

A REAL-TIME DISPLAY FOR TACTILE IMAGES

*Filip Fuma and
John Bradley*

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**Department of Computer and Information Science
School of Engineering and Applied Science
University of Pennsylvania
Philadelphia, PA 19104**

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by Filip Fuma and John Bradley
Grasp Lab
Computer and Information Science Department
University of Pennsylvania
Philadelphia, PA

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Introduction

The tactile array sensor is a key component of the multi-sensory integration work at the General Robotics and Active Sensory Perception Laboratory (GRASP Lab) at the University of Pennsylvania.

In our work, tactile sensors provide information about the nature of the contact between an actuated tool, such as a robotic gripper, and its physical domain. This information is used for feedback control of the gripper and robot manipulator to which it is attached, and for tactile perception.

The sensor we currently use, LTS-200 from Lord Corp. [*ref. 1*], consists of a two separate modules (see figure 1):

- a 10 x 16 tactile array, which measures displacement (or deflection) via optical technology.
- a 6 degree of freedom force/torque module using strain gauge technology. The force/torque module is mounted under the tactile array. This is not an array, its output is scalar.

The interface and signal processing circuitry is located in an external box.

The data obtained from the LTS-200 tactile array describes the amount of deformation of the sensor cover. The sensor cover, made from a synthetic rubber, can deform, up to a point, to comply with the surface of the object under investigation (see figure 2). The sensing array samples this surface and data is obtained describing the texture and local shape of the contact area. This tactile sensor can be compared to a range finder, but with very limited span.

The second module of the LTS-200 provides overall force, in x, y and z direction, and overall moments, around the x, y and z direction, which

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result from pressing the sensor against an object.

In the course of using the LTS-200, or evaluating new sensors, we felt a need for visualizing the tactile information obtained. We looked for a format that provides insight into the tactile image and is suitable for further post-processing.

Motivation

Displaying the tactile data in numeric format, organized as an array similar to the arrangement of the actual sites, is not very visually meaningful. We also considered the '3-d mesh' representation. With proper software, the tactile data can be viewed from many angles, and provides some analogy to the actual relief of the explored surface. However, it is our experience that this method of display is not intuitively advantageous, and can become fatiguing with extended viewing.

Given our work with computer vision, we decided to represent the tactile data as a gray-scale image. We find this preferable as we are familiar with this format, and, by making it compatible, the tactile image can be processed with our predeveloped image processing tools. Such a format requires fewer computations than the 3-d mesh, making it easier to display in real-time.

Following the analogy of the tactile sensor to a range camera, but for proximity use, we chose to think of the tactile sensor as a tactile camera, describing a tactile image, in much the same way that a video camera describes an optical image. This is a useful data-representation metaphor, as it is consistent with the desire to represent tactile data as a gray-scale image. Taking the metaphor further, we have designed the software tools for capturing, retrieving, and displaying tactile data along the lines of a video cassette recorder.

Implementation

We have developed an interface [ref. 2] that performs the following functions:

- visualize the tactile output of the sensor array as a gray scale, with choice of color mapping. Forces and moments are displayed numerically, and a subset are displayed as a pitch-yaw graph.
- record the tactile sensor data for further computer processing.
- display prerecorded tactile sensor data.

This program is called Tactile Camera Recorder, TCR. It requires a platform consisting of an IBM PS/2 running PC-DOS 3.3, with a color VGA display and mouse. The data is stored on floppy or hard disk, in a binary format suitable for transfer to Unix machines via ftp or kermit, for further analysis.

The interaction between the user and the program was designed to be intuitively simple and friendly. Most actions require 'clicking' the mouse on the right iconic object. We have been influenced by the Macintosh interface, yet built an interface that is specific to the application.

Terminology: TCR operations are, in many respects, analogous to those of a video tape recorder, or a movie camera (with built-in playback unit and editing lab). The Lord sensor does not generate a continuous stream of data. Instead, the controlling program asks it "What is your state?," and a short time afterward the sensor returns a snapshot of its state when the request was made. These snapshots are called *frames*, in keeping with the film analogy. These frames are organized into a *sequence*, the analog of a strip of film. TCR operates on a single sequence, which can be up to 200 frames long.

Operation: TCR has two main modes of operation: Playback Mode and Record Mode.

In *Playback Mode* (figure 3) previously recorded sequences from disk can be viewed. It is also possible to inspect measurements at individual sites. *Playback Mode* doesn't require a Lord sensor attached to the machine.

Record Mode (figure 4) requires a Lord sensor to be connected to the computer. 'Live' data coming from the sensor can be viewed in real time. The LTS-200 is capable of transmitting this information approximately 4-5 times per second. In Record Mode it is also possible to record sequences, edit them, and save them to disk.

TCR provides two different manners of viewing at the tactile image: Detail View and Strip View.

Detail View (figure 4) is the default view and features a single, large 10x16 grid. Displacement values for each individual site can be read, and selectable cross-sectional profiles along the two axes can be seen.

Strip View (figure 3) loses these features, in favor of viewing several frames from a sequence simultaneously. This provides a visual time history of the tactile exploration. Editing sequences with the Recording Controls can be done in this view. A comment which was entered when the sequence was saved is also displayed.

The user interacts with TCR by clicking the mouse on the various objects on the screen.

The Menu Bar (figure 3b or 4b) lists several commands that may be executed at any time. Some of them may be 'dimmed', and cannot be selected at that time. (For example, 'Save' cannot be selected while in *Playback Mode*, since nothing was recorded.) These commands can be selected by clicking the mouse in the menu bar, and dragging it to the desired

command. Alternately, a command can be invoked by typing its first letter (except in the case of "LoRd", where the command-key is "R", the "L" already having been used for "Load").

<i>About</i>	Clicking the mouse on this command brings up an 'About' box, which lists the authors and gives the version number of the program.
<i>Load</i>	Loads recorded sequences from disk. Loading a sequence overwrites any sequence that was already in memory.
<i>Save</i>	Only available while in <i>Record Mode</i> . Saves the current sequence to disk, for later analysis.
<i>New</i>	Clears the current sequence.
<i>Colors</i>	<p>Cycles between the three color schemes used to represent the amount of sensor displacement. The default is a gray-scale where no displacement corresponds to black, and maximum displacement corresponds to white.</p> <p>A second color scheme is the inverse gray-scale, where white equals no displacement, and black equals maximum displacement.</p> <p>The third color scheme utilizes pseudo-color to represent displacement. The colors follow the standard spectrum, with the 'colder' colors (blue, violet) corresponding to small displacement, and the 'warmer' colors (yellow, red) corresponding to large displacement.</p>
<i>View</i>	Toggles between the two display modes, <i>Detail View</i> , and <i>Strip View</i> .
<i>Mode</i>	Toggles between <i>Playback Mode</i> and <i>Record Mode</i> . Active only when there is a Lord sensor connected to the machine.
<i>Lord</i>	Used to establish communications to an attached sensor. Also used to reset the sensor.
<i>Quit</i>	Used to exit the program.

The *Detail Window* (see figure 4a) shows a greatly magnified view of a frame of sensor data. Along the four edges are *Indicators*, which specify two cross-sections through the tactile image. The corresponding profiles are displayed in the *Cross Section* window (see figure 4d). The indicators can be moved with the arrow keys on the keyboard, or by clicking the mouse in the data area. The value of the site at the intersection of these two lines is

shown at the top right of the window, where it says "VALUE=nn". The button at the top left of the window, where it says "TAPE", selects whether the detail window will show the current frame from the recorded sequence, or live action ("LIVE"). Live action can only be selected in *Record Mode*.

The *Force/Torque Sensor* display (figures 3d or 4d) presents the force data that the Lord sensor is capable of measuring. The first three values are the forces along the X, Y, and Z axes, respectively, in hundredths of a pound. The last three values are torques around the X, Y, and Z axes. The small window shows three of these values graphically, as a pitch-yaw graph.

Z force range is represented by the color of the small square. The coloration is as follows:

FORCE	COLOR
0.0 -- 0.5 lbs	Gray
0.5 -- 8.0 lbs	Green
8.0 lbs and above	Red

When taking measurements, best results are obtained when the sensor is operated with normal forces (along the z-axis) in the 'green zone'. X torque and Y torque are indicated by the displacement of the small square from the center point. X torque results in vertical displacement, and Y torque results in horizontal displacement.

The *Cross Section* window (figure 4d) is available only in *Detail View*. This window shows plots of displacement values along the x and y axes. The axes are selected in the *Detail Window*.

The *Playback Controls* window (figure 3e) contains all the controls that handle sequence playback. The large left and right arrows run the sequence forward or backward. The center square stops the playback. The arrows with the vertical lines advance the sequence (in either direction) by a single frame. Holding either of these buttons down continues to advance the sequence until you let go. The top center button specifies whether sequence playback 'wraps-around' at the ends, or simply stops.

The frame counter control (at the top-right of the window), performs three separate functions. The two arrows in the counter instantly move to the beginning or end of the sequence. Clicking in the numeric part of the frame counter allows entry of a frame number, and jumps directly to that frame.

The *Recording Controls* window (figure 4e) contains all the controls that handle sequence recording and editing. The two buttons with the arrows move forward and backward within the sequence. The 'OVR' and 'INS' buttons select whether recording new frames OVerwrites existing frames, or INSerts new frames at the current frame number.

The '1', '16', and 'CONT' buttons select how many frames are to be recorded. The '1' button records 1 frame, the 'CONT' button records CONTinuously, until stopped, and the '16' button selects any fixed number of frames, between 1 and 199, to be recorded. These buttons only affect the number of frames that will be recorded. Once number of frames to be recorded has been determined, pressing 'REC' will start the actual recording. Pressing 'REC' again, or any of the controls in this box will stop the recording. Recording will turn off automatically when the selected number of frames has been recorded, unless CONTinuous recording has been selected.

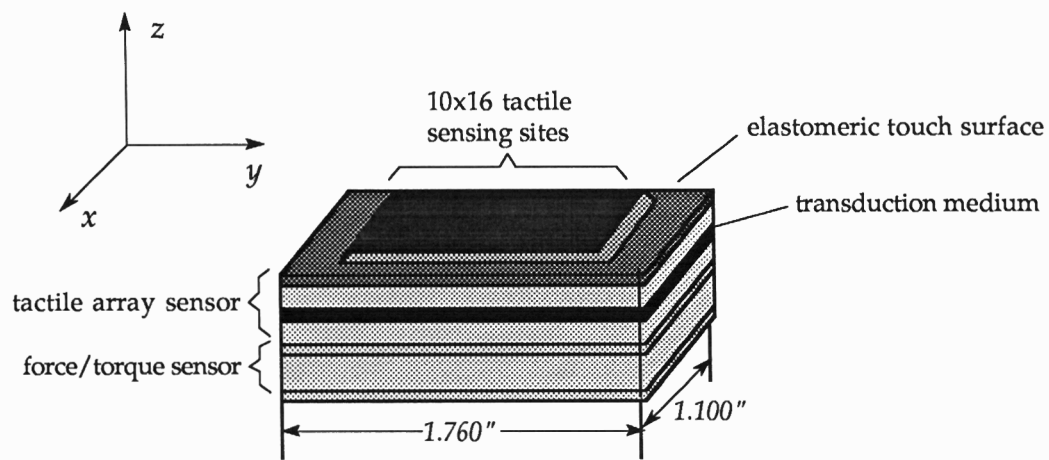
The 'DEL' button deletes the current frame. The frame counter operates just like Playback Mode: press the left arrow to move to the beginning of the sequence and press the right arrow to move to the end of the sequence. To move to any random frame within the sequence, click on the numeric part and type in the new frame number.

The *Lord* dialog box (figure 5) is used to establish communications with an attached Lord sensor, select the serial port where the sensor is connected and zero calibrate or reset the sensor. These functions are invoked by clicking the mouse on the appropriate 'button'. This is a 'pop-up' box, it disappears from the screen when its function is completed.

With the implementation described here, tactile data becomes visually meaningful in a user-friendly environment. The results can then be used for further tactile perception and exploration.

References:

- [1] *"Installation and Operations Manual for the LTS-200 Sensor,"* LORD Corporation; Cary, North Carolina, 1985.
- [2] Fuma, Filip and Bradley, John *"A Procedure for Characterizing Tactile Sensors,"* University of Pennsylvania GRASP Laboratory Technical Report 171, MS-CIS-88-102, Philadelphia, Pennsylvania, 1988.



LTS-200 Sensor

figure 1

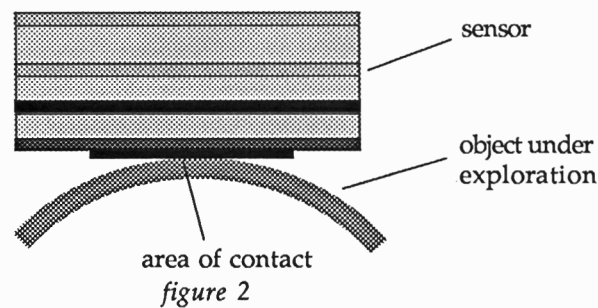
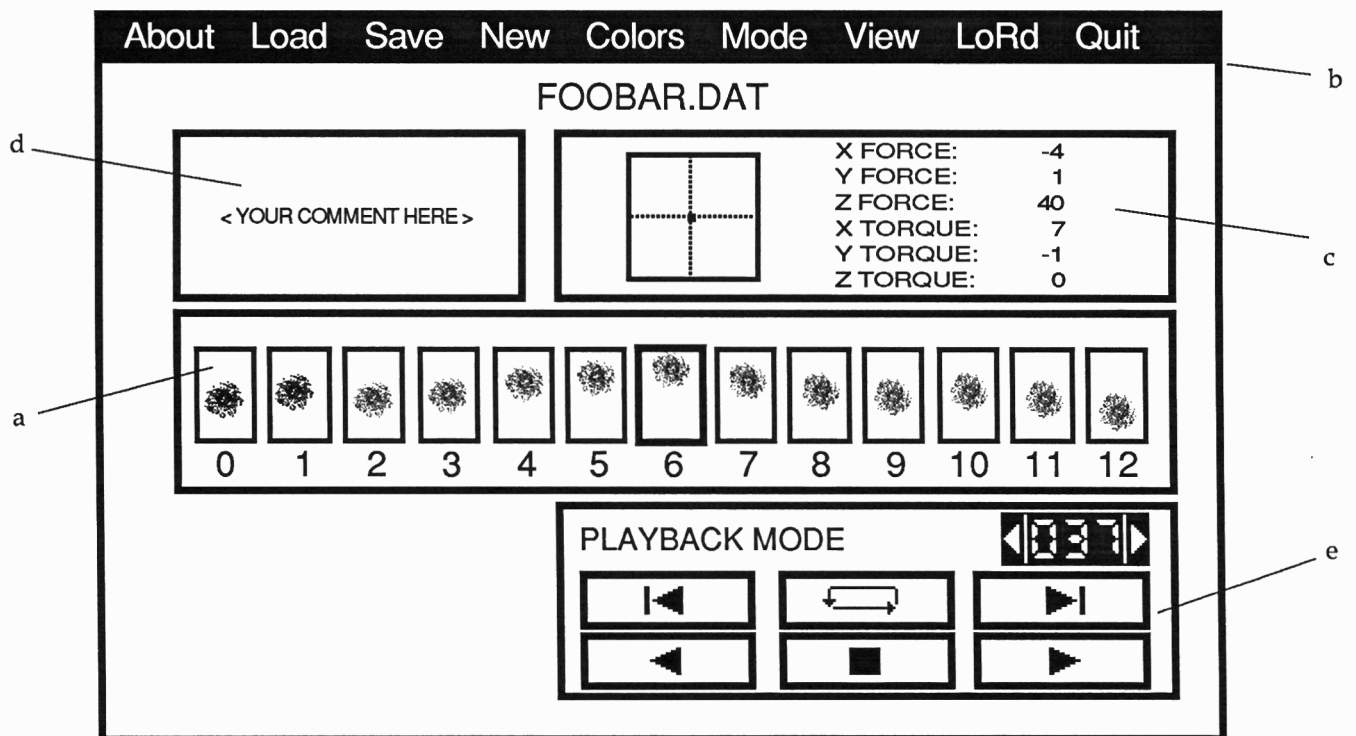


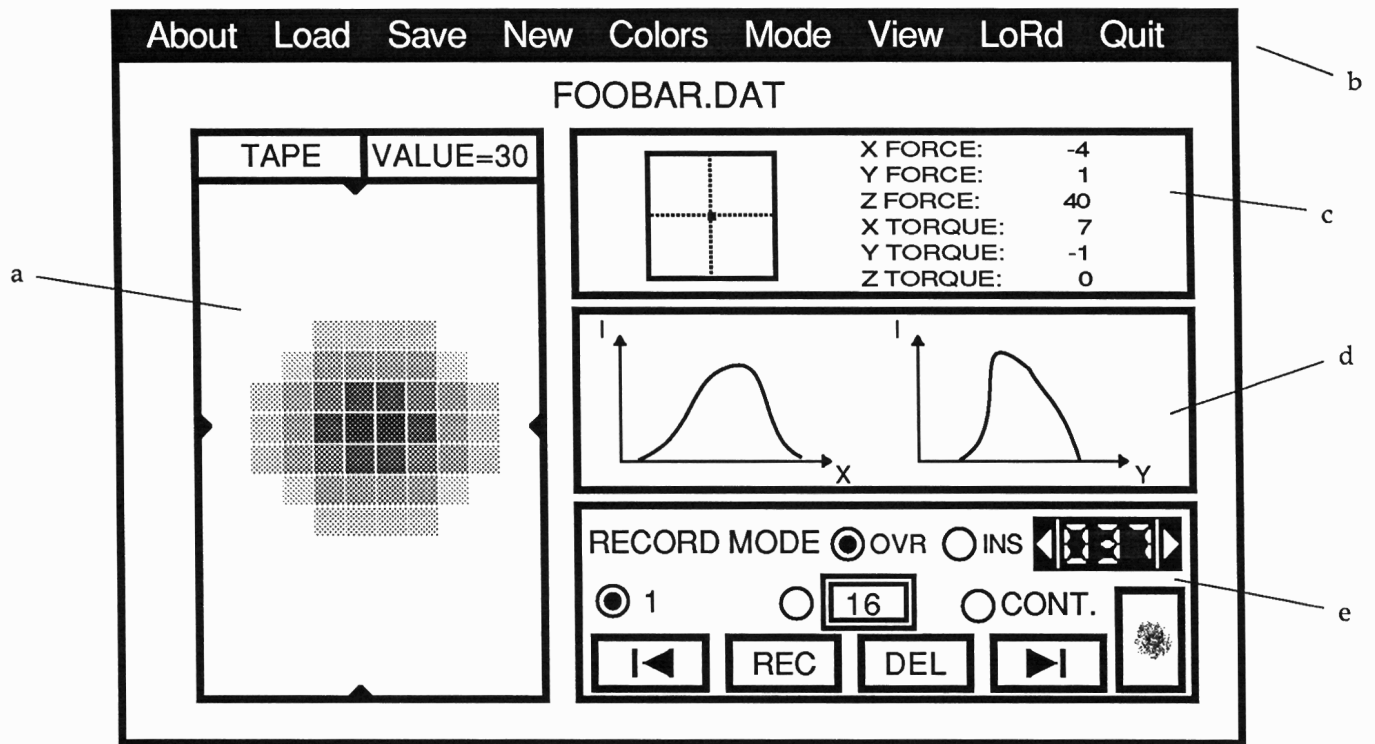
figure 2



Appearance of Screen for Playback Mode and Strip View

figure 3

- a - strip window
- b - menu bar
- c - force/torque window
- d - comment window
- e - playback mode controls



Appearance of Screen for Record Mode and Detail View

figure 4

- a - detail window
- b - menu bar
- c - force/torque window
- d - cross-section window
- e - record mode controls



figure 5