Research Note 83-31

AD A132596

PRELIMINARY EVALUATION OF THE LIGHT PEN AS THE KEY COMPONENT IN A MICROCOMPUTER-BASED SIMULATOR

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September 1983

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83 09 16 025

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: Research Note 83-31	2. GOVT ACCESSION NO.: A132 596
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): Preliminary Evaluation of the Light Pen as the Key Component in a Microcomputer-Based Simulator	5. TYPE OF REPORT & PERIOD COVERED
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): James E. Schroeder, W. Alfred Cook, Jr.	8. CONTRACT OR GRANT NUMBER(s): MDA 903-80-C-0345
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Litton Mellonics, P.O. Box 2498, Fort Benning, GA 31905	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 2Q263743A794
11. CONTROLLING OFFICE NAME AND ADDRESS: US Army Research Institute for the Behavioral and Social Sciences, Fort Benning Field Unit, Ft Benning, GA 31905	12. REPORT DATE: September 1983
	13. NUMBER OF PAGES: 24
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

light pen
microcomputer
arcade
simulator
trainer

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Army Research Institute has developed a low-cost, microcomputer-based, part-task trainer named MACS (Multipurpose Arcade Combat Simulator). The key hardware element in MACS is a light pen that reads the raster scan on the monitor and provides the microcomputer with X and Y coordinates signifying where the light pen was aimed at that moment. The purpose of the present research was to conduct a preliminary evaluation of the reliability of the light pen and determine the extent that some real-world variables influence it (e.g., ambient light, glare, distance from the monitor to the light pen, etc.) The reliability of the

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) light pen was found to vary widely depending on the conditions of the test. The most important finding was an interaction between screen brightness and location on the screen in their joint effect on light-pen reliability. The light pen's reliability was found to be unaffected by some of the variables (e.g., ambient light and trigger switch closure). The results of these tests will provide valuable information about the hardware and/or software changes needed to maximize the reliability of the MACS system.

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PRELIMINARY EVALUATION OF THE LIGHT PEN AS THE KEY COMPONENT IN A MICROCOMPUTER-BASED SIMULATOR

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PRELIMINARY EVALUATION OF THE LIGHT PEN AS THE KEY COMPONENT IN A MICROCOMPUTER-BASED SIMULATOR/TRAINER

INTRODUCTION

The MACS system (Multipurpose Arcade Combat Simulator) was developed by the Army Research Institute as a low-cost trainer/simulator alternative for small weapon systems. Figure 1 shows the hardware configuration for the MACS system. The heart of the system is a microcomputer that is programmed to present realistic target scenarios on the monitor. The key hardware element that makes MACS possible is the light pen, which reads the raster scan on a television or monitor and gives the computer X and Y coordinates signifying where the light pen was pointed at that moment. Using the input from the light pen, the computer shows the soldier where he would have hit (immediate feedback) and other relevant training information. The system was designed to be flexible in that the light pen can easily be detached from one weapon (e.g., the M16) and attached to another weapon (e.g., the M72A2 light antitank weapon). For a more detailed description of the original MACS system, see Schroeder, 1983.

The purpose of this paper is to provide a general analysis of the reliability of the light pen and a preliminary investigation of the effects of certain variables on the reliability of the light pen. More specifically, the effects of screen color, screen brightness, light pen sensitivity adjustment, distance to the screen, ambient light, glare, location on the screen, equipment warm-up, and trigger-switch closure on the reliability of the light-pen readings were assessed. High reliability means that the light pen reported constant X and Y coordinates when the light pen was secured in a stable position and low reliability means that the light pen reported inconsistent X and Y coordinates when the light pen was secured in a stable position. In this paper, the index of reliability is the standard deviation of the X readings (Sx) and the standard deviation of the Y readings (Sy). High reliability corresponds to low Sx and Sy values and visa versa. A second purpose was to identify potential problems for the use of the light pen in the MACS configuration. Although hardware and software changes may be indicated, such solutions and tests of those solutions will be reported in future papers. The third purpose of the present paper was to provide recommendations about the hardware configuration for the MACS system.

APPARATUS

The hardware configuration for the current testing consisted of an Apple II+ computer with two disk drives, a Symtec light pen which had been specially constructed for long-distance use, an Apple Language Card to enable Pascal programming, and a Sony 12-inch monitor.

For testing purposes two programs were written. The first program initially painted the screen green. Next, the program took repeated readings of the X and Y coordinates from the pen, each time placing a white dot on the screen to indicate the light pen's position and then painting that position green again. The purpose of this program was to allow the experimenters to

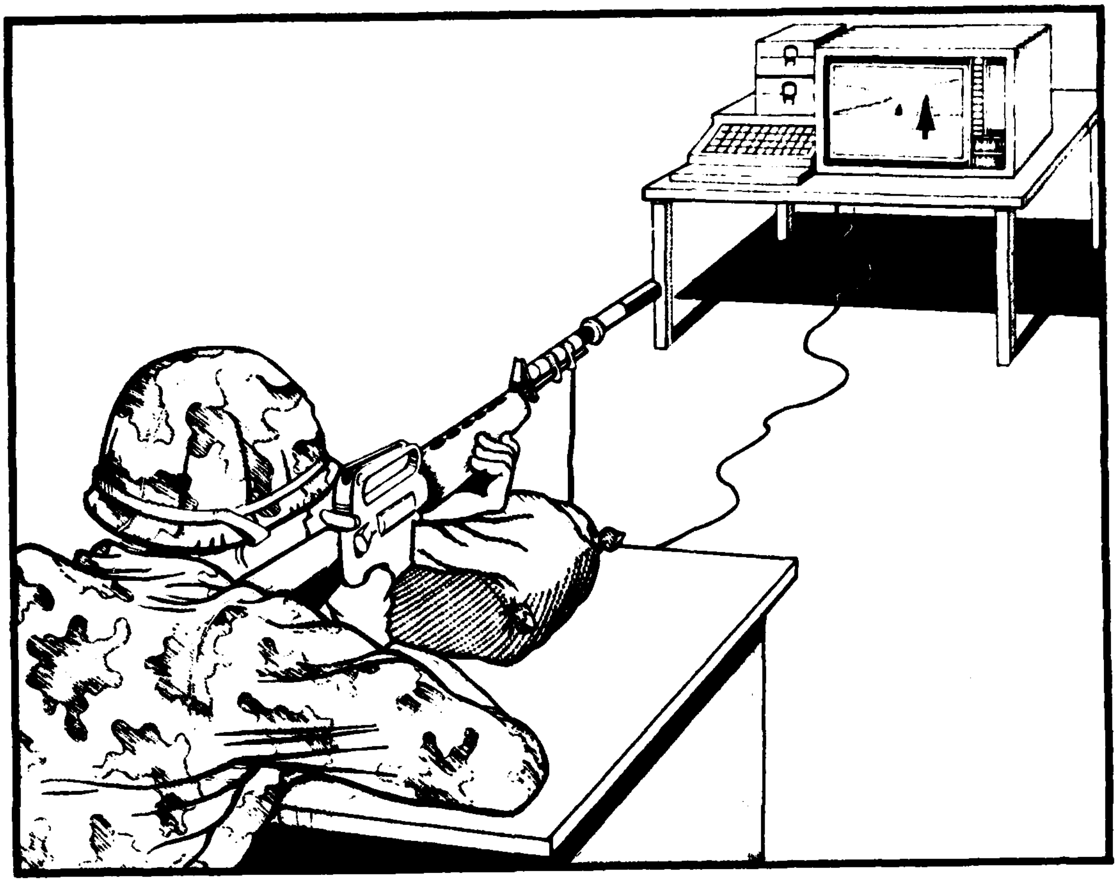

Figure 1. The MACS hardware configuration consisting of M16 with attached light pen, microcomputer with disk drives, and monitor.

determine the location of the point of aim for the light pen and, in later testing, to help calibrate what turned out to be a very complex system. The latter point will be discussed in a later section.

The second program written was the basic data collection program. It was written to be flexible (i.e., different screen colors were an option and the program could collect samples of different sizes). For all program runs, the light pen was secured in a stable position. When executed, the program collected a number of readings for both the X and Y coordinates (either 10 or 100 readings for each). The program would then print both arrays in the order they were collected. Next, the means and standard deviations for both sets were calculated and printed. On some test runs, the correlations between X and Y samples were computed. Finally, both X and Y distributions were sorted and the rank ordered results were printed. The measure of most importance for the following tests was the standard deviation since it reflects the reliability of the light pen. It is important to note that the basic unit for all measurements in this paper was the pixel (picture element). In Apple high resolution graphics mode, the screen is composed of a 280 by 192 matrix of pixels with 0 to 279 pixels on the X coordinate (left to right) and 0 to 191 pixels on the Y coordinate (bottom to top). However, because the Symtec light-pen software provides Y coordinates which are the compliments of the Apple Y coordinates (0 to 191 from top to bottom), all Y coordinates presented in the present paper are Symtec Y coordinates (i.e., 0 to 191 from top to bottom).

All testing was done in a darkened room unless otherwise specified. The computer and monitor were placed on a heavy wooden stand in a darkened cubicle with little ambient light (one 75 watt bulb located 25 ft. away provided indirect lighting for the experimenters). The testing was conducted during the daylight hours in a basement room with two small painted windows. The light pen was cradled on a cast iron tripod with height adjustable from 3 ft. to 7 ft. This tripod allowed easy aiming adjustments of the light pen along with a secure and stable position. The height of the light pen was adjusted to be parallel with the center of the monitor. The above testing environment was selected because it provided a reasonable representation of the setting in which MACS would eventually be fielded. All testing was conducted with the X, Y, and Synch adjustments on the light-pen Apple card held constant. Unless otherwise specified, all testing was done with the light-pen trigger switch always closed and the light pen positioned 8 ft. from the monitor.

RESULTS AND DISCUSSION

Screen Brightness and Screen Position

The results of the early tests to determine the effects of screen brightness revealed an interesting interaction between screen brightness and screen position in their effects upon both (1) whether the light pen would register at all and (2) the reliability of the light pen (the standard deviations of the X and Y readings). Clearly, if the brightness on the monitor is set too low, the light pen will simply not register. The surprising findings were that the brightness of the screen affected both the area of the screen where the light pen would register and the reliability of the light pen readings. More specifically, when the screen brightness was set high, the light pen would make X and Y readings on virtually the entire screen. However, when the brightness was intermediate, the light pen would only take readings if directed at the center part of the screen. This "readable" portion of the screen extends toward the periphery as screen brightness is increased. In addition, the reliability varied as a function of the brightness and the screen location. In general, the light pen's reliability was lowest at the center of the screen and increased as the pen was moved toward the periphery (assuming that the light pen was registering on the peripheral screen). Table 1 demonstrates part of this relationship. Each of the columns of Table 1 presents a different screen location and the statistics for that particular set of 100 light-pen readings. Columns 1-4 and 13-14 represent baseline readings for the center of the screen. The reliability of the light pen readings is best reflected in the standard deviation of the X readings (Sx) and the standard deviation of the Y readings (Sy). Notice how the reliability of the light pen dramatically increases (both Sx and Sy decrease) when the light pen was directed at the corners of the screen.

As mentioned above, both the readable portion of the screen and the light-pen reliability were affected by the brightness of the screen. This relationship is shown most clearly in Table 2. Brightness of the monitor is difficult to directly measure and calibrate without special equipment. Rather, the following calibration method was used. First, the center of the screen was determined and marked. Next, a diagonal line was drawn from the center of the screen to the lower right corner of the monitor. This line was then marked off in 1-cm increments from the center of the screen. For a given reading in Table 2, the light pen was aimed at the mark representing that distance (e.g., 3 cm). Next, the screen brightness was adjusted until the light pen was on the threshold of not registering (i.e., any decrease in brightness would result in no light-pen readings). Finally, the light pen was re-aimed at the center of the screen and 100 readings taken. The statistical results of those readings are shown in Table 2. The columns in Table 2 represent an ordinal measure of screen brightness, increasing from left to right (i.e., the screen brightness had to be increased to go from a 3 cm to a 4 cm screen, increased even more to go to a 5 cm screen, etc.). The light-pen readings were taken in the following counterbalanced sequence (numbers represent cm from the center of the screen) 3, 4, 5, 6, 7, 8, 9, 10, 10, 9, 8, 7, 6, 5, 4, 3, 4, 6, 8, 10, 10, 8, 6, and 4. Of course, the markings on the screen could affect both the location and the reliability of the light pen, so care was taken never to aim the light pen too close to the markings.

As shown in Table 2, the reliability systematically decreased as the screen brightness increased and, hence, as the readable part of the screen increased (i.e., the standard deviations for both X and Y readings increased). The one exception to the systematic increments in Sx and Sy was for the 8-cm screen.

Another very interesting finding was the presence of high negative correlations between the sets of X and Y light-pen readings. As can be seen in the bottom row of Table 2, these high negative correlations were found for all screen sizes. The average correlation for this set of tests was -.76.

Table 1

Light-Pen Reliability at Different Screen Positions*

	1	2	3	4	5	6	7
Screen Position	Center	Center	Center	Center	Upper Left	Upper Left	Lower Left
Sx	4.50	4.48	4.67	5.27	.66	1.26	.96
Sy	3.12	2.86	2.38	3.05	.41	.63	.45
$\overline{X}$	137.64	140.33	136.62	137.58	11.15	11.45	19.84
$\overline{Y}$	90.67	89.49	90.48	90.27	29.93	29.81	155.72

	8	9	10	11	12	13	14
Screen Position	Lower Left	Lower Right	Lower Right	Upper Right	Upper Right	Center	Center
Sx	1.08	.78	.67	1.34	1.40	4.36	4.25
Sy	.46	.28	.24	1.10	1.05	3.97	4.14
$\overline{X}$	19.98	246.48	246.09	242.08	242.27	131.59	131.29
$\overline{Y}$	155.71	162.91	162.94	28.44	28.27	89.08	89.41

* All means and standard deviations are reported in pixels (picture elements).

TABLE 2

The Effects of Screen Brightness on Light-Pen Reliability*

Ordinal Scale of Brightness	Low Brightness 1	2	3	4	5	6	7	High Brightness 8
Readable Screen Threshold	3 cm	4 cm	5 cm	6 cm	7 cm	8 cm	9 cm	10 cm
Number of Samples with 100 Readings Each	2	4	2	4	2	4	2	4
$\bar{S}x$	.40	1.21	1.84	1.84	2.32	1.95	4.61	4.78
$\bar{S}y$	.45	.76	.87	1.01	1.35	1.23	1.92	3.04
$\bar{X}$	147.70	144.30	143.70	147.18	141.88	148.09	142.75	142.11
$\bar{Y}$	97.73	96.57	96.28	96.07	95.56	97.33	92.81	97.65
r	-.72	-.79	-.76	-.80	-.74	-.70	-.91	-.72

* All means and standard deviations are reported in pixels (picture elements).

This fact can hopefully be used in the software to increase the reliability of the light-pen readings.

Light-Pen Sensitivity and Distance from the Monitor

The one adjustment that can be made on the light pen itself is the Light-Pen Sensitivity. This adjustment was found to do just what its label suggested. In fact, the effects of the brightness of the monitor's screen and the Light-Pen Sensitivity were found to be additive. One can consider the Light-Pen Sensitivity to be a rather gross adjustment and the monitor's screen brightness to be a fine adjustment of sensitivity. By adjusting the Light-Pen Sensitivity, all of the changes in readable screen size and reliability of readings discussed in the screen brightness section above can be effected. In fact, when the light pen is moved to a new distance from the screen, the Light-Pen Sensitivity would probably have to be adjusted to a level that would (1) allow light-pen readings to be made and (2) allow some flexibility for the adjustment of the monitor's screen brightness (e.g., one should be able to adjust the screen brightness to a comfortable viewing level while keeping reliable readings).

The general effect of moving the light pen away from the screen was the same as reducing the brightness on the screen. That is, as the light pen moved away from the screen, the readable part of the screen reduced in size from the periphery inward and the reliability of the light pen increased until the point where the light pen was no longer registering. There were no problems moving the light pen back 15 ft. However, for training purposes that much distance is unwise because the trainee would lose the ability to see the details of the target scene and feedback on the monitor. As discussed above, when the light pen is moved 15 ft. from the screen, the Light-Pen Sensitivity and/or the monitor's screen brightness has to be increased accordingly.

Screen Color

Changing the screen's color also changes the screen's brightness. Therefore it was not surprising that screen color was found to affect the light pen's readings in the same way that the screen brightness affected the light pen's readings. More specifically, the "darker" the colors the smaller the readable screen and the more accurate the light pen in the center of the screen. In addition, the color of the screen was also found to influence the mean light-pen readings. This fact (as well as many others reported in this paper) was already known and was incorporated into the earlier MACS design. More specifically, the screen on which the light pen is being aimed must be of one brightness (and, therefore, probably one color) if the light pen is to maintain its accuracy. If the scene were to incorporate graphics features with mixed colors and or brightness, the light pen could yield widely disparate readings. Table 3 shows the general effect of screen color on the light pen readings. The light pen was stabilized and no changes were made in any variables except screen color (houselights were on during the collection of these data but glare was minimal). As shown in Table 3, there was a systematic effect of different colors on both the mean and standard deviations of the different samples. Dark colors can be operationally defined as those colors that produce the same effect as turning down the

Table 3

Effects of Different Screen Colors*

	1	2	3	4	5
Color	Orange	Green	Violet	Blue	White
$\bar{X}$	141.67	131.42	126.05	123.23	123.29
$\bar{Y}$	91.89	87.69	82.86	82.87	82.24
S_x	.93	2.81	5.13	4.13	5.38
S_y	.65	3.23	6.25	5.63	6.72

	6	7	8	9	10
Color	White	Blue	Violet	Green	Orange
$\bar{X}$	124.68	124.03	125.39	132.96	141.30
$\bar{Y}$	80.85	83.12	84.18	87.20	91.68
S_x	5.21	4.47	4.90	3.18	.86
S_y	6.00	6.22	6.26	2.88	.62

* All means and standard deviations are reported in pixels (picture elements).

brightness on the monitor (i.e., those that produce small "readable screens" and those that produce high reliability in the center of the screen). Hence, orange and green were operationally defined as "darker" given the color, hue, and picture control settings at the time of this test because they had relatively low values for Sx and Sy in the center of the screen. In general, the "darker" colors tended to yield higher X readings and higher Y readings. However, one must be very cautious about making any generalizations about the relationships between the various colors and corresponding means and/or standard deviations of the light-pen readings because the critical variable appears to be relative brightness and that can easily be altered within and/or between colors by adjusting the brightness, color, hue, or picture controls on the monitor. The important point is that reliability can probably be adjusted to an acceptable level for any color, but multiple colors in the portion of the screen where the light pen is aimed have an extreme effect on the accuracy of the system.

Ambient Light

Because the MACS system will be used in a number of unpredictable settings, and because the light pen is obviously sensitive to at least one light source (the monitor), the effects of various sources of ambient light and glare were investigated. In order to assess the effects of ambient light, a 75 watt incandescent lamp was used as the extraneous source of light. This light was placed in a number of "worst case" positions in order to assess the resistance of the light pen to such ambient light sources. In one case, the lamp was placed on the top of the monitor (less than 12 inches from the center of the screen) facing directly at the light pen. In another case the lamp was turned directly on the face of the monitor (less than 15 inches from the center of the monitor). Finally, the lamp was physically moved about, flashing toward the light pen and then toward the monitor while readings were being taken. Between each test measurement a control sample was taken with negligible ambient light. The results of these tests are shown in Table 4. As can be seen, there was little if any effect due to the ambient light sources in either mean readings or standard deviations.

Another source of light may have a more direct effect on the light pen's accuracy. It seemed possible that direct glare reflecting from the monitor straight at the light pen could have a large effect on the readings yielded by the light pen. To test this possibility, two tests were conducted. In Test 1, the light source was situated directly above the light pen (within 6 inches). In Test 2, the light source came from overhead and 8 feet behind the light pen. In both tests the lamps were directed at the screen and adjusted so that the experimenter when looking directly over the light pen could not see the spot on the screen where the light pen was aimed because of the reflection of the lamp (using the first test program described above). The results of both tests are shown in Table 5. As can be seen, the light pen was surprisingly resistant to the effects of glare. There was a significant difference in mean light pen X readings for glare and no glare conditions in Test 1 ($t(78)=2.13$, $p<.05$), but there were no other statistically significant differences in mean readings for either test (all three other t's <1.0). There was also a significant difference in variances for the X readings in Test 1 ($F(39,39)=2.01$, $p<.05$), but none of the other three tests for heterogeneous variance were significant (all F's<1.05). In

Table 4

Effects of Ambient Light*

	1	2	3	4	5	6
Source of Ambient Light	None	Light Directly Facing Light Pen	None	Light Directly Facing Light Pen	None	Directly Illuminating Monitor's Screen
S_x	2.43	2.23	1.73	2.34	2.44	2.50
S_y	1.36	1.12	.93	1.20	1.32	1.41
$\overline{X}$	127.82	127.24	126.64	127.28	127.54	127.10
$\overline{Y}$	100.66	100.62	100.90	100.57	100.52	100.38

	7	8	9	10	11
Source of Ambient Light	None	Directly Illuminating Monitor's Screen	None	Flashing Light	None
S_x	2.35	2.32	2.42	2.63	2.02
S_y	1.26	1.19	1.30	1.28	1.16
$\overline{X}$	126.77	126.68	126.77	127.33	126.51
$\overline{Y}$	100.44	100.49	100.45	100.08	100.70

* All means and standard deviations are reported in pixels (picture elements).

Table 5

Effects of Direct Glare*

Test 1

	1	2	3	4	5
Condition	No Glare	Glare	No Glare	Glare	No Glare
$\bar{X}$	191.10	190.30	191.50	190.60	192.40
$\bar{Y}$	70.70	71.20	70.50	71.00	71.00
S_x	2.08	1.57	1.90	1.58	2.12
S_y	1.06	1.48	.71	.82	1.76

	6	7	8	Means	
Condition	Glare	No Glare	Glare	No Glare	Glare
$\bar{X}$	191.20	191.90	191.50	191.73	190.90
$\bar{Y}$	70.50	70.90	70.50	70.78	70.80
S_x	.79	1.97	1.43	2.02	1.34
S_y	.53	1.37	.71	1.23	.89

* All means and standard deviations are reported in pixels (picture elements).

Table 5 (Continued)

Effects of Direct Glare

Test 2

	1	2	3	4	5	6
Condition	No Glare	Glare	No Glare	Glare	No Glare	Glare
$\overline{X}$	104.90	105.00	104.20	105.00	105.30	107.00
$\overline{Y}$	97.30	97.00	97.70	96.70	96.80	96.30
S_x	.74	.94	.63	2.54	2.41	4.92
S_y	1.25	1.05	1.06	1.06	1.40	2.26

	7	8	9	10	Means	
Condition	No Glare	Glare	No Glare	Glare	No Glare	Glare
$\overline{X}$	108.70	104.90	106.00	105.20	105.82	105.42
$\overline{Y}$	94.40	96.50	96.20	95.90	96.48	96.48
S_x	2.41	2.28	3.89	1.62	2.02	2.46
S_y	1.35	1.18	2.15	1.20	1.44	1.35

general, ambient light and direct glare seemed to have little effect on the light pen's reliability. Nevertheless, if fielded, it would probably be wise to advise users to (1) keep the lighting constant within a training period, (2) if lighting changes occur, then re-zero the weapon, and (3) try to avoid direct glare that reflects straight at the light pen. Direct glare should be avoided anyhow because of its effect on the shooter's ability to see the target.

Equipment Warmup

Two tests were conducted to determine whether changes in the hardware of the system due to equipment warmup had any effects on the accuracy of the light pen. In the first test, the test program collected an initial sample of 100 readings for both X and Y, and then the program was re-run every 5 min. until 65 min. had passed. This program was designed to assess any long-term changes due to warmup. As shown in Table 6, there was not much change in mean X or Y readings over the period, but the standard deviations varied considerably from test to test with some of the largest variance found early in the period (in the first 15 min.). Because of this fact and also because the screen brightness had been set at maximum for Test 1, another test was conducted.

In Test 2, the following changes were made: (1) the test was run immediately after power-up and then every minute for the next 19 min., (2) the number of readings per X and Y sample was reduced from 100 to 10 in order to complete the test in a one-minute period, and (3) the screen threshold was adjusted to 8 cm and then the light pen was re-aimed at the center of the screen. The results of the short-term warmup test are shown in Table 7. As can be seen, there was quite high stability in the mean readings for X and Y over the 19-minute period. Also, the reliability was relatively high (given the sample size of 10) for both X and Y with the possible exception of the first three measurements. In total, the two tests seem to indicate general stability with regard to mean readings but increased variability in the early warmup period. For this reason, the equipment should probably be allowed to warm up for 10 to 15 min. before any serious shooting occurs. However, more testing will be conducted to confirm this hypothesis.

Trigger-Switch Closure

The following test was conducted to ensure that the switch closure in the trigger mechanism had no effect on the readings made by the light pen. In the following tests everything was kept constant except the independent variable: trigger-switch closure. On control readings, the connection that activates the light pen readings was shorted out so that the test program initiated the reading procedure. On the experimental test runs, the closure was made manually with a switch. The switch was not the actual trigger switch because pulling the trigger switch would probably destroy the steady position of the weapon. Rather, a similar external switch was wired in parallel with the trigger switch and physically removed from the weapon and cradle so that a steady position could be maintained for the weapon. On each test, 10 X and Y readings were recorded. The results are shown in Table 8. As can be seen, there was virtually no effect due to the experimental manipulation. The means were virtually identical and the mean standard

Table 6

Test 1: Long-Term Warm Up Effects*
(100 Readings/Sample and Maximum Screen Brightness)

Time	Initial	5 Min.	10 Min.	15 Min.	20 Min.	25 Min.	30 Min.
$\bar{X}$	127.46	127.43	126.70	126.96	127.06	126.99	127.03
$\bar{Y}$	139.92	137.39	139.37	139.01	138.20	137.53	138.54
S_x	1.69	1.03	1.51	1.12	1.27	.73	1.02
S_y	5.61	1.27	4.78	4.65	3.46	1.89	3.95

Time	35 Min.	40 Min.	45 Min.	50 Min.	55 Min.	60 Min.	65 Min.
$\bar{X}$	126.88	127.18	127.04	127.10	127.13	127.26	127.30
$\bar{Y}$	137.87	137.66	138.00	138.19	137.79	137.91	138.44
S_x	.92	.98	1.13	1.13	1.01	.61	1.38
S_y	2.81	1.79	2.87	3.22	2.30	2.09	3.02

* All means and standard deviations are reported in pixels (picture elements).

Table 7

Test 2: Short-Term Warm Up Effects *
(10 Readings/Sample and Adjusted 8-cm Screen)

Time	0	1 Min.	2 Min.	3 Min.	4 Min.	5 Min.	6 Min.
$\bar{X}$	148.10	147.60	149.30	147.80	148.80	148.80	147.90
$\bar{Y}$	94.00	94.70	94.70	95.60	95.60	95.40	95.50
S_x	4.36	1.27	3.27	.92	.95	3.05	.99
S_y	1.63	.82	1.64	1.07	1.35	1.35	.71

Time	7 Min.	8 Min.	9 Min.	10 Min.	11 Min.	12 Min.	13 Min.
$\bar{X}$	147.90	147.60	147.90	147.60	147.70	147.90	147.30
$\bar{Y}$	95.40	95.30	95.70	95.60	95.50	95.40	95.90
S_x	.99	.84	1.52	.84	1.25	.99	.48
S_y	.97	.82	1.25	1.07	1.18	.84	.88

Time	14 Min.	15 Min.	16 Min.	17 Min.	18 Min.	19 Min.
$\bar{X}$	148.00	148.10	148.00	148.40	148.70	148.90
$\bar{Y}$	95.40	95.30	95.80	95.00	94.80	94.70
S_x	1.05	1.52	1.05	2.27	2.26	2.73
S_y	1.26	1.06	1.40	1.05	.92	1.16

* All means and standard deviations are reported in pixels (picture elements).

Table 8

The Effects of Trigger-Switch Closure*

	1	2	3	4	5	6	7	8	9
Condition	Shorted	Switch	Shorted	Switch	Shorted	Switch	Shorted	Switch	Shorted
$\bar{X}$	149.00	147.10	147.90	147.00	146.60	147.50	147.60	147.40	147.20
$\bar{Y}$	99.00	100.20	99.60	100.10	99.90	99.80	99.90	99.80	99.70
S_x	1.70	.32	1.91	.82	.70	1.27	1.27	1.27	.63
S_y	.67	.42	.84	.57	.32	.79	.99	.63	.68

	10	11	12	13	14	15	16	Means	
Condition	Switch	Shorted	Switch	Shorted	Switch	Shorted	Switch	Shorted	Switch
$\bar{X}$	147.20	148.00	147.10	147.60	148.30	148.60	147.50	147.81	147.39
$\bar{Y}$	99.90	99.40	100.20	99.60	99.50	99.60	99.80	99.59	99.91
S_x	.42	1.89	.32	1.27	1.49	2.22	1.58	1.45	.94
S_y	.57	.84	.42	.70	.85	1.07	.63	.76	.61

* All means and standard deviations are reported in pixels (picture elements).

deviations were actually slightly smaller for the switch condition than for the control condition (probably due to chance). In any case, the actual switch mechanism didn't seem to have the effect of reducing the reliability or changing the average aiming position.

General Discussion

The main finding of the present research was the effect of screen brightness on reliability of light-pen readings and area of readable screen. This finding becomes even more complicated when considering the number of variables that either directly or indirectly affect the screen brightness: sensitivity adjustment on the light pen; brightness, color, tint, and sharpness adjustments on the monitor; color of the screen; and distance from the light pen. Hopefully, hardware changes will be able to minimize some of these interactions.

Other findings indicated that the light pen was generally resistant to some other possible sources of contamination (i.e., ambient light, glare, distance from the screen (at least out to 15 ft.), and trigger-switch closure). The major problem with the light pen remains its general reliability. However, with the results of the present research and more research that is planned, it is anticipated that hardware and/or software changes will move the reliability of the light pen into the range necessary for basic marksmanship training.

An acceptable level of accuracy for the MACS light pen readings would be accomplished if the simulator's shot group were similar to the "average" shot group of the "average" M16. Empirical evidence indicates the mean extreme spread of three-round shot groups for a cradled M16 is 2.11 cm at 25 m (see Osborne, Morey, and Smith, 1980). The 59 weapons used by Osborne et al. were a representative sample from two categories of rifles at Fort Benning: the weapons pool and OSUT training. Based on the finding from Osborne et al. and the statistical guidelines provided by Grubbs (1964), the unbiased estimate of the population standard deviation is .87 cm at 25 m. The SONY monitor used in the present testing had a high resolution viewing width of 20.48 cm. With 280 pixels on the horizontal axis, each pixel was approximately .073 cm wide. Trigonometrically, to a viewer at a distance of 10 ft., a pixel is equivalent to .599 cm at 25 m, 1.796 cm at 75 m, 3.593 cm at 150 m, 5.988 cm at 250 m, and 7.185 cm at 300 m. Since the standard deviation of the M16 is .87 cm at 25 m, and the size of a pixel is .599 cm at 25 m, then the maximum acceptable standard deviation in pixels is equal to 1.45. In other words, if the standard deviation of the MACS light-pen readings can be kept below 1.45 pixels, then the MACS system will have adequately simulated the shot group of the "average" M16. The results of the present research indicate that this is probably attainable, given certain software features. For example:

(1) The screen brightness must be set to a level that is bright enough to allow an adequate screen size, but not so bright that the light pen's reliability is low. This can be accomplished by a calibration routine at the beginning of the MACS scenario.

(2) As in the original MACS software, the graphics on the screen must be configured so that multiple colors do not appear in the area of the screen

where the light pen is registering.

(3) As in the original MACS software, multiple readings must be taken and then an ordinal measure of central tendency such as the median must be determined. This procedure has a dramatic effect in reducing the standard deviation of the errors. In the results of the present paper, only means and standard deviations of raw light pen readings were reported. When those readings were grouped in sets of 5 readings and the medians of those sets were determined, the standard deviation of the resulting averages drops considerably. For example, in the test conducted to determine the effects of brightness on the light pen's reliability for the 8 cm screen, the original mean standard deviations for the four sets of 100 raw readings for X and Y were 1.95 and 1.23 respectively. These readings were taken in a "worst case" situation, i.e., when the light pen was aimed at the center of the screen. When each of those sets of 100 raw readings was divided into 20 sets of 5 scores and the medians determined, the mean standard deviations for X and Y dropped to .72 and .64 respectively. With the new information about the negative correlation between X and Y, it is hoped that the reduction in error can be further increased. However, moving targets present a larger problem. Although multiple readings are taken for moving targets in the original MACS software, the point of aim is constantly changing if the soldier is correctly tracking the target. To use the last X and Y coordinates as the location for the shot would probably result in standard deviations which are unacceptably high. Rather, the present authors are currently examining the possibility of employing a regression solution, using a number of pre-shot readings to predict the final location of the shot.

(4) Persons using the system should be advised to keep all the brightness variables as constant as possible (e.g., screen brightness, color, hue, etc.) and that if changes are intentionally or accidentally made, to re-zero the weapon.

(5) The targets can be programmed to appear at locations so that the light pen is aimed at areas of the screen with maximum reliability. For example, the targets should never appear just above the center of the screen because then the light pen would be aimed at the center of the screen, an area that results in low reliability.

(6) Hardware changes which result in an increase in reliability would negate any of the above software features and greatly simplify the MACS development. Such hardware changes will be sought.

In summary, although more research is indicated, the results seem to indicate that the reliability of the MACS system can, with appropriate software and hardware features, be high enough to provide meaningful training/simulation. Of course, the final answer will come with training-effectiveness research. The reader should be reminded that currently, on the live fire ranges in Basic Rifle Marksmanship, the only immediate feedback received is hit/miss information. Therefore, a MACS system that allows immediate feedbach in the same range of reliability as the actual weapon should be a valuable training contribution.

CONSIDERATION OF OTHER MACS HARDWARE

This section of the paper provides recommendations for the hardware configuration of the final MACS system. The primary consideration regarding hardware configuration for MACS was the cost. The goal was to develop a simulator/trainer that would be affordable in large numbers using off-the-shelf components. However, cost was considered only to the extent that it did not compromise the training capabilities of the system. Given these criteria, the currently recommended computers for MACS are the Apple IIe and the Commodore 64.

The Apple IIe, while more expensive than the Commodore 64, is still a cost-effective choice. The original MACS software was written in Pascal on an Apple II+ (see Schroeder, 1983). The Apple II+ has since been discontinued and replaced by the upwardly compatible Apple IIe. The Apple IIe has the necessary memory and light-pen capabilities, as well as graphics capabilities including 280 x 192 pixel resolution, 6 colors, and Turtlegraphics. Turtlegraphics simplifies the software development by allowing both relative polar coordinates and Cartesian coordinates to be used in generating the graphics. The Apple IIe will generate audio, which adds to the realism and feedback capabilities of MACS. The Apple IIe supports Pascal, a high-order structured language that facilitates the development of sophisticated software. Also, a full assembler is available on the Apple IIe. Assembler programs run faster than high-order language programs, an important feature for the real-time programming used in the MACS system.

The Commodore 64 is a low-cost computer with the memory (64k) and light-pen capabilities necessary to support the MACS system. Also, the Commodore 64 is compatible with cartridge ROM (read only memory), which is plug-in hardware similar to the game cartridges used in home video-arcade machines. The MACS software could be stored permanently on cartridges. Such storage would eliminate the need for a disk drive, increase the portability of MACS, and reduce the cost of the MACS system. In addition, the reliability of the MACS system would be improved by removing the disk drives because both disks and diskettes easily malfunction due to dirt, static electricity, and physical abuse.

The Commodore 64 has extended graphics capabilities including a 320 x 200 pixel resolution and 16 colors. The Commodore 64 also has a Sprite graphics feature, that allows the programmer to pre-define shapes which can be moved quickly to any location on the screen. This permits more realistic simulated motion. Other features such as full keyboard, assembler capabilities, a sophisticated audio synthesizer capability, and a simple peripheral interface would also aid software development.

Other potential MACS equipment, such as a videodisc player, could add realism to the simulation. Real enemy vehicles and personnel targets could be shown on the monitor and computer graphics superimposed to provide feedback about shot location. However, the addition of a videodisc is not recommended at the present time for the following three reasons: (1) the cost of the system would dramatically increase, (2) given the results of the tests reported in the present paper concerning unreliability due to different screen colors, there would be technical problems associated with videodisc

applications, and (3) training-effectiveness data should be obtained and analyzed before additional costly features are considered.

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