Pragmatic Approach to Device-Independent Color

Roger D. Brandt and Kris S. Capraro
Jet Propulsion Laboratory, California Institute of Technology
Pasadena, California 91109-8099

Abstract

This paper describes the results of an effort to implement device-independent color on three types of devices. The goal was to produce near the same eye-brain response when the observer viewed the image produced by each device under the correct lighting conditions. The procedure used to calibrate and obtain each device profile is described. A commercial color management software system (CMS) was used to transform the input image data to device dependent data.

1. Introduction

The Jet Propulsion Laboratory (JPL) in Pasadena, California has been producing images of planetary bodies for more than three decades. Both continuous tone black and white images and continuous tone color images have been produced for scientists and investigators. Since 1980, over sixty thousand high resolution images have been produced by one recording group alone.

The benefit to JPL of successfully implementing device-independent color on a workstation with a twenty-four bit color monitor, on a twenty-four bit color printer, and on a high precision twenty-four bit color recorder is a significant reduction in cost. The reduction in cost is due to:

Less time is required by analysts to produce an acceptable photo product

Less computer time is required to produce an acceptable product

Less photographic material is required because fewer photographic products need to be produced.

2. Calibration and Profiling

The calibration of the camera systems used to take images of planetary bodies are rigorous and extensive. Calibration files of the camera system are saved for future use when the camera system begins sending images back to earth. The calibration files are used to obtain the complete transfer function of the camera system and to provide information for processing the image data.

The scientists and analysts who reconstruct the images from the digital data received from the camera system aboard a spacecraft normally begin their work at a computer workstation. The transfer function of the color monitor (CRT) on the workstation thus becomes an important part of the total transfer function of the image reconstruction system. Thus there is a vital need to be able to know and maintain the characteristics of the color monitor.

The calibration of the color monitor was done by setting the white-point of the monitor to a desired value and adjusting the gray scale for the best tracking with equal input digital signals for red, green, and blue. At this point two methods were investigated. The first method involved measuring the chromaticity coordinates of the three primary colors and a series of measurements were taken from which the gamma of the monitor was calculated for each color. The second method involved measuring the response of the CRT with a Minolta Color Analyzer, model CA-100, to known digital input signals. These signals included a series (33) of equal digital input signals for red, green, and blue and several hundred combinations of the red green, and blue digital signals that covered the entire input signal space.

At some time in the reconstruction process, the scientist or analyst will want to obtain a hardcopy print of the image that appears on the CRT. If the image on the CRT is deemed to be correct, the analyst expects the identical image to be produced on the device producing the hardcopy print. This expectation, although correct, is not usually realizable in the "real world" for several reasons. For example, the interaction of light with the dyes and pigments of practical printers to form colors is more complex than the color forming mechanism of CRTs. This interaction makes it more difficult to construct an accurate mathematical model for a printer.

Thus the printing device or film recorder also becomes part of the total transfer function of the image reconstruction process and these devices have nonlinear transfer functions. In addition, these devices may have a smaller reproducible gamut of colors than the color CRT and thus limit the efficacy of the general procedure.

The method used to profile the color printers (XL 230 and FU) and the color recorder (MDA) was the same as the second method mentioned above for a CRT except that more combinations of digital input signals were used. The hardcopy print of the known input signals was measured using a Minolta Chroma Meter, model CR221. The measurements were made in the xyY color space and used as input to CMS.

The color gamut for each device is shown in the following diagram. It should be noted that the color gamut of the high precision recording device (MDA) includes any limitations due to the photographic print material. The twenty-four color patches of the Macbeth ColorChecker* test pattern were used to test the three devices. The luminous factor, Y, and the x and y chromaticity coordinates of the Macbeth ColorChecker are shown in the table below.

3. Results

The following diagrams show how the CRT and the printers/recorder reproduced the color patches of the Macbeth ColorChecker. The input signals to the CMS were the xyY chromaticity coordinates shown for the Macbeth ColorChecker.

If all of the devices can produce all of the desired input colors, then an adequate calibration and profiling procedure could be implemented to yield an output image that would be near the same for all devices. However, when one or more of the devices cannot produce all of the desired colors because the colors are outside their color gamut, a serious problem occurs. The procedure(s) that a CMS uses to handle out of gamut colors is critical to implementing device independent color. The particular reconstruction task will determine the method for dealing with out of gamut colors.

Consider a user who is using a color CRT that has a sufficient color gamut to display all of the colors in the image data Assume that the output printer has a smaller color gamut than the gamut of the image data; the user would like to know what the image on the output device will look like before he/she sends the image data to the printer. That is, the user would like to see a "look-alike" or "soft-copy" of the final image from the printer before it is printed. This begs the question. How would the user like the CMS to handle out of gamut colors? For example, should all the colors in the output image be compressed (linearly or nonlinearly) until they fit within the gamut of the output device or should the out of gamut colors be clipped at the gamut boundary?

The MDA and FU each have a smaller color gamut than the CRT (ALT). Seven of the color patches are either outside or near the boundaries of the color gamut for the MDA and the FU devices. The results confirm that these out of gamut colors pose serious problems to creating near the same output image on all the devices. The XL230 which has a larger color gamut yields less difference between the "softcopy" image displayed on the color CRT and the actual image produced. These variations are quantitative and may not necessarily be of the same magnitude on a qualitative scale as determined by actual observers.

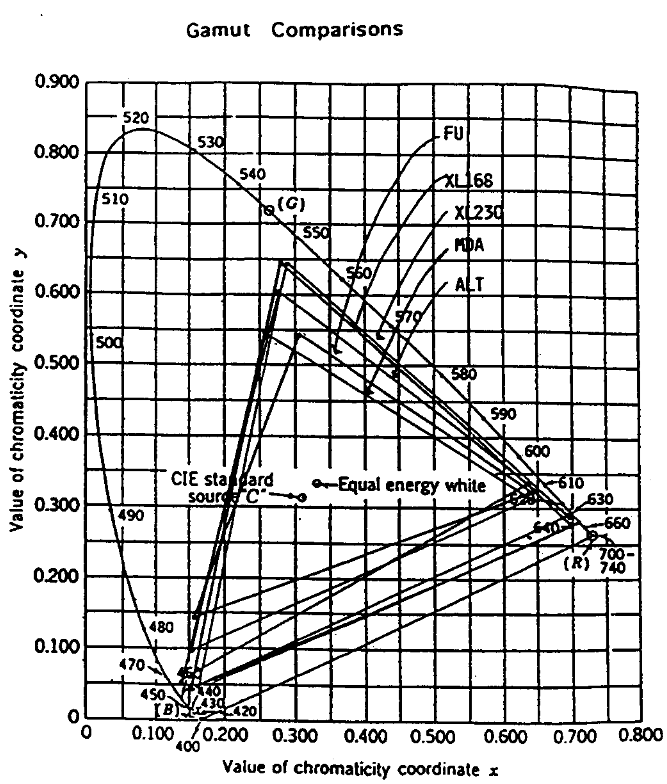
4. Conclusions

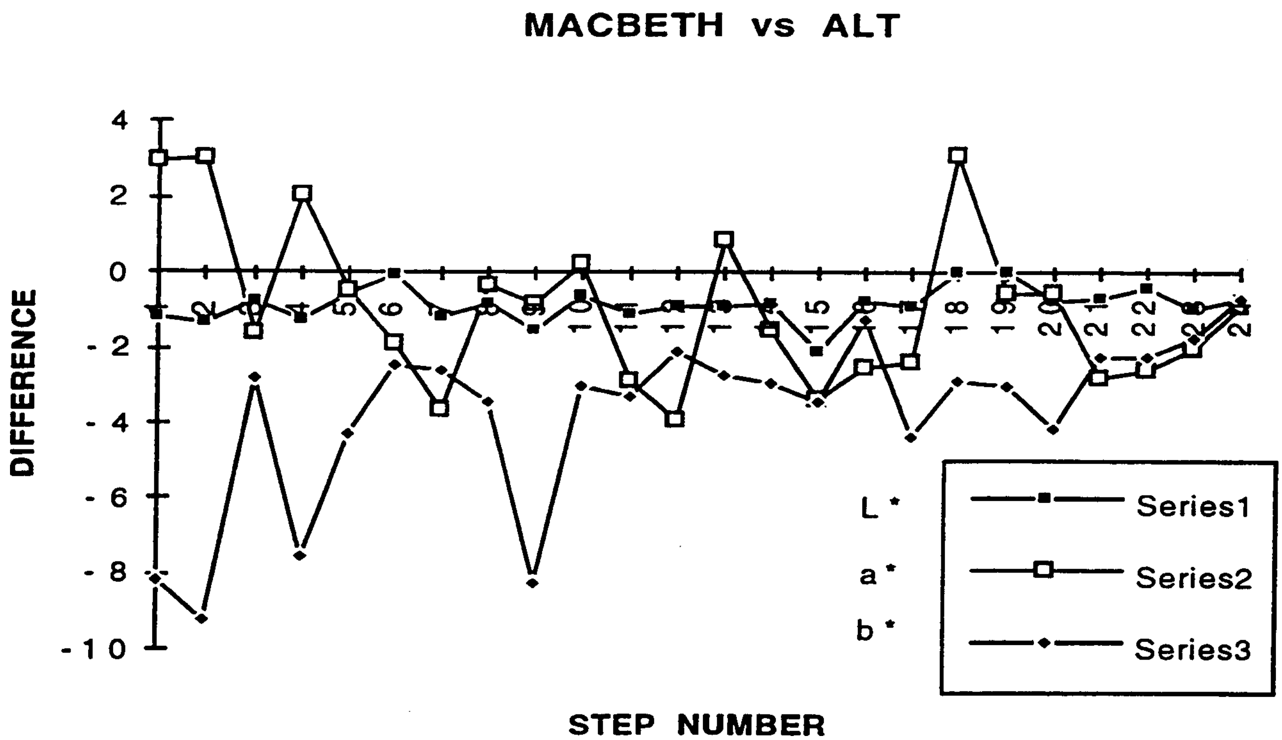
The results of the effort to produce device-independent color on the three subject devices shows promise in the methodology used. The users should be given adequate "real-time" options to deal with out of gamut colors when using a CMS. This procedure has a high potential of reducing the time and cost of producing photo products that meet the requirements of users.

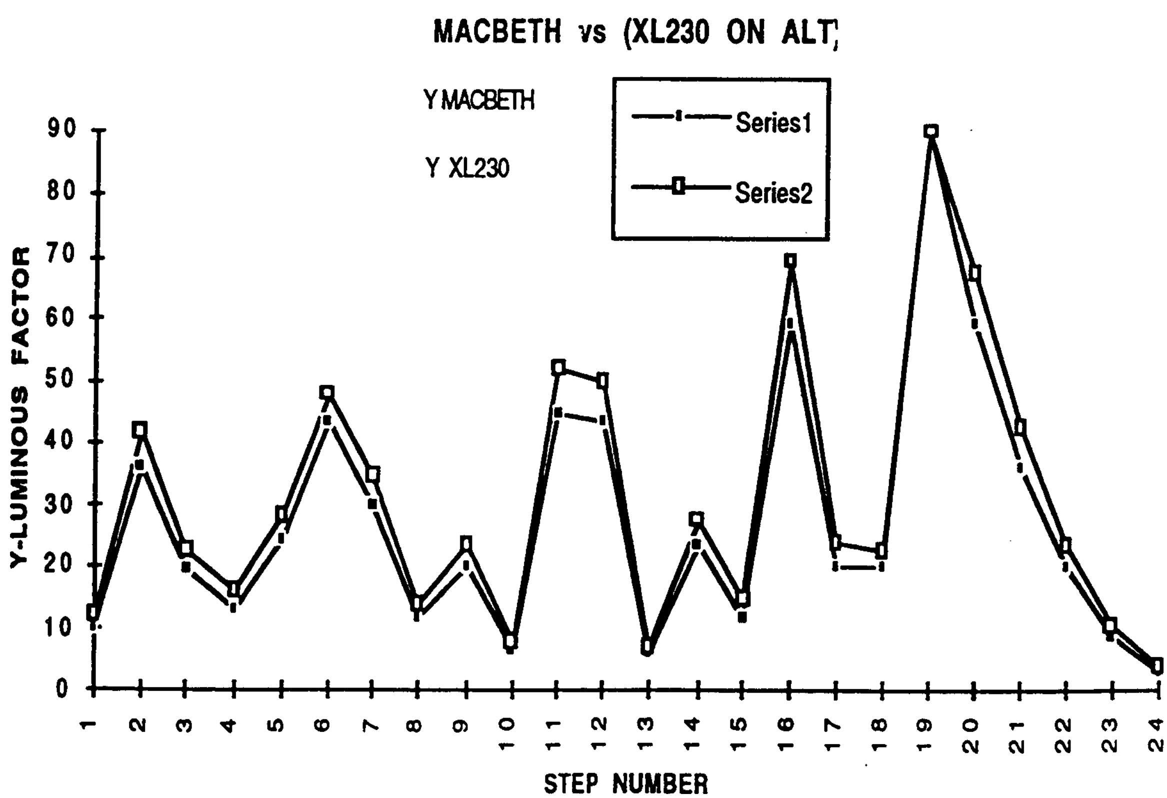
* ColorChecker is a registered trademark of Macbeth, A division of Kollmorgen Corporation

STEP

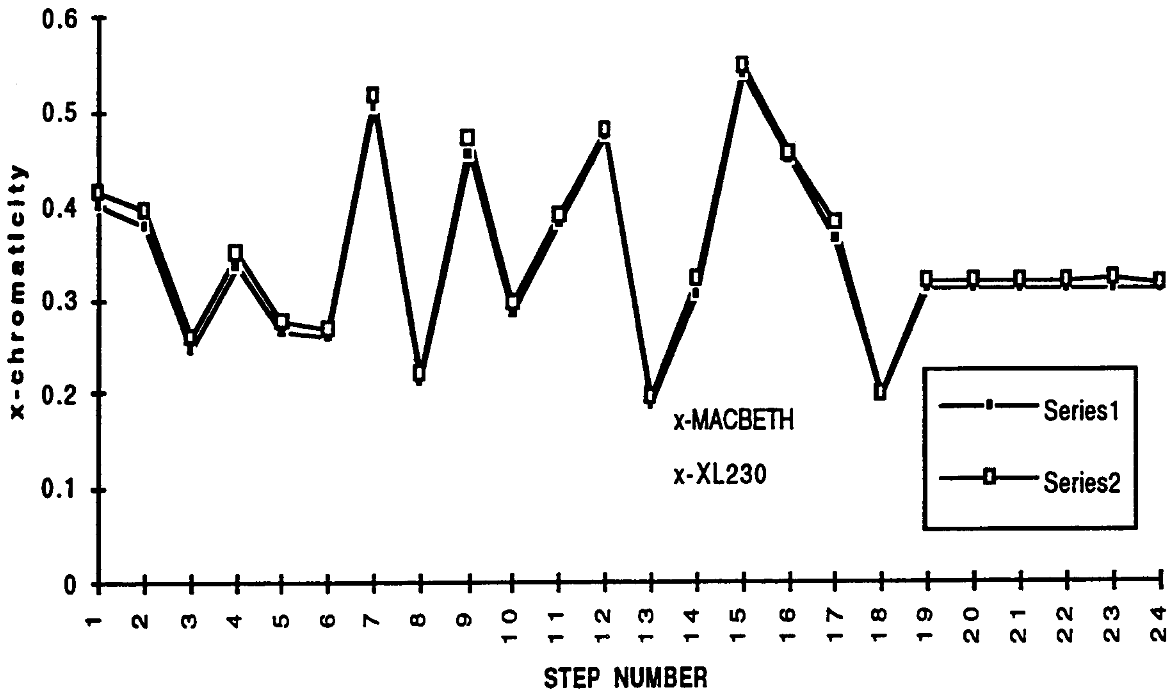
#	x	y	Y
1	0.4	0.35	10.1
2	0.377	0.345	35.8
3	0.247	0.251	19.3
4	0.337	0.422	13.3
5	0.265	0.24	24.3
6	0.261	0.343	43.1
7	0.506	0.407	30.1
8	0.211	0.175	12
9	0.453	0.306	19.8
10	0.285	0.202	6.6
11	0.38	0.489	44.3
12	0.473	0.438	43.1
13	0.187	0.129	6.1
14	0.305	0.478	23.4
15	0.539	0.313	12
16	0.448	0.47	59.1
17	0.364	0.233	19.8
18	0.196	0.252	19.8
19	0.31	0.316	90
20	0.31	0.316	59.1
21	0.31	0.316	36.2
22	0.31	0.316	19.8
23	0.31	0.316	9
24	0.31	0.316	3.1



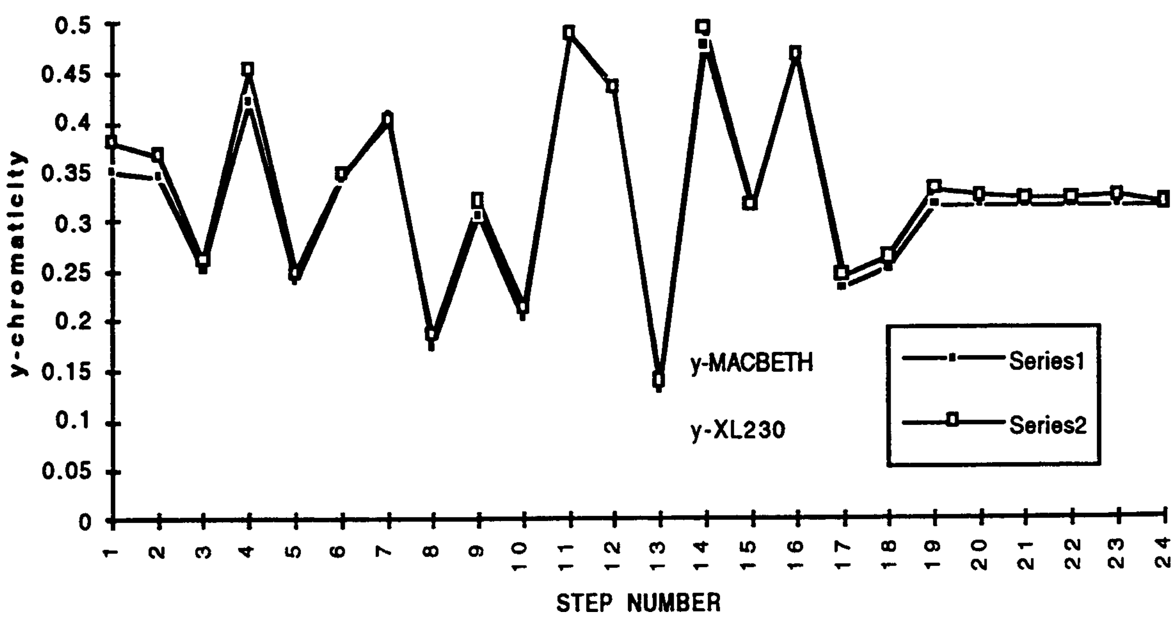

MACBETH vs ALT
DIFFERENCE
STEP NUMBER
L *
a *
b *
Series1
Series2
Series3


MACBETH vs (XL230 ON ALT)
Y MACBETH
Y XL230
Series1
Series2
Y-LUMINOUS FACTOR
STEP NUMBER

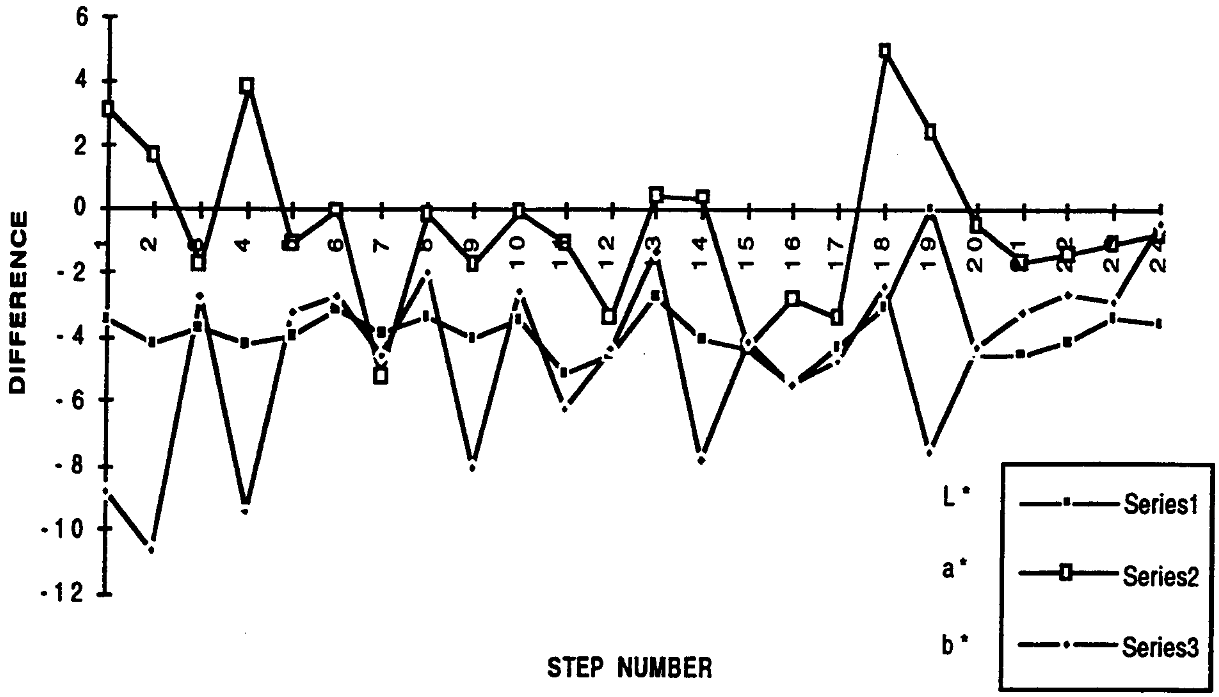
MACBETH vs (XL230 ON ALT)



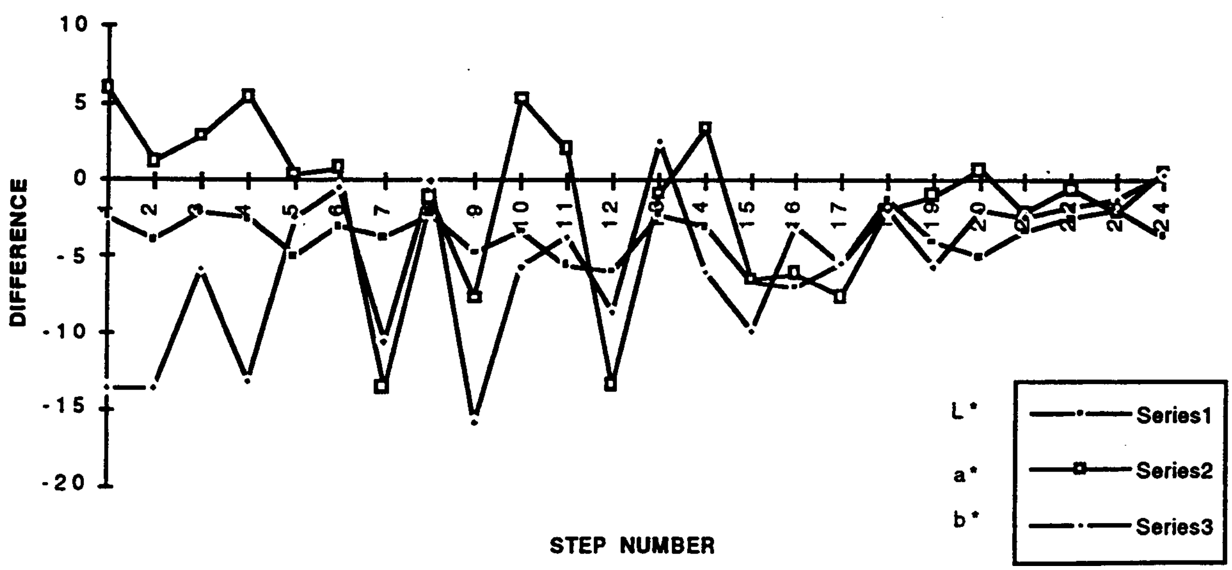
MACBETH vs (XL230 ON ALT)

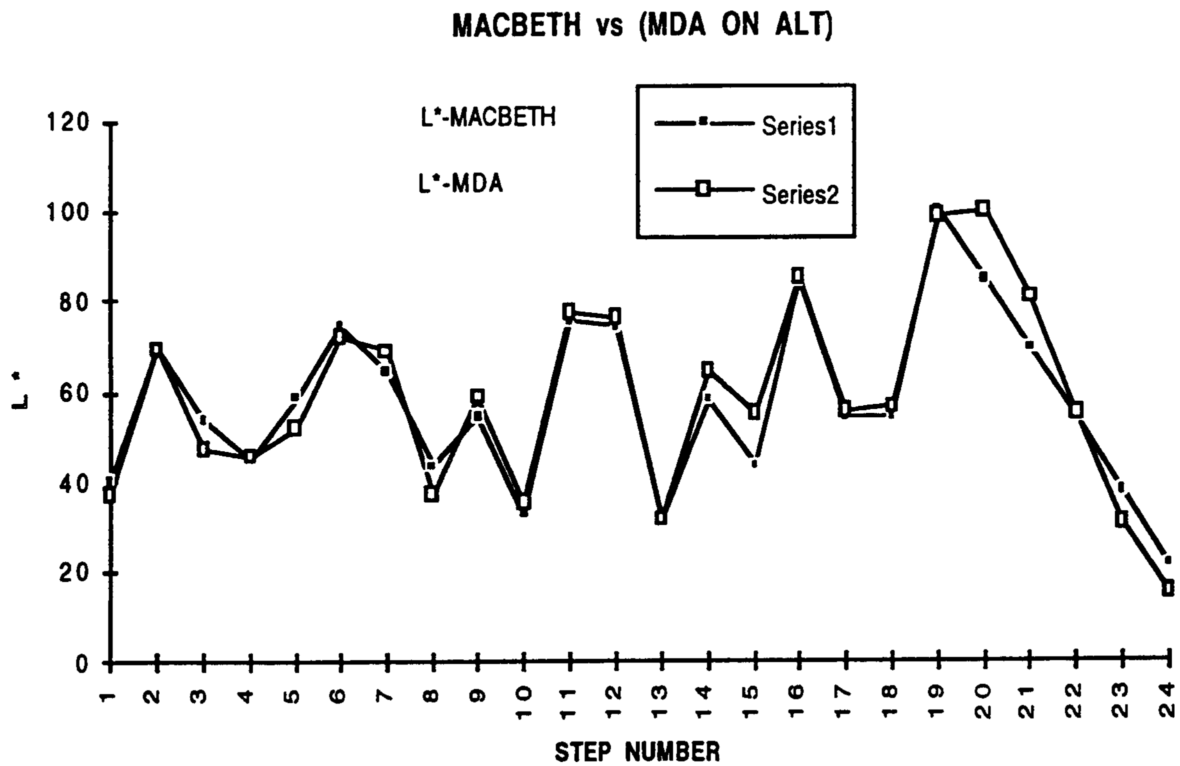


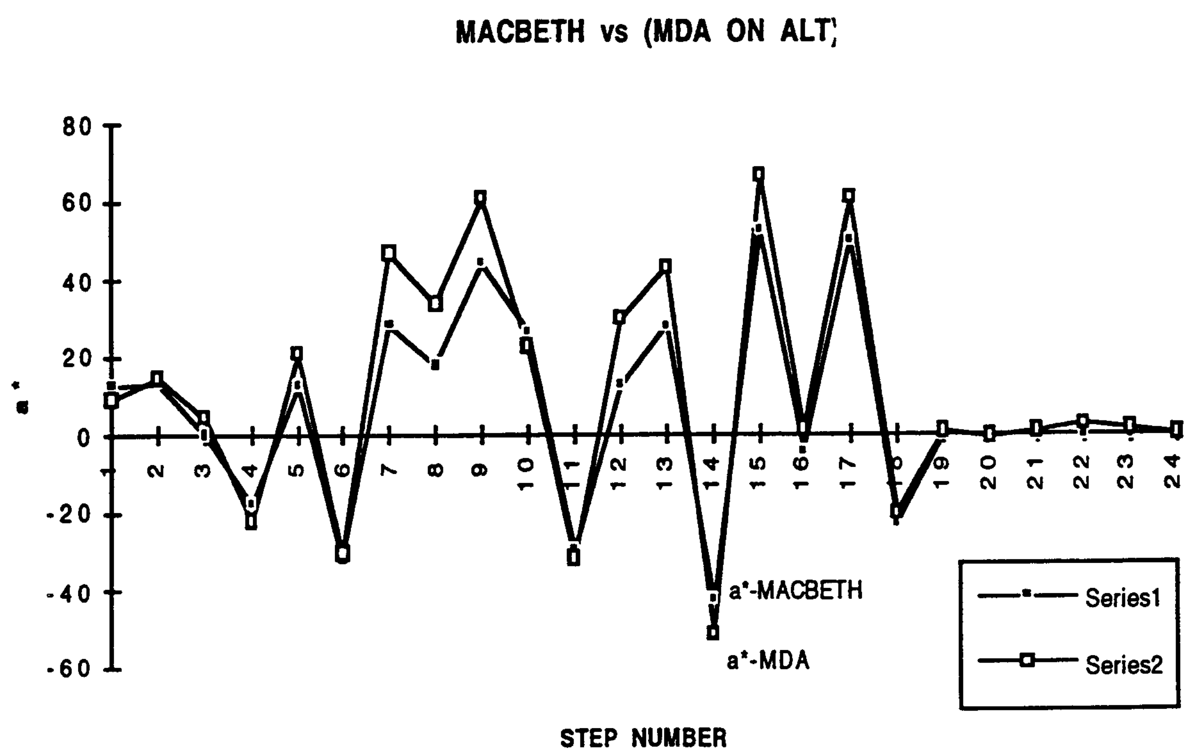
MACBETH vs (XL230 ON ALT) - DIFFERENCE

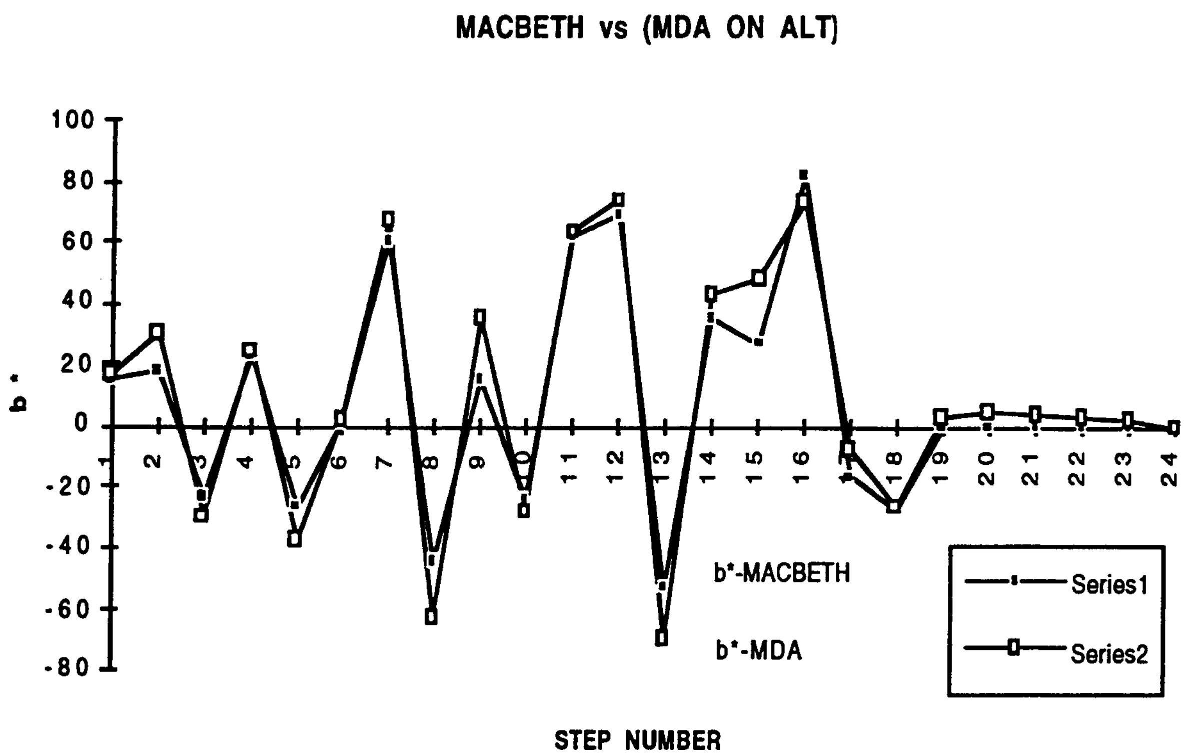


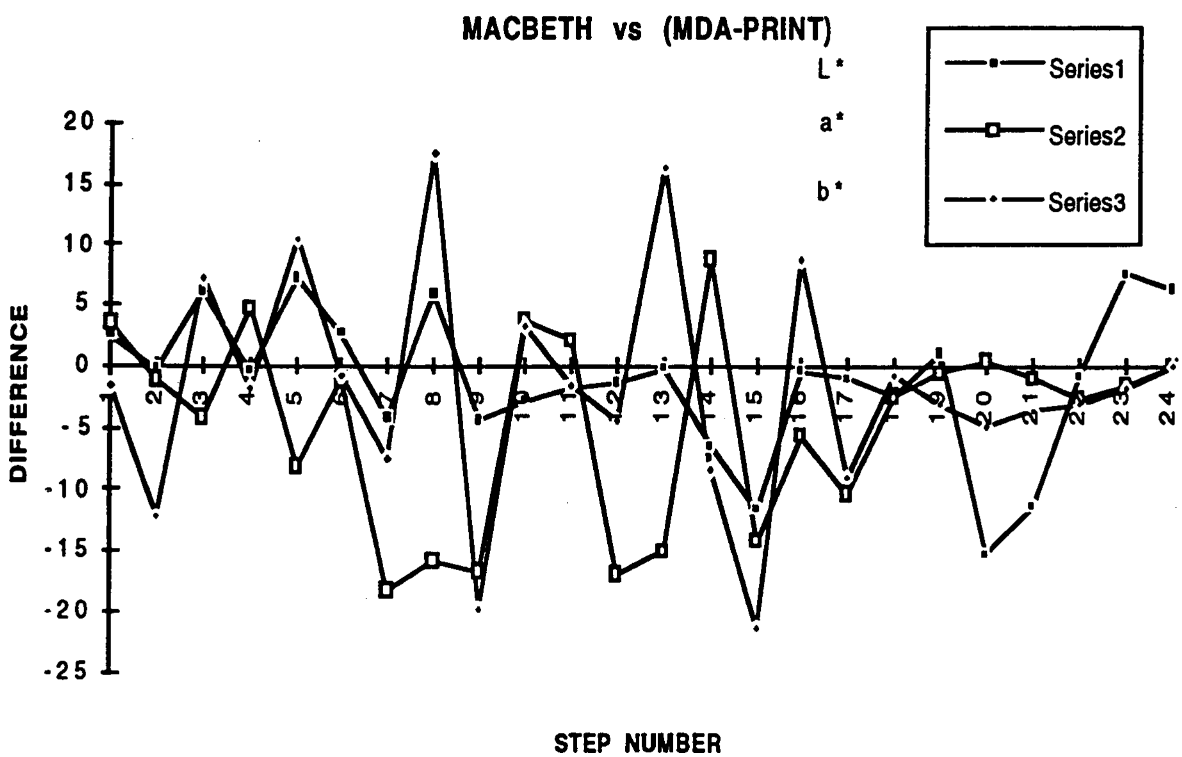
(XL230-PRINT) vs (XL230 ON ALT)

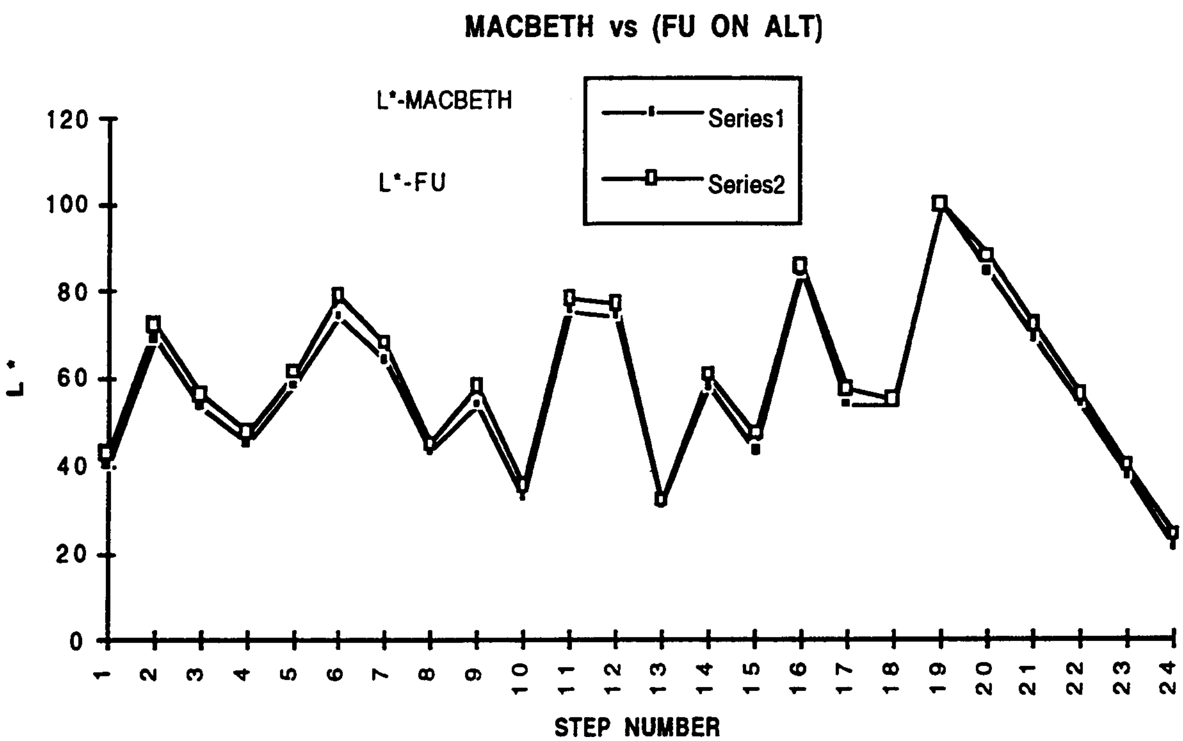


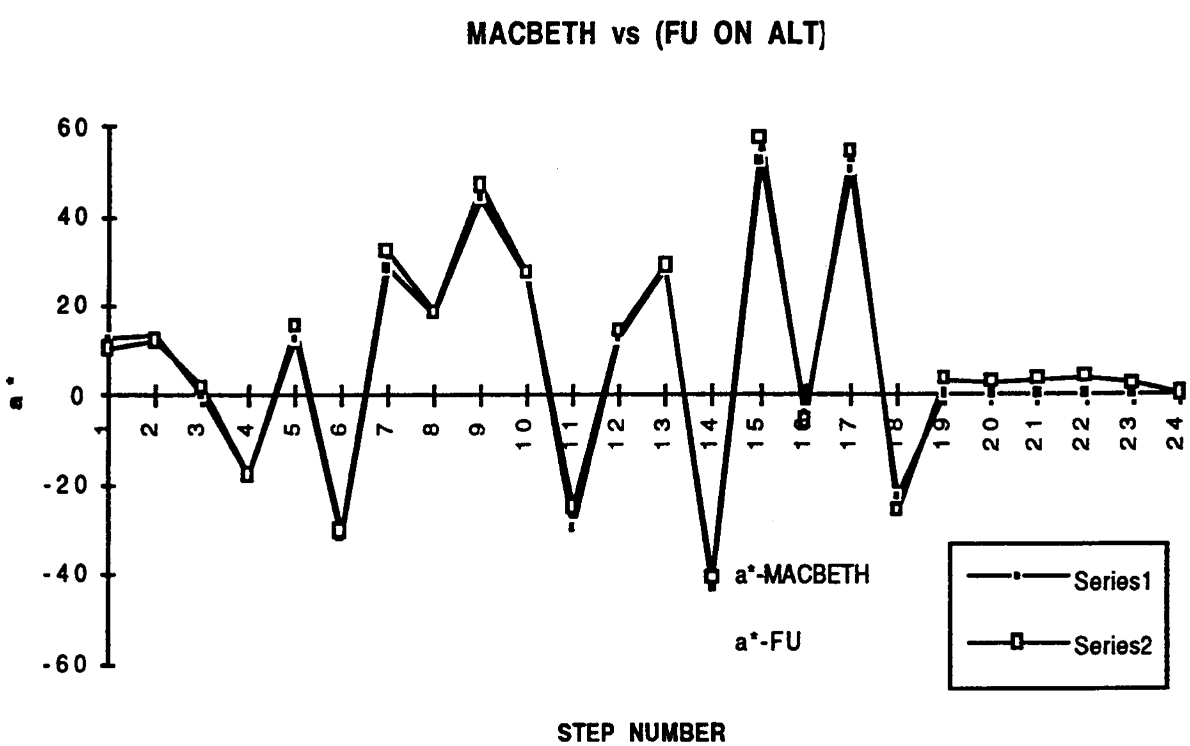

MACBETH vs (MDA ON ALT)
L*-MACBETH
L*-MDA
Series1
Series2
120
100
80
60
40
20
0
L *
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
STEP NUMBER

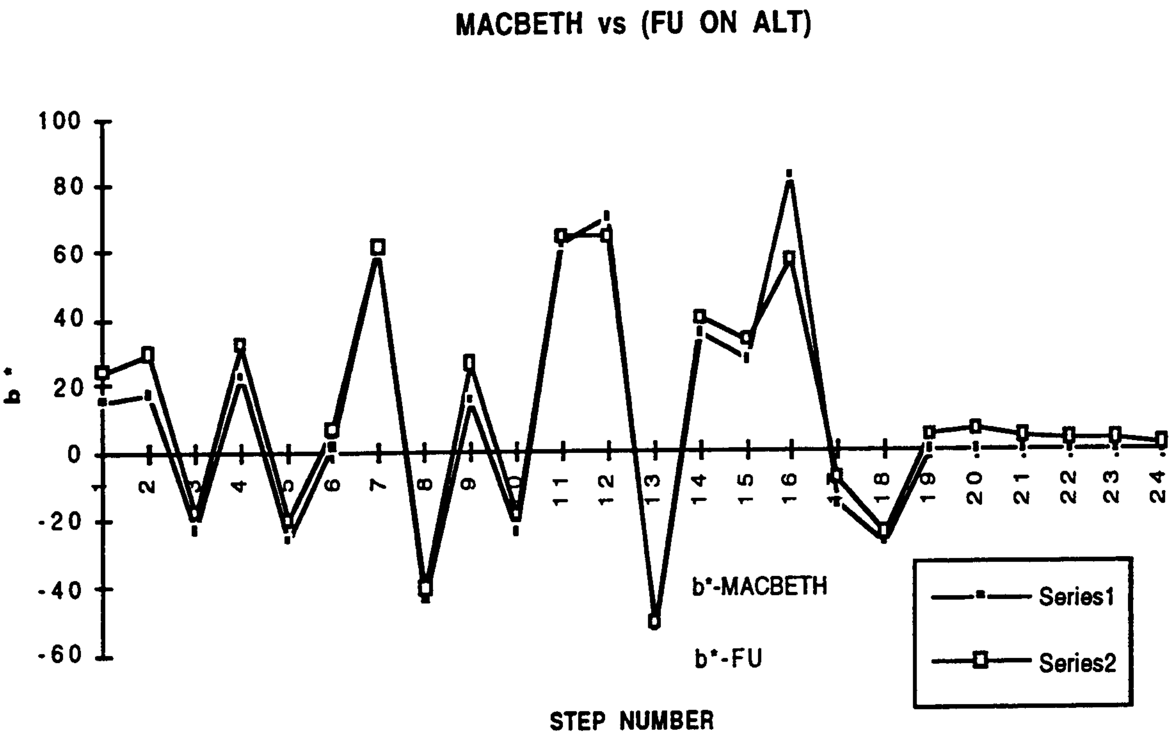

MACBETH vs (MDA ON ALT)
80
60
40
20
0
-20
-40
-60
a *
a*-MACBETH
a*-MDA
Series1
Series2
STEP NUMBER

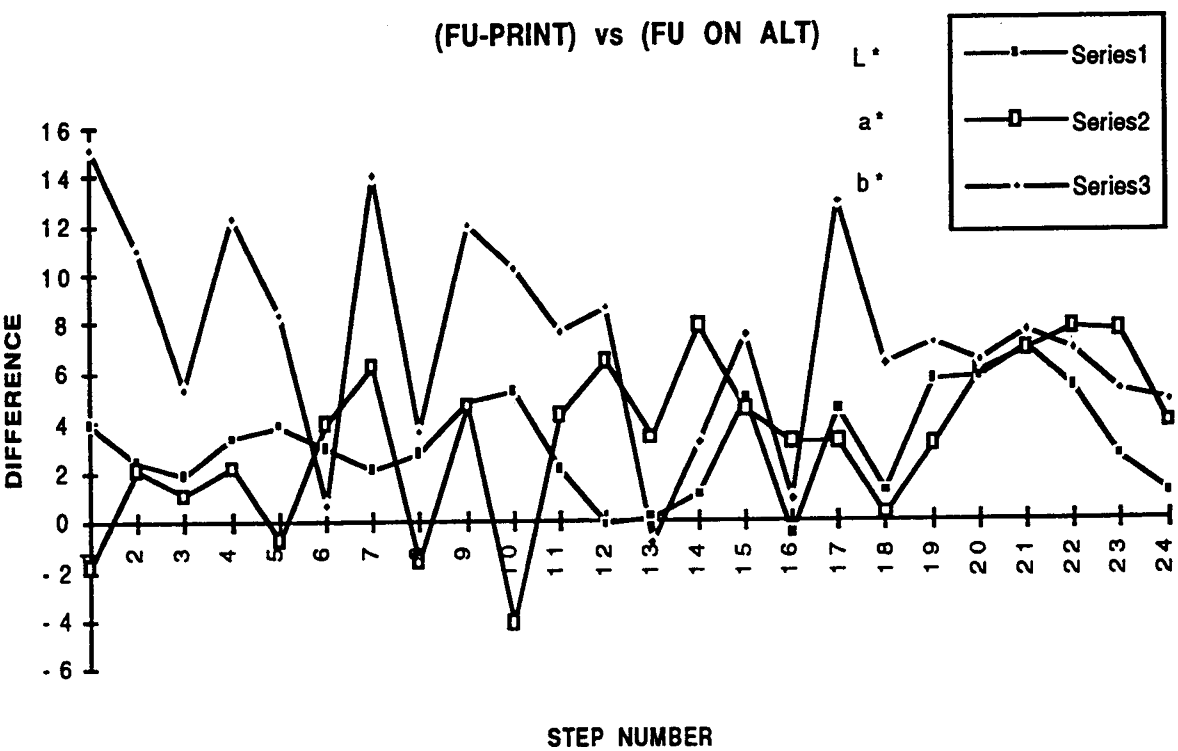

MACBETH vs (MDA ON ALT)
100
80
60
40
20
0
-20
-40
-60
-80
b*
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
b*-MACBETH
b*-MDA
Series1
Series2
STEP NUMBER


MACBETH vs (MDA-PRINT)
L*
a*
b*
Series1
Series2
Series3
20
15
10
5
0
-5
-10
-15
-20
-25
DIFFERENCE
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
STEP NUMBER


MACBETH vs (FU ON ALT)
L*-MACBETH
L*-FU
Series1
Series2
L*
STEP NUMBER


MACBETH vs (FU ON ALT)
a*-MACBETH
a*-FU
Series1
Series2
a*
STEP NUMBER





Acknowledgment

The work described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

☆ This paper was previously published in *SPIE,* Vol. **2414**, p. 178 (1996).