it would be useful for the operator to annotate some of the criteria and information that they used in selection and placement of the sensing points.

The theoretical background of behavior sampling is developed in the rest of this subsection and an implementation is discussed in §4.2.

#### 2.2.2 Input and Output Characteristics

The input to a behavior sampling system consists of the video image of the slave environment and the time stamped control information. The control information includes such items as the location of the objects in the environment and the type of control desired. The control information is typically specified by sensing points and the desired relationship of the final state of the sensing points. All of this information is processed and converted into the behavior sampling data representation. (see Figure 5)

![Figure 5. Behavior Sampling Process](image)

The output of behavior sampling is an indexable, structured file or stream that contains both the visual and control information. The output stream is parsable in such a manner that the form and style of the control performed on a given object in a past sequence is usable for control of a different object in a future situation. In other words, the behavior sampling output is suitable as the input to the status on demand functions.

#### 2.2.3 Visual Objects and Hypermedia

Behavior sampling is partially based on the concepts of hypermedia and syntactical or semiotic analysis. In the visual domain, a basic element is the designation of visual representations of the objects in the environment and their spatial and temporal locations in the scene. These are referred to as visual objects.

<table>
<thead>
<tr>
<th>DOMAIN</th>
<th>IMAGES (SPATIAL)</th>
<th>VIDEO (TEMPORAL)</th>
<th>CONTROL (VISUAL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meta Sign</td>
<td>Picture</td>
<td>Episode</td>
<td>Completed work/assembly</td>
</tr>
<tr>
<td>Signs</td>
<td>Objects</td>
<td>Scene</td>
<td>Individual object task</td>
</tr>
<tr>
<td>SubSigns 1</td>
<td>Surfaces</td>
<td>Shot/Global motion</td>
<td>Sensing pairs</td>
</tr>
<tr>
<td>SubSigns 2</td>
<td>Lines</td>
<td>Objects/Local motion</td>
<td>Sensing points</td>
</tr>
<tr>
<td>SubSigns 3</td>
<td>Pixels</td>
<td>Stationary</td>
<td>Change</td>
</tr>
</tbody>
</table>

The syntactical or semiotic analysis method exploits the underlying structure of the real world scene in the representation. Syntactic methods extract structural information without understanding the meaning or semantics of the visual objects since the elements can be derived through low-level vision techniques. The structure of the visual and control information is extracted by observing signs. The first two columns of Table 1 show Gonzalez’s proposed assignment of signs for the images and video.
domains [7]. The third column shows the control domain signs developed specifically for behavior sampling.

### 2.2.4 OCI Tree Structure

Typically the extracted information is structured into a hierarchical tree-like structure. Traditional scene description techniques are able to describe the spatial temporal relationship between objects and the association of a sensing point to an object. However, a scene description without an appropriate description to describe the overall control change between the objects (as described by the control relationships between sensing point pairs). Each sensing point of the pair would be part of separate objects in the scene description and therefore would not have direct links in the description tree.

We introduce an enhanced tree structure with node control associations (NCA). NCA allow explicit linkage of control information directly between arbitrary nodes through “associative information” in a higher common node. (See Figure 6) These associations can be arbitrarily added and deleted to indicate the control information changes between nodes. The most common case is the association of control information between an individual sensing point in one visual object with an individual sensing point in another visual object. NCA describe three types of information in the nodes: 1) generic: information applicable to the node and all its descendants; 2) intrinsic: information applicable only to the node and not its descendants; and 3) associative: information that relates two or more of the node’s descendants [8].

Figure 6. Visual and Control Tree. Spatial information is represented in linked boxes while NCA fields describe the control information.

### 2.2.5 Syntactical Analysis/Extraction Techniques

The techniques for syntactical analysis are based upon observing the signs listed in Table 1. Syntactical analysis occurs for both the visual and control data domains. Extracted information from the two domains is complementary in that observation of a sign in one domain is often useful for structure segmentation in the other domain.

Segmentation of automated control behavior is rather simplistic since the control actions occur in well-defined states and relationships. Events that are extracted include definition of new status points, when status points coincide, relationships between status point sets, segues, and task transitions.

The lowest level of the visual structuring begins with statistical analysis of the image sequence. Detected signs include motion of the visual objects, global motion, and other significant changes in image statistics. Monitoring of global geometric translations and rotations allows indirect monitoring of camera work. For example, global motion can indicate a change in the operators intended work area. Likewise, analysis of localized translations and rotations indicates manipulation of the visual objects. (See Table 2)

### 2.2.6 Reduction of Visual Data

During the recording phase, the preservation of all aspects of the video is typically redundant for capturing the essence of the control state changes. Although the control subsystem needs to monitor an image tracking window associated with each sensing point, it does not need to record the entire visual object. However, for later analysis by the status on demand functions, the system records the individual visual objects. Also, the later availability of the visual objects is advantageous for human observation of the progress. Often the images of the manipulated objects themselves are sufficient for human understanding of the manipulation. The “background” both literally (in the image) and figuratively (the objects not represented by sensing points) is relatively unnecessary for human understanding. Thus the actual amount of imagery that is recorded and presented is often spatially and temporally sub-sampled based on its relevance to the motion behavior of the operator interacting with the manipulator.

### 2.3 Status on Demand Method

The status on demand functionality is a visually based interface to the behavior sampled data in a status driven system. It displays status transition milestones through imagery, graphics, and text. Thus, an operator is able to view the past sequence of tasks and events in an easy to comprehend and partition manner. The task status at each relevant point in time of the procedure is then available for reference and visual re-manipulation by the operator.

The status on demand subsystem has several levels of functionality. Lower level (Short term) functions provide immediate short term support for the operator to modify a recent manipulation. Higher level (Long term) functions allow for analysis, replay, or reuse of previous manipulation procedures in new control situations.

Several short term functions are described in §4.3.1, however the “undo” function is introduced here as an example. The undo function embraces the typical notion of being able to return the situation to a previous state or condition. In particular, the previous manipulation states are segmented by changes in the state of the sensing points (ie, between status driven function tasks)

The long term status on demand functionality aids the teleoperator and future teleoperators to effectively analyze, reuse, and archive collections of behavior sampled visual control files. The baseline functionality allows the visual and control data of the behavior sampled data files to be reassembled and "played" in a manner similar to the view the operator observed during the teleoperation procedure. Individual visual objects and graphical dis-
plays of the control data are to be individually display-
able.

Complete teleoperation sequences can be quite
lengthy so status on demand should provide a summariza-
tion feature based on the state change hierarchy of multi-
ple tasks in an visual and control tree [9]. The control data
syntax is evaluated in a top-down process and then visual
data associated with the syntax is displayed.

An operator may wish to review teleoperation se-
quences which contains a certain type of object shape or a
certain sequence of tasks. The syntax of the behavior
sampled data also allows the status on demand system to
search for individual components in the teleoperation
since the visual objects and the control data are separately
and hierarchically stored.

3. CELL HANDLING APPLICATION AND
HARDWARE

3.1 Application Description and Motivation

The CHS is used in the preparation of single Mato
fluorescent granular perithelial (FGP) cells for analysis.
Mato FGP cells are found in the brain and studied for
their relationship to aging and high-fat diets. Mato FGP
cells, sometimes referred to as perivascular cells, are ap-
proximately 10 microns in diameter and exhibit an auto-
fluorescent glow in the range 520 - 570 nm (green light)
when exposed to ultraviolet light. This auto-fluorescent
property is exploited in the image processing to help es-
tablish the approximate boundaries of the cell.

Individual cell analysis and manipulation is becom-
ing increasing important for biological investigation.
Herefore methods of processing typically involved
processing enmass without regard to the potentially dis-
rupting effects of the tissue surrounding the cells. As in-
dividual cell manipulation is a developing field, there is
very little human experience in such areas as how to ma-
nipulate the cell, tolerances of manipulations, appropriate
tools, appropriate processes, etc. To help rapidly accu-
mulate and exploit the new experiences and techniques
currently being developed, the behavior sampling system
is especially effective and being actively used. Biologists
can maintain extremely accurate records of manipulation
trials by visually reviewing the specific steps that a par-
ticular cell underwent. Status on demand functions can
then be used to help recreate processes that were deemed
effective.

One of the first examples of the Mato FGP cell pro-
cessing is isolating the cell from the surrounding tissue.
Although special lighting conditions combined with the
auto-fluorescent property of the Mato FGP cell do provide
good general cell boundary discrimination information,
studies of various segmentation techniques are performed
manually in order to observe the variances of the separa-
tion processing results. Thus behavior sampling is used to
record the scraping path control information along with
the visual information of the work environment.

3.2 Hardware Architecture

Experiments with the bilateral behavior media sys-
tem connected to the cell handling system (CHS) [10]
were conducted. The CHS is capable of manipulating
individual biological cells under optical microscopes. The
scraping tool effective width is approximately two mi-
crometers and the translation accuracy is 0.5 micrometers.
(Figure 8)

The hardware used for the experiments includes: an
Olympus BX60 microscope, 420-480 nm ultraviolet and
white light sources, Sony XC-711 CCD camera, Matrox
Genesis PCI image capture and processing board with TI
320C80 multi-DSP, Sun with Fujitsu Tracking Vision,
Sigma mini-40XY pulse stepping motor stage, SMC-
3(PC) pulse motor controller board, i686 MMX 266 MHz
PC. (see Figure 7) The Windows NT 4.0 hosted software
allows mouse based two D.O.F. control of the scraper tool
and two D.O.F. control of the cell stage by simply clicking
on the captured image of the magnified work area. Sugg-
ested techniques for controlling three dimensional ma-
nipulators and integrating force functions is described in
[9].

![Figure 7. CHS Experiment system block diagram](image)

![Figure 8. Microscope and Cell Handling System](image)
system implementation, sensing point synchronization is accomplished using the Fujitsu tracking vision template matching hardware. The system attempts to move the tool sensing point to the operator selected environment sensing point in a straight path. As the tool moves, tissue is scrapped from the cell slide surface.

The operator is not required to wait for the manipulator to complete its move to an individual environment sensing point. The operator can continue to designate successive environment sensing points and the system will successively use each one as the goal sensing point for the tool sensing point. This feature is referred to as click ahead.

An earlier implementation of status driven teleoperation was in conjunction with the micro handling system (MHS) [11] and implementation details are given in [6]. That system provides the operator several methods for manipulating objects on a micrometer scale and implements all of the function shown in Figure 2.

4.2 Behavior Sampling for Cell Handling

The recording and display composer mechanisms of the behavior sampling system are based upon the draft MPEG-4 framework [12]. MPEG-4 provides a toolbox of functions for video encoding such as specifying and encoding individual objects and specifying how the individual objects are composed to form a complete scene. (Figure 10).

MPEG-4 does not provide mechanisms for segregating or extracting objects from a video frame nor does it provide a mechanism for describing control relationships between objects. Implementation of a behavior sampling system entailed developing two main components 1) an automated video segmentation method and 2) control information processing and storing.

Although many schemes have been introduced to automatically segment an arbitrary video frame into meaningful objects, most have encountered only limited success or required highly constrained video sequences. Edge detection and morphological techniques can be used to provide proposed scene segmentation based on inter pixel contrast, however it is desirable to relegate as many of the proposed objects to the background object plane to dramatically reduce the number of relevant objects to be tracked and encoded. The behavior sampling system exploits the teleoperated control (sensing point) nature of the video scene to aid in the segmentation of the video image into individual control objects. The specification of the sensing points provides an efficient and non-intrusive means of separating relevant video objects by only selecting the object edges in proximity to the sensing points. Table 2 shows some typical transitions and signs that are detected by the low level syntax analyzer.

Table 2. Extraction by Syntax Transitions and Thresholds

<table>
<thead>
<tr>
<th>Step</th>
<th>Transition</th>
<th>Sign / Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scrape initial path</td>
<td>Scraper movement</td>
<td>Tool sensing point control data</td>
</tr>
<tr>
<td>Irrigate around cell</td>
<td>Bubble refraction</td>
<td>Intensity histogram</td>
</tr>
<tr>
<td>New cell</td>
<td>Slide stage movement</td>
<td>Global motion vector</td>
</tr>
</tbody>
</table>

The visual control spatial-temporal hierarchical object description of the scene follows the MPEG-4 scene description mechanism: Binary Format for Scenes (BIFS) [13] combined with NCA. Relevant groups of pixels in the image are grouped to form the target and environment object nodes. Compound sets of object nodes form tasks. Individual objects typically will have one or more sensing points associated with it. In this aspect, the sensing points are part of the spatial-temporal aspect of the scene even though the sensing points themselves are not part of the image representation.

During the time of the status driven control, the behavior sampling system is recording the operator selected sensing points and the intermediate location of the tool sensing point as it is transition between environment sensing points. (See Figure 11(c)) Further, image fragments of the tool, cell area, and background visual objects are also recorded.

Further implementation details of behavior sampling can be found in [14].

4.3 Status on Demand

4.3.1 Short Term Functions

In this system implementation, the short term status on demand functions include: undo, redo, compound manipulation designation, enhanced redo, and rectangular scrape.

Undo returns the manipulator to the previous state and if the process is reversible, returns the environment to the previous state. This is useful when the previous move was undesired. Redo returns the manipulator to the previ-
ous state and then tries to redo the manipulation with a straighter path. This is useful when surface factors or tool dynamics prevented the previous movement from being a straight enough line.

The system also allows the operator to designate a compound set of manipulations as a single unit. This is useful to describe the series of piece-wise linear scrapes around a single Mato cell as a single manipulation. The enhanced redo function can then be used to repeat the entire compound set on manipulations with differing start and end sensing points.

The rectangular scrape function allows the operator to specify two environmental sensing points that are the upper left and lower right vertices of a rectangular region inside of which the manipulator will raster scan scrape.

### 4.3.2 Long Term Functions

The interface to the long term status on demand subsystem allows the user to navigate the visual and control structure contained in the visual control (MPEG-4) file (See Figure 9(b)). The user can select which of the visual objects and control information is displayed. The display of visual objects can be independently selected. Likewise, display of control information is independent of the display of visual information. For example, the user may choose to display the tool visual object and the sensing point information and choose to not display the background information nor text messages.

The visual control data can be "played" in real time, paused, "fast forwarded", or "jumped". The jump functionality allows the user to step through the stream and automatically pause at the next state change or a point in the syntactic control structure. This can be used to create a summary of the sequence in a few still images.

### 5. EXPERIMENTS

#### 5.1 Status Driven Experiments

Several experiments were conducted to compare the speed and accuracy of status driven control versus manual control. The manual control replicates the Sigma MINI-5P controller used in conjunction with the Sigma MINI-40XY pulse stepping motor stage. A path similar to the outline of a Mato cell was displayed on the control screen (Figure 11(a)). The users were asked to attempt to follow the path manually. Figure 11(b) shows the typical difficulty of the operator to follow the path accurately. Figure 11(c) uses status driven control and shows the sensing points (drawn as larger crosses) that were set by the operator and the dots show the path followed by the tool. Figure 12 show the significantly shorter time to accomplish the task using status driven interface compared to manual manipulation. If the operator exploits the sensing point “click ahead” feature, the specification time requires less than one fourth of the time compared to manual control. The overall execution time for status driven execution is also improved when the operator uses click ahead.

One of the most favorable points cited by the status driven teleoperators was the reduction of direct concentration. The operators typically can specify sensing points faster than the tool can scrape and the user does not need to concentrate or observe the completing motion. This is in marked contrast to the manual control method where the user must continually concentrate during the entire execution time.

![Figure 11](image)

**Figure 11.** (a) test path. Control Data: (b) manual. (c) status driven. (d) status driven with status on demand enhanced redo. (e) Enhanced redo on actual cell.

![Figure 12](image)

**Figure 12.** Scrape execution time (5 subjects)

#### 5.2 Behavior Sampling Experiments

The complete BBM-CHS system is able to simultaneously accomplish real-time image capture, status driven control, behavior sampling, storage of the compressed structured data, and short term status on demand functions. A behavior sampling visual control (MPEG-4) file is typically 1/100 the size of raw video and typically 1/12 the size of compressed full frame video.

The behavior sampling system combined with the cell handling system has accumulated numerous cell manipulation trials from several operators and different types of tasks. For example, manipulations with a combination of the scraping tool and a pick & place using a micro pipette (Figure 13) were collected. Analysis of the collected data has lead to improvements in the sampling rates.
5.3 Status on Demand Experiments

The status on demand experiments show the effectiveness of enhanced redo function, summarization feature, and easy customization feature.

Separating the Mato FGP cell from the surrounding tissue requires a band of sufficient width from the surrounding tissue. This band is wider than the scraping area of the tool, thus several passes of the tool are required. A specialized form of the status on demand enhanced redo function has been developed to automatically scrape increasingly wider paths. This allows the operator to precisely specify the cell boundary but then allows the system to automatically clear a successively wider zone around the cell. (See Figure 11(d) and (e).)

The summarization feature selects images from the sequences where changes in the state indicate changes in the individual steps to form a task. A typical example is shown in Figure 14. Since the behavior sampled files are syntactically based, it is easy to add other analysis functions for new users.

Figure 14. Summarization of scrape and pick sequence

The use of the micro-pipette in CHS experiments (Figure 13 and Figure 14) was added to the basic CHS with minimal effort by another experimenter. Since Pick & Place with the micro-pipette had a rather low success rate, custom analysis functions were developed to improve the positioning of the micro-pipette prior to applying suction for the pick operation.

6. CONCLUSIONS

We have introduced the bilateral behavior media paradigm as an effective way of visually interacting for teleoperation. The status driven control method allows visual specification and verification of task states. Behavior sampling allows the system to sample, structure, and store motion control sequences and their associated imagery. Status on demand allows the behavior sampled data to be accessed and reused to repeat or redo a recorded sequence.

Experiments have shown the effectiveness of the approach in microworld manipulation of biological cells. The BBM CHS system allows significantly faster and more robust control of individual cell manipulations. Experiments using the cell handling system accumulated and archived many sequences of biological cells manipulations that are available for training new operators and improved manipulation techniques. Future work involves developing additional status on demand functions for general and specialized operator assistance.

Acknowledgments

We wish to thank Takashi Miyoshi and Taichi Mita for use of the cell handling system and the MPEG-4 IM1 team for their encoder and decoder software.

References


