A STUDY ON ANALYTICAL CALIBRATION FOR NON METRIC CAMERA AND ACCURACY OF THREE DIMENSIONAL MEASUREMENT

Shunji Murai, Ryuji Matsuoka and Tsutomu Okuda

Institute of Industrial Science, University of Tokyo

Japan

Commission V

ABSTRACT

A number of non metric camera as well as a metric camera were calibrated analytically by using forty control points with high accuracy.

Specially designed targets with height of 0.0 m, 1.0 m and 1.6 m were set up on the ground and photographed from a gondola with altitude of 8.0 m and 13.0 m.

Single photograph orientation as well as multiple photographs orientation with or without self calibration using the error model which has been developed by the authors were adopted to thirty photographs taken by nine different cameras or lenses.

Accuracies in terms of root mean square of residuals on film and erros of three dimensional coordinates were compared with respect to types of camera, length of focal length, camera altitude, base/ height ratio, orientation methods, types of error models and so on.

It is concluded that non metric camera can be utilized for three dimensional measurement with high accuracy as similar as metric camera, if a proper orientation method and environmental condition of photography are fulfilled.

It can be said also that the error model for self calibration which has been developed by the authors is very useful for non metric camera.

INTRODUCTION

Accuracy of photogrammetry with use of non metric camera depends on the following parameters.

1) Camera type 2) Focal length 3) Film type 4) Altitude or photo scale
5) Base/ height ratio (B/H ratio) 6) Orientation method
7) Error model of self calibration 8) Measurement accuracy of control points and photographic coordinates

The objectives of the study are

1) to evaluate capability of non metric camera for three dimensional measurement by comparing the accuracies with respect to the above mentioned parameters,

2) to determine the optimum error model of self calibration for non metric camera

   and

3) to propose a practical orientation method for three dimensional measurement by non metric camera.

PHOTOGRAPHY BY NON METRIC CAMERA

Photogrphy was carried out in the tall building named "Remote Sensing Experimental Hall" in the campus of Geogrphic Survey Institute, Ministry of Construction. A motor drive gondola as shown in Figure 1 was utilized as camera station. Nine different camera or lenses, that is, seven 35mm cameras or lenses(Olympus and Nikon), a 70mm camera (Hasselblad) and a metric camera (WILD P-32) were utilized as shown in Table 1.

Specially designed targets as shown in Figure 2 were set up on the floor as shown in Figure 3. Forty one targets in total, that is, thirty two targets with 0.0 m altitude, eight targets with 1.0 m altitude and a target with 1.6 m altitude were allocated and measured with accuracy of ± 1 mm.

Photographs were taken from two different altitudes of 8.0 m and 13.0 m with horizontally moved stations as indicated in Table 1. Figure 4 is an example photograph taken by 35 mm non metric camera.

Photographic coordinates were measured by Stecometer (Carl Zeiss Jena; minimum reading unit= 1 um) two times per each point.

Table 1 Camera, Lenses, Film Format, Altitude and Station

No.	Camera	Lenses	Format	Altitude	Station
1	Olympus OM-1(A)	28 mm (wide angle)	36X24 mm	8 m 13 m	2B,B,0,-B,-2B B,0,-B
2	Olympus OM-1(B)	28 mm (wide angle)	36X24 mm	8 m 13 m	2B,B,0,-B,-2B B,0,-B
3	Olympus M-1	28 mm (wide angle)	36X24 mm	8 m	2B,-2B
4	Olympus M-1	50 mm (normal angle)	36X24 mm	13 m	B,-B
5	Nikon F-2	24 mm (wide angle)	36X24 mm	8 m	2B,-2B
6	Nikon F-2	50 mm (normal angle)	36X24 mm	13 m	B,-B
7	Nikon F-2	55 mm (normal angle)	36X24 mm	13 m	B,-B
8	Hasselblad	120 mm(normal angle)	55X55 mm	13 m	B,-B
9	Wild P-32	64.09 mm(wide angle)	81X60 mm	8 m 13 m	B 0

SINGLE PHOTOGRAPH ORIENTATION WITH SELF CALIBRATION

The following collinearity equation with error model for self calibration has been proposed by Murai Laboratory.

$$x = -f \frac{a_{11}(X-X_0) + a_{12}(Y-Y_0) + a_{13}(Z-Z_0)}{a_{31}(X-X_0) + a_{32}(Y-Y_0) + a_{33}(Z-Z_0)} + dx$$

$$y = -f \frac{a_{21}(X-X_0) + a_{22}(Y-Y_0) + a_{23}(Z-Z_0)}{a_{31}(X-X_0) + a_{32}(Y-Y_0) + a_{33}(Z-Z_0)} + dy$$

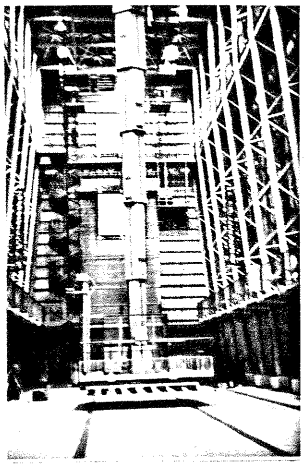

Figure 1 Gondola

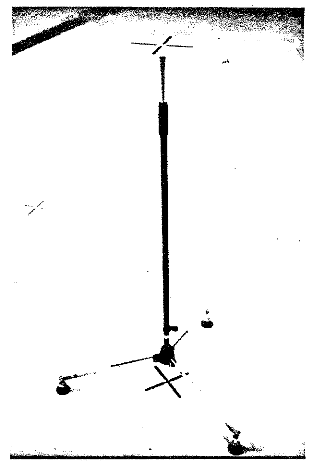

Figure 2 Target

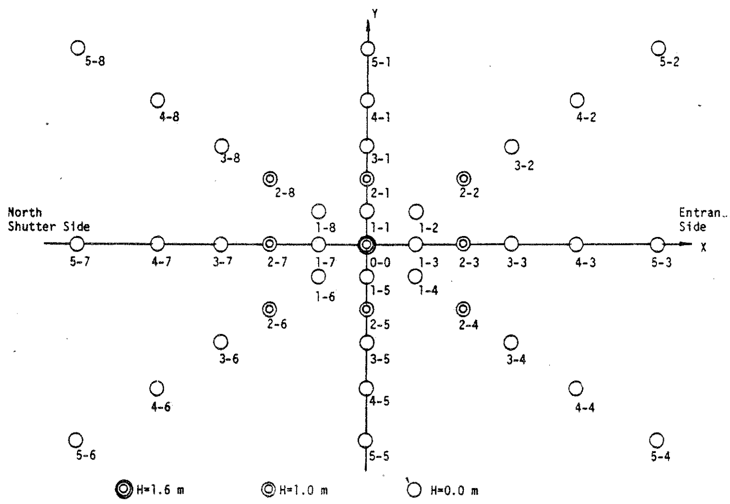

Figure 3 Allocation of Control Points

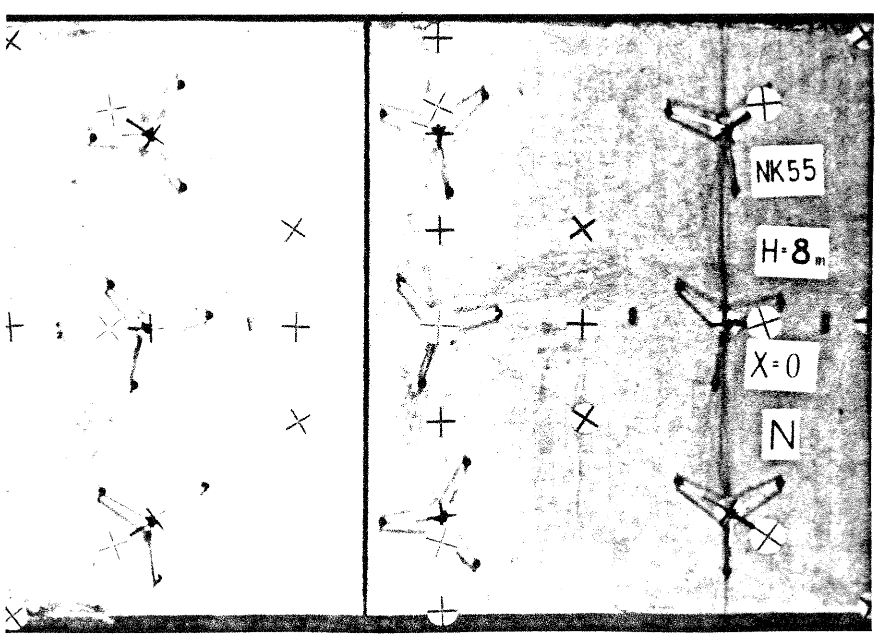

Figure 4 Example of Photograph taken by 35 mm Camera

where

$$dx = x_0 + x\ (\ k_1\ r^2 + k_2\ r^4\ ) + (\ p_1 x + p_2 y + p_3 xy + p_4 y^2\ )$$

$$dy = y_0 + y\ (\ k_1\ r^2 + k_2\ r^4\ ) + (\ p_5 xy + p_6 x^2\ )$$

$$x = x - x_0\ ,\quad y = y - y_0\ ,\quad r^2 = x^2 + y^2$$

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\omega & -\sin\omega \\ 0 & \sin\omega & \cos\omega \end{bmatrix} \begin{bmatrix} \cos\phi & 0 & \sin\phi \\ 0 & 1 & 0 \\ -\sin\phi & 0 & \cos\phi \end{bmatrix} \begin{bmatrix} \cos\kappa & -\sin\kappa & 0 \\ \sin\kappa & \cos\kappa & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

The accuracies in term of root mean square of residuals on film were compared for the following three cases.

Case 1: Exterior Orientation Alone
Unknown parameters: X_0, Y_0, Z_o, ω , ϕ , κ

Case 2: Exterior Orientation Plus Self Calibration Up To Lense Distortion
Unknown Parameters: X_0, Y_0, Z_0, ω , ϕ , κ
x_0, y_0, f, k_1, k_2

Case 3: Exterior Orientation Plus Self Calibration Up To Film Deformation
Unknown Parameters: X_0, Y_0, Z_0, ω , ϕ , κ
x_0, y_0, f, k_1, k_2, p_1- p_6

Table 2 shows the root mean square of residuals on film which were obtained from three cases of single photograph orientation without or with self calibration.

Table 3 shows the accuracy of three dimensional measurement in term of root mean aquare of errors at forty one control points.

From those results, it can be said as follows.

1) It is necessary for non metric camera with wide angle lense to adopt self calibration up to lense distortion at least. The accuracy was improved five times to twelve times in the case of self calibration. Root mean square of residuals on film was improved from 20-50 um in case 1 (without self calibration) to 4-10 um in case 2 and 3-7 um in case 3 (with self calibration).

2) Metric camera shows good accuracy all in case 1, case 2 and case 3. Improvement of accuracy by self calibration was very little.

3) Accuracy of three dimensional measurement by non metric camera was much improved to 0.2-0.4 per mil in term of relative height accuracy in case 2 and case 3 (with self calibration) , which is similar accuracy as metric camera.

Table 2 Accuracies of Single Photo Orientation

No.	Camera	Altitude	Station	Root Mean Square of Residuals(um)		
				Case 1	Case 2	Case 3
1	Olympus OM-1(A)	8 m	2B	49.0	7.4	3.6
			B	51.7	8.5	3.5
			0	52.2	7.5	3.7
			-B	46.3	6.9	3.8
			-2B	50.0	8.5	5.1
		13 m	B	19.3	4.0	2.8
			0	22.0	6.7	4.2
			-B	21.7	6.3	4.0
2	Olympus OM-1(B)	8 m	2B	33.7	7.9	5.3
			B	37.5	5.6	4.1
			0	41.5	6.1	4.4
			-B	37.2	6.8	4.7
			-2B	41.5	5.7	4.9
		13 m	B	14.3	5.2	2.8
			0	17.4	3.9	3.6
			-B	18.8	3.9	3.7
3	Olympus M-1/28	8 m	2B	43.9	9.2	6.2
			-2B	41.4	8.2	6.0
4	Olympus M-1/50	13 m	B	24.5	7.8	4.1
			-B	24.0	8.7	4.7
5	Nikon F-2/24	8 m	2B	37.7	9.2	4.2
			-2B	38.2	7.4	5.6
6	Nikon F-2/50	13 m	B	26.0	6.0	3.2
			-B	28.2	5.8	4.2
7	Nikon F-2/55	13 m	B	12.2	10.6	5.3
			-B	12.7	11.2	6.2
8	Hasselblad/120	13 m	B	21.9	15.3	8.4
			-B	18.1	11.7	9.4
9	WILD P-32	8 m	B	6.2	6.0	5.2
		13 m	-B	6.8	6.4	5.6

Table 3 Accuracies of Three Dimensional Measurement

No.	Camera	B/H ratio	Case	dX(mm)	dY(mm)	dZ(mm)	dZ/Z(‰)
1	Olympus OM-1(A)	1: 1.69	1	12.4	7.8	17.8	2.08
			2	1.5	1.6	2.0	0.24
			3	0.7	0.8	1.5	0.18
		1: 2.14	1	8.9	6.1	8.7	0.48
			2	1.6	1.6	4.5	0.33
			3	1.0	1.0	4.1	0.30
2	Olympus OM-1(B)	1: 1.71	1	9.3	6.0	9.9	1.19
			2	1.5	1.2	2.7	0.33
			3	1.2	1.0	2.6	0.31
		1: 2.14	1	6.7	5.6	10.1	0.73
			2	1.5	1.5	5.3	0.38
			3	1.1	1.1	3.8	0.27
3	Olympus M-1/28	1: 1.72	1	9.2	6.3	10.4	1.2
			2	1.8	1.7	3.5	0.42
			3	1.5	1.2	2.9	0.34
4	Olympus M-1/50	1: 2.14	1	5.3	3.8	9.0	0.66
			2	1.6	1.4	3.1	0.22
			3	0.9	0.7	1.9	0.14
5	Nikon F-2/24	1: 1.71	1	10.1	7.3	10.6	1.27
			2	2.2	1.7	4.1	0.49
			3	1.1	1.0	3.5	0.41
6	Nikon F-2/50	1: 2.10	1	6.3	4.6	7.1	0.51
			2	1.1	1.1	2.7	0.19
			3	0.7	0.6	2.2	0.15
7	Nikon F-2/55	1: 2.10	1	2.3	2.4	4.0	0.28
			2	1.8	2.0	4.4	0.32
			3	1.2	0.9	3.4	0.24
8	Hasselblad	1: 2.11	1	1.6	1.5	2.5	0.18
			2	1.0	1.1	2.0	0.14
			3	0.6	0.6	1.3	0.09
9	WILD P-32	1: 3.13	1	0.8	0.8	2.5	0.22
			2	0.7	0.8	2.1	0.19
			3	0.6	0.7	1.5	0.14

MULTIPLE PHOTOGRAPHS ORIENTATION

In order to compare the accuracies between the following three methods, which are classified by how different or common parameters are taken into account for multiple photographs.

In this study, the following three methods were applied to eight films taken by Olympus OM-1(A), 35 mm camera, 28 mm in focal length.

Method 1 : Different paprameters are applied to each film

Method 2 : Common parameters up to lense distortion (f, x_0, y_0, k_1, k_2) are applied to all films and different paprameters of film deformation ($p_1 - p_6$) are applied to each film

Method 3 : Common parameters are applied to all films

Table 4 shows the root mean square of residuals on film for the three methods.

Table 5 shows the parameters which were determined by three methods.

Table 6 shows the root mean square of errors of three dimensional measurement corresponding to the three methods.

From these results, it was concluded as follows.

1) Method 1(different parameters) shows the best accuracy while Method 2 and Method 3 shows the second and third best respectively.
2) Obtained parameters were different on each film. However, the average parameters of eight films show very near values to the parameters determined by Method 2 and Method 3.
3) The results of Method 1 and Method 2 show very little difference though the result of Method 3 shows rather low accuracy, that is, parameters up to lense distortion can be treated as common.

ERROR MODELS FOR SELF CALIBRATION

Several error models for bundle adjustment with self calibration in aerial triangulation have been proposed as shown in Table 7. However, those error models show very little differences in accuracy for aerial triangulation because aerial survey camera used to be of good quality in its geometry.

Since the geometric performance of non metric camera is incomplete, differences in accuracy by error models would be big. In order to compare the differences by these error models, same data taken by Olympus OM-1(A) were adopted to the bundle methods with self calibration listed in Table 7.

Table 8 shows the root mean square of residuals on film for nine different error models as well as the bundle method without self calibration.

Since the results in the case when focal length was treated as unknown show very little improvement in accuracy, focal length was treated as known. That is, focal length is not involved in the unknown parameters.

Table 4 Comparison of Accuracies with Respect to Parameters of Self Calibration Adopted to Eight Films Taken by Olympus OM-1(A) (unit: um)

Photo No.	Method 1 Different Parameters for Each Film	Method 2 Common Parameters for Lense Distortion and Different for Film Deformation	Method 3 Common Parameters for All Films
1	3.1	3.5	3.9
2	2.9	2.9	3.2
3	3.2	3.5	4.0
4	3.3	3.4	3.5
5	3.8	4.0	4.9
6	3.3	3.5	3.9
7	3.8	3.9	4.1
8	2.5	2.8	3.0
Average	3.3	3.5	3.9

Table 5 Inner Orientation Parameters Determined by Self Calibration Methods

Methods	Photo No.	f (mm)	x_0 (mm)	y_0 (mm)	k_1 (10^2)	k_2 (10^5)
Method 1	1	28.349	-0.295	-0.132	1.481	-2.198
	2	28.156	-0.301	-0.118	1.379	-2.198
	3	28.222	-0.273	-0.082	1.328	-1.855
	4	28.169	-0.298	-0.107	1.343	-1.896
	5	28.142	-0.313	-0.138	1.298	-1.772
	6	28.131	-0.275	-0.190	1.559	-2.933
	7	28.164	-0.305	-0.167	1.501	-2.644
	8	27.886	-0.209	-0.080	1.347	-1.533
	Average	28.152	-0.284	-0.127	1.405	-2.100
Method 2	1-8	28.205	-0.294	-0.118	1.381	-1.973
Method 3	1-8	28.188	-0.281	-0.120	1.378	-1.967

Table 6 Accuracies of Three Coordinates

	Method 1	Method 2	Method 3
Planimetric Error (mm)	1.30	1.44	1.64
Height Error (mm)	2.78	2.85	3.16

Table 7 Error Models for Self Calibration

No.	Model	Parameters
1.	Murai, Matsuoka, Okuda ; $dx = x_0 + x\,(k_1r^2 + k_2r^4) + p_1x + p_2y + p_3xy + p_4y^2$ $dy = y_0 + y\,(k_1r^2 + k_2r^4) + p_5xy + p_6x^2$	10 parameters
2.	Brown ; $dx = a_1x + a_2y + a_3xy + a_4y^2 + a_5x^2y + a_6xy^2 + a_7x^2y^2$ $+ x/f((x^2- y^2) + a_{14}x^2y^2 + a_{15}(x^4- y^4)) + x(a_{16}r^2+a_{17}r^4+a_{18}r^6) + x_0$ $dy = a_8xy + a_9x^2 + a_{10}x^2y + a_{11}xy^2 + a_{12}x^2y^2$ $+ y/f((x^2- y^2) + a_{14}x^2y^2 + a_{15}(x^4-y^4)) + y(a_{16}r^2+a_{17}r^4+a_{18}r^6) + y_0$	20 parameters
3.	Ebner ; $dx = b_1x+b_2y-b_3(2x^2-4B^2/3)+b_4xy+b_5(y^2-2B^2/3)+b_7x(y^2-2B^2/3)+b_9(x^2-2B^2/3)y$ $+b_{11}(x^2-2B^2/3)(y^2-2B^2/3) + x_0$ $dy = -b_1y+b_2x+b_3xy-b_4(2y^2-4B^2/3)+b_6(x^2-2B^2/3)+b_8(x^2-2B^2/3)y+b_{10}x(y^2-2B^2/3)$ $+b_{12}(x^2-2B^2/3)(y^2-2B^2/3) + y_0$	14 parameters
4.	El-Hakim, Faig $dx = a_1 + a_2y + qx/r + x_0$ $dy = -a_1y + a_2x + qy/r + y_0$ $q=a_3r\cos\lambda + a_4r\sin\lambda + a_5r^2 + a_6r^2\cos2\lambda + a_7r^2\sin2\lambda + a_8r^3\cos\lambda + a_9r^3\sin\lambda$ $+a_{10}r^3\cos3\lambda + a_{11}r^3\sin3\lambda$ $r^2=x^2+y^2, \quad \lambda = \arctan(y/x)$	13 parameters
5.	Grün ; $dx = a_1y + a_2xy + a_3xy^2 + a_4x^2y + a_5y^2 + a_6x^2y^2 + x_0$ $dy = b_1y + b_2xy + b_3xy^2 + b_4x^2y + b_5y^2 + b_6x^2y^2 + y_0$	14 parameters
6.	Kölble, Juhl $dx = a_3x/r(r^3-r/r_0^2)+a_4x(\sin r\pi/r_0)^2+a_5x/r\sin(2r\pi/r_0)+r^{1.85}y/r(a_6\cos\alpha$ $+a_7\sin\alpha + a_8\cos2\alpha + a_9\sin2\alpha) + x_0$ $dy = a_1x+a_2y+a_3y/r(r^3-r/r_0^2)+a_4y(\sin r\pi/r_0)^2+a_5y/r\sin(2r\pi/r_0)+r^{1.85}(a_6\cos\alpha$ $+a_7\sin\alpha + a_8\cos2\alpha + a_9\sin2\alpha) + y_0$ $\alpha = \arctan(y/x), \quad r_0 = \text{constant}$	11 parameters
7.	Mauelshagen ; $dx = a_4xy+a_5y^2+a_6x^2y+a_8xy^2+a_9y^3 + x_0$ $dy = b_1x+b_2y+b_3x^2+b_4xy+b_7x^2y+b_8xy^2+b_9y^3 + y_0$	14 parameters
8.	Schut ; $dx = c_3xy+c_5y^2+c_7x^2y+c_9xy^2+c_{11}x^2y^2+c_{13}x^3 + x_0$ $dy = c_1y+c_2x+c_4x^2+c_6xy+c_8x^2y+c_{10}xy^2+c_{12}x^2y^2+c_{14}y^3 + y_0$	16 parameters
9.	Salmenperä, Kilpelä $dx = b_1x+b_2y+b_3xr^2(1-r_0/r)+b_4xr^4(1-r_0/r)+b_5xr^6(1-r_0/r)+b_62xy+b_7(r^2+2x^2)+x_0$ $dy = -b_1y+b_2x+b_3yr^2(1-r_0/r)+b_4yr^4(1-r_0/r)+b_5yr^6(1-r_0/r)+b_6(r^2+2y^2)+b_72xy+y_0$ $r_0 = \text{constant}$	9 parameters

Table 8 Root Mean Square of Residuals for Various Error Models

	no. of parameters	Residuals (um)
0. Without Self Calibration	0	56.4
1. Murai, Matsuoka, Okuda	10	5.7
2. Brown	20	5.6
3. Ebner	14	36.5
4. El-Hakim, Faig	13	9.7
5. Grün	14	36.5
6. Kölble, Juhl	11	15.2
7. Mauelshagen	14	16.1
8. Schut	16	16.1
9. Salmenperä, Kilpelä	9	5.8

Remarks: Number of Photographs = 8
Number of Control Points = 41
Number of Bundles = 324

From the results obtained from the comparative study on error models, it was concluded that ;

1) those physical models to take into account the lense distortion, such as Murai's model, Brown's model and Salmeperä and Kilpelä's model showed best accuracy, while those polinomials models such as Ebner's model,Grün's model, Mauelshagen's model and Schut's model showed low accuracy,

2) Brown's model showed the best accuracy while Murai's model and Salmenperä and Kilpelä's model showed the second and third best respectively. These three models were classified as the best group. As compared with Brown's model, the latter two models are more economical because the number of parameters is half,

and

3) physical model to consider the lense distortion should be designed at least in the error model for non metric camera with wide angle lense.

References

1) Shunji Murai and Hideshi Nakamura; " Analytical Orientation for Non-metric Camera in the Applications to Terrestrial Photogrammetry" Proceedings of ISP Congress, Hamburg, 1980, Commission V

2) Hartmut Ziemann and Sabry F. El-Hakim; " System Calibration versus Self Calibration" Proceedings of International Symposium, Com. I, ISPRS, Canberra, April, 1982

****

Presented Paper to ISPRS Congress, Rio de Janeiro, June 1984