**Report Title**: AN AUTOMATED OPTICAL DISPLAY SYSTEM FOR VISUAL PHYSIOLOGY EXPERIMENTS

**Authors**: J. D. Daniels and T. R. Myers

**Performing Organization**: Center for Neural Science, Brown University, Providence, Rhode Island 02912

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AN AUTOMATED OPTICAL DISPLAY SYSTEM
FOR VISUAL PHYSIOLOGY EXPERIMENTS*

J. D. DANIELS and T. R. MYERS
Center for Neural Science
and
Division of Engineering
Brown University
Providence, Rhode Island 02912

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Abstract

Control of a visual physiology overhead projection system has been achieved by an 8085 microprocessor system, with a supporting array of a-d converters, voltage-to-current amplifiers, d-a converters, and analog switches. Image position, speed of movement, direction, length of sweep and number of sweeps can all be programmed by the operator. Handshake lines send the "start" and "end" signals to another device which correlates nerve cell activity with stimulus movement.
INTRODUCTION

For the recording of single neurons in the visual system two extreme approaches to stimulation are possible. In the *manual* approach the experimenter waves various pictures, props, light sources or patterns in the animal's field of view, correlating in his mind the audio output of a nerve cell response amplifier with aspects of the stimuli. In the *automatic* approach a programmed controller advances the electrode, attempts to separate signal from noise in the electrode amplifier and determines all nerve cell-recognized features of the stimuli: position, size, shape and movement. The controller can occlude one eye or the other for ocular dominance testing. The computer associated with the controller can print out histograms of response versus stimulation and even make decisions about nerve cell classification.

The manual approach suffers from the usual problems of qualitative analysis—requirements for subjective judgement and lack of repeatability. In our case the experimenter becomes additionally preoccupied with the physical activity necessary to move stimuli in front of the animal and he or she may miss important events (such as change in heart rate of EEG) that could affect results. The automatic approach also has drawbacks. The programmer must be completely familiar with every detail of the experiment and predict all contingencies with his code. Computer analysis becomes troublesome when patterns must be recognized or judgements with imperfect knowledge must be made. Cost rises when more and more sensors and motors are placed in system to interface with the central processor.
The interactive approach places the most worthwhile features of a computer controlled system at the disposal of a human experimenter who makes critical judgements and dexterous manipulations. The computer provides precise, repetitive stimuli and records the nerve spike history associated with the stimuli. The experimenter "points" the machine to the approximate field of view, moves the electrode from one nerve cell to another and adjusts surgical and optical components to ensure that the animal and stimuli are in proper condition. In short, the human provides supervision and judgement while the machine provides precise record keeping, and stimulus control.

We have designed and built an interactive computer controller for visual physiology experiments. Our machine controls X and Y servo motors for horizontal and vertical movement of a target, and a high speed shutter. It can receive input either from a joy stick and foot switch in the manual mode or from a portable parameter box in the automatic mode. The parameter box can specify speed, direction, length, delay and number of repetitions for each stimulus. Output terminals provide hand shake signals to a nerve spike counting device.

SYSTEM DESCRIPTION

Figure 1 shows an overview of the experimental set-up. The elements of our controller and its inputs and outputs are shown in crosshatch. On the left, one meter from the screen, is an animal prepared for single unit recording of visual cortex neurons. The experimenter can sit in a
chair near the bench and use the manual mode to make an initial determination of a neuron's visual response preferences (see other technical notes associated with this project for details of neuron responses). The large plexiglass sheet functions as a beam splitter providing an image on a screen for the animal and a reflection down to the bench for the experimenter to draw and study. The three photographs of figures 2 provide views of (a) the main electronics board and power supply, (b) the joystick, with offset control potentiometers, and (c) the portable parameter box with its LED display and keyboard, with display functions.

**SPEED** Numbers entered between 000 (min) and 255 (max) are converted to degree per second speeds shown in the Speed Conversion Table. The 0-9 buttons are used.

**DELAY** Inter-scan delays between 00.0 sec. and 25.5 sec. may be entered. 0-9 buttons are used.

**AUTO** Establishes unlimited number of scans. When Scan is pressed, the machine scans ad infinitum. The scan count displayed increments after each scan. Counter goes to 000 after 255.

**TRIALS** Numbers entered between 000 and 255 cause scanning to halt when the scan count equals the number entered. The 0-9 keys enter the number of trials. When the scan key is pressed, the scan counter is reset to 000 and counts up to the number of trials; the machine is then halted.
HALT RESET  
Halt is the only key acknowledged during scanning. The display shows the number of scans completed. Reset is performed if pressed while the machine is halted. It resets the scan counter to 000.

SCAN  
When pressed, scanning is initiated. The display shows the scan counter, and is incremented after each complete scan.

ORIGIN MANUAL  
Opens the shutter and gives servo control over to the manual joystick. The display shows the A to D conversion of the screen position of the light beam (H or V). "Enter" and "display" apply to the origin registers.

CENTER MANUAL  
Same as "origin manual" but the "center" registers are used instead of the "origin" registers.

ENTER  
The A to D conversion of the joystick screen position is entered into the "origin" or "center" registers, depending upon the function selected. The H or V positions are shown in the display and the light beam is frozen at the entered point. Either manual button returns joystick control.

DISPLAY  
The light beam is frozen at the existing point in the selected register. The H or V positions are shown in the display.

H or V  
Puts the H or V coordinate of the origin, center, or joystick into the display.

0-9  
Enter numbers into the speed, delay, or trials registers. The display shows the updated registers.
ALGORITHM FOR DIRECTED MOVEMENT

Because of memory and coding limitations we required a method of moving the stimulus (along a particular orientation) which could be done by simple calculation, without resort to large table look-up extrapolations schemes. Basically, we need to avoid computing or storing trig functions. As can be noted from the keyboard function table the operator does not enter the angle of a scan, rather the origin and center are put in the system through A to D conversion, with the help of the operator using the joystick.

Figure 3 and following discussion explain the algorithm.

Fig. 3
Using "center" and "origin" information the program computes "end".

\[
\text{assume} \quad \text{origin} = x_1, y_1 \\
\text{end} = x_2, y_2.
\]

The program converts any pair of origin and end points to a special problem of movement away from \((0,0)\) point into the upper right hand quadrant. See Figure 3 for an example. This conversion establishes that

\[
x_2 > x_1 \\
y_2 > y_1 \\
dx > dy.
\]

where

\[
dx = x_2 - x_1 \\
dy = y_2 - y_1.
\]

Four more parameters are defined:

\[
I_1 = 2dy \\
I_2 = 2(dy - dx) \\
d = 2dy - dx \\
c = dx (\text{digitizes } dx \text{ to be an integer counter value}).
\]

To begin,

\[
x = x_1 \\
y = y_1.
\]
For the algorithm, \((x,y) = \text{OUTPUT}\).

If \(c=0\), then STOP.

There are two loops in the algorithm:

**LOOP TOP:**

\[
x = x + 1
\]

If \(d < 0\), THEN GO TO \(d < 0\).

If \(d > 0\), THEN GO TO \(d > 0\).

\(d < 0:\)

\[
d = d + 1,
\]

GO TO **LOOP BOTTOM**

\(d > 0:\)

\[
y = y + 1
\]

GO TO **LOOP BOTTOM**

**LOOP BOTTOM:**

\((x, y) = \text{OUTPUT}\)

\[
c = c - 1
\]

IF \(c = 0\), THEN STOP GO TO **LOOP TOP**

The program can also be stopped by a hardware interrupt.

In the limit, as \(x \to \infty\), we achieve the line equation

\[
y = mx + b
\]

where

\[
d = \left(\frac{1}{m} dy - dx\right) \cdot K
\]

\([K = \text{constant of proportionality}]\)

\[
\text{dy} = m \text{dx}
\]

so

\[
\lim_{x \to \infty} d = 0.
\]
Output is digitized to eight bit resolution. The short horizontal and diagonal line segments generated on the screen by the algorithm are used to achieve the illusion of a single direction, oriented, movement. Speed is determined in a separate timing loop.

Figure 4 is a photograph of the screen while a 40 cm. movement of a tiny spot is executed. The arc of the sweep length is 20 degrees and each of the 60 or so dots represents about a third of a degree movement either horizontally or at 45 degree angle. With the 8-bit D-to-A conversion of the system a slightly choppy movement at low speeds can be detected by a human observer one meter distant from the screen. At speeds greater than 10 degrees per second movement looks reasonably smooth to a human observer. On nearly all kitten and cat nerve cells tested at low speed we find no bursting rate in synchrony with the slightly choppy movement. We conclude that 8-bit accuracy is just sufficient to stimulate kitten nerve cells with apparently smooth movement.

The speed conversion chart shows a range from 0.2 degrees per second up to 140 degrees per second with most emphasis on speeds less than 10 degrees per second. Sweep length maximum is nominally 22 degrees, determined somewhat by the limitations of the MFE scanning servo motors, and otherwise by the scanner-to-screen distance.
We show the major hardware components in Figure 5. It provides a block diagram overview of the circuitry, including input and output. The system features Intel's 8085 microprocessor, 8279 40 pin keyboard and display chip and 8155 RAM I/O with 3 ports, each of which are utilized by the system. In addition, TI's 2508 200 nanosecond 1K X 8 EPROM and National Semiconductor's MM5357 CMOS monolithic A to D converter provide more large scale integration of electronic function.

The 8085 is Intel's 70-fixed-instructions 8 bit microprocessor, which executes statements stored in the 2508 ROM's. We operate it at 4 MHZ. Five control lines and two interrupt allow interface to the slave chips in the circuit. The 8279 is a specialized 40 pin LSI chip which handles all keyboard and display tasks, with signals from the 8085. The 8155 stores dynamic values, provides output ports for digitized signals on the way to D/A converters, and also for control of the LF13331 analog switch set the one amp op amps--LH0021--drive 8 ohm MFE scanning motors which control the x and y positions of the projection mirrors. A bank of 8212 latches handle input and output for the manual control mode, including the status display lights on the programmer's selection module. Joystick potentiometer signals pass through MM5357 8 bit A/D converters. Their end-of-conversion pulses are taken in by the 8085, which in turn delivers start-of-conversion control.
Fig. 5
SOFTWARE FLOWCHARTS AND THE MEMORY MAP

The entire assembly language code which fits in 2K of ROM and was written without the benefit of an assembler. A complete listing is available from the authors. Basically, when the system is on and running it is either reading the keyboard or executing a scan (moving a target).

Details of the keyboard monitor software are given in the figure 6 flowchart. Note that a "wait loop" exists for the condition in which no buttons are pressed. Once the scan button is pressed an interrupt is executed and the particulars of the scan program are shown in figure 7. Here the calculations are made for the decision parameter "d", a shutter is opened and closed at appropriate times, digital to analog outputs are updated, and a delay for speed control is generated.

The memory map for the system is shown in figure 8. From bottom to top we have ROM, RAM, input-output and open expansion. The ports of the RAM I/O chip are addresses in memory; port A is assigned to horizontal movement, port B to vertical movement and port C is a control port. Figure 9 at the bottom shows the four parameters assigned to port C, including shutter control. The top half of figure 9 shows how the status lights are controlled from a port which uses two 8212's. The right side of figure 8 relates the memory map to chip select lines shown in figure 5. In all, \[1C00_{16} = 7000_{10}\] memory locations are used for this system.
SUMMARY

An interactive automated low cost microprocessor driven optical display system has been described. Total cost of the hardware including logic chips, power supplies, cables, servo motors, optical and mechanical hardware is about $700. Development time was 9 months of twelve hours per week work of a senior engineering student. The hardware in its present form is not general purpose or portable; it is custom built for our particular lab needs. However, it fills those needs completely and makes the tedious work of collecting data on single neuron responses to visual stimuli much more productive than either the primitive manual method or the unnecessarily costly fully-automated method. The ideas of the design can be extended easily to other interactive optical displays systems.

ACKNOWLEDGMENT:

We thank Marjory Schwartz for help with graphics.
KEYBOARD MONITOR

15.5

- INPUT KEY CODE
  - SCANNING
    - YES
    - HALT KEY?
      - NO
      - C.E.I
      - RETURN TO SCAN
    - YES
    - C.E.I
    - WAIT LOOP
  - NO
  - IDLE STATE?
    - YES
    - 0-9 PUSHED?
      - YES
      - C.E.I
      - GOTO WAIT LOOP
    - NO
    - MANUAL LOOP?
      - YES
      - 0-9 PUSHED ?
        - YES
        - H/R? (H/V FLAG)
          - YES
          - C.E.I
          - GOTO MANUAL LOOP
        - NO
        - C.E.I
        - GOTO WAIT LOOP
      - NO
      - C.E.I
      - GOTO WAIT LOOP
    - NO
    - CENTER OR ORIGIN MODE?
      - YES
      - 0-9 PUSHED ?
        - YES
        - H/R?
          - YES
          - C.E.I
          - GOTO WAIT LOOP
        - NO
        - C.E.I
        - GOTO WAIT LOOP
      - NO
      - C.E.I
      - GOTO WAIT LOOP
    - NO
    - C.E.I
    - GOTO WAIT LOOP
  - NO
  - 0-9 PRESSED ?
    - YES
    - NUMBER TABLE VALUE TO FUNCTION REGISTER
      - C.E.I
      - GOTO WAIT LOOP
    - NO
    - FUNCTION ROUTINE ADDRESS TABLE
      - GOTO FUNCTION ROUTINE
      - C.E.I
      - GOTO WAIT, MANUAL, OR SCAN LOOPS.

SCAN START INTERRUPT LOCATED AT 02C0,16

16.5

- RESET→O
- TRIG OUT BIT
- GOTO SCAN PROGRAM

Fig. 6
SCAN PROGRAM

LOCATED AT 04A0

15.

IF AUTO, DISPLAY THE COUNT.
IF COUNT, DISPLAY COUNT=000.

CALCULATE P/8 INDEX, dx, dy, I, I', d, and C.
SET H=X, V-Y; OR H=Y, V=X; AND H+H OR V+V.

OPEN SHUTTER ORIGIN-OUT

IF C=0, GOTO FINISH

EXECUTE DELAY=TO SPEED

IF d<0, d=d+1;
IF d>0, d=d+1;
C=C-1
(X,Y)-OUTPUTS [H or V]

IF [X or Y] = [00 or FF], GOTO FINISH.
IF C=C, GOTO FINISH.

COUNT=COUNT + 1
CLOSE SHUTTER IF COUNT, AND COUNT=
TRIALS, GOTO HALT PROGRAM.

FINISH

EXECUTE DELAY

Fig. 7
### MEMORY/PORT MAP

#### MEMORY MAPPED I/O SYSTEM

<table>
<thead>
<tr>
<th>ADDRESS</th>
<th>CONTENTS</th>
<th>CHIP SELECT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000</td>
<td>ROM Ø (2K)</td>
<td></td>
</tr>
<tr>
<td>0400</td>
<td>ROM 1 (2K)</td>
<td></td>
</tr>
<tr>
<td>07FF</td>
<td>RAM (256)</td>
<td></td>
</tr>
<tr>
<td>0900</td>
<td>COMMAND/STATUS REGESTER: 8155</td>
<td></td>
</tr>
<tr>
<td>0A00</td>
<td>KEYBOARD/DISPLAY DATA I/O: 8279</td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>STATUS RD/WR PORT: 2x8212</td>
<td></td>
</tr>
<tr>
<td>1400</td>
<td>HAID PORT IN</td>
<td></td>
</tr>
<tr>
<td>1800</td>
<td>VAD PORT IN</td>
<td></td>
</tr>
<tr>
<td>1C00</td>
<td>OPEN</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 8
### STATUS PORT 1000\text{16}

<table>
<thead>
<tr>
<th>A/C</th>
<th>H/V</th>
<th>S/H</th>
<th>M</th>
<th>M'</th>
<th>F</th>
<th>F</th>
<th>F'</th>
</tr>
</thead>
<tbody>
<tr>
<td>A/C=0: AUTO MODE</td>
<td>A/C=1: COUNT MODE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H/V=0: HORIZONTAL COORD.</td>
<td>DISPLAY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H/V=1: VERTICAL COORD.</td>
<td>DISPLAY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S/H=0: SCANNING</td>
<td>S/H=1: HALTED</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(M_1)</th>
<th>(M_0)</th>
<th>MODE</th>
</tr>
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<tbody>
<tr>
<td>0 1</td>
<td>MANUAL</td>
<td></td>
</tr>
<tr>
<td>1 0</td>
<td>AUTO</td>
<td></td>
</tr>
<tr>
<td>1 1</td>
<td>COUNT</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(F_2)</th>
<th>(F_1)</th>
<th>(F_0)</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 0 0</td>
<td>DELAY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 0 1</td>
<td>SPEED</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 1 0</td>
<td>ORIGIN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 1 1</td>
<td>CENTER</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 0 0</td>
<td>TRIALS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 0 1</td>
<td>MANUAL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 1 0</td>
<td>AUTO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 1 1</td>
<td>COUNT</td>
<td></td>
<td></td>
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</table>

### CONTROL PORT 0C03\text{16}

<table>
<thead>
<tr>
<th>0</th>
<th>0</th>
<th>0</th>
<th>SCAN TRIG OUT</th>
<th>S</th>
<th>H</th>
<th>U</th>
<th>T</th>
<th>E</th>
<th>R</th>
<th>D/A OUT</th>
<th>JOY OUT</th>
</tr>
</thead>
</table>

- **D/A OUT:** 1 selects output to servos
- **JOY OUT:** 0 blocks output to servos
- **SHUTTER:** 1 opens shutter; 0 closes shutter
- **SCAN TRIG OUT:** 1 or 0 sent to histogrammer
- **TRIG IN:**

Fig. 9
<table>
<thead>
<tr>
<th>SPEED</th>
<th>DEG/SEC</th>
<th>SPEED</th>
<th>DEG/SEC</th>
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<tr>
<td>000 (MIN)</td>
<td>.20</td>
<td>130</td>
<td>22</td>
</tr>
<tr>
<td>005</td>
<td>.20</td>
<td>135</td>
<td>23</td>
</tr>
<tr>
<td>010</td>
<td>.21</td>
<td>140</td>
<td>24</td>
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<td>015</td>
<td>.22</td>
<td>145</td>
<td>25</td>
</tr>
<tr>
<td>020</td>
<td>.23</td>
<td>150</td>
<td>26</td>
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<td>025</td>
<td>.24</td>
<td>155</td>
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<td>060</td>
<td>.37</td>
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<td>38</td>
</tr>
<tr>
<td>065</td>
<td>.40</td>
<td>195</td>
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<td>070</td>
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<td>.75</td>
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<td>100</td>
<td>.89</td>
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<td>105</td>
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<td>110</td>
<td>1.4</td>
<td>240</td>
<td>96</td>
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<td>115</td>
<td>1.9</td>
<td>245</td>
<td>111</td>
</tr>
<tr>
<td>120</td>
<td>3.1</td>
<td>250</td>
<td>125</td>
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<tr>
<td>125</td>
<td>8.0</td>
<td>255 (MAX)</td>
<td>140</td>
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FILMED
7-8