DEVELOPMENT OF IMAGE BASED INTEGRATED MEASUREMENT SYSTEM AND PERFORMANCE EVALUATION FOR CLOSE-RANGE APPLICATION

T. OHDAKE*, H. CHIKATSU

Tokyo Denki University, Dept. of Civil and Environmental Engineering,
350-0394 HATOYAMA, SAITAMA, JAPAN – (ohdake, chikatsu)@g.dendai.ac.jp

Commission V, WG V/1

KEY WORDS: Integration, System, Calibration, Algorithms, Measurement, Image, Laser, Performance

ABSTRACT:

A convenient 3D measurement using amateur digital cameras is enormously expected in various fields with appearance of the high-resolution amateur digital cameras. In these circumstances, software for low-cost digital photogrammetry "3DiVision" was designed to perform convenient 3D measurement using amateur digital cameras. However, there are still problems for efficient digital photogrammetry. These problems are distance measurement for absolute orientation and previous interior orientation, and these restrictions should be removed for ideal convenient photogrammetry using amateur digital cameras.
With this objective, Image Based Integrated Measurement (IBIM) System consisting of 5 parts: mirrors, amateur digital camera, laser range finder, personal computer and monitor was developed by the authors. The most remarkable point of this system is its ability to calculate both of exterior and interior orientation parameters without scale distance or GCP in object field. This paper describes the Image Based Integrated Measurement System, and its performance evaluation.

1. INTRODUCTION

The change in photogrammetry from analog to digital means a change from film to CCD (Charge Coupled Device) sensor, and real-time imaging became possible. CCD, which was invented in 1970's, is one of the electric charge transfer device in semiconductor, and its resolution was about only 10K bytes at the first stage. However, there are various high-resolution armature digital cameras, which have more than 3 mega pixels on the market nowadays, and 43,400,000 sets of amateur digital cameras were shipped in 2003. On the contrary, 13,930,000 sets of film camera were shipped (CIPA, 2004). Furthermore, acceleration of downsizing is current trends. In these circumstances, amateur digital cameras are expected to contribute enormously to digital photogrammetric field, and there are various digital photogrammetric software on the market.
The authors have been concentrating on developing a convenient 3D measurement system using amateur digital cameras. Performance evaluation of 3-mega armature digital cameras was investigated (Kunii & Chikatsu, 2001). Measurement device using amateur digital cameras and laser range finder was developed which doesn't need any surveying on an object field, and software "3DiVision" was designed to perform convenient 3D measurements (Chikatsu & Kunii 2002). Furthermore, application of 3DiVision to 3D modelling of historical object was also investigated from the viewpoint of digital archives (Nakada & Chikatsu 2003).
In order to realize convenient digital photogrammetry by using armature digital camera, however, there are still issues including 3DiVision. These problems are ground control points, previous interior orientation procedures. Generally, digital photogrammetry is performed using under alternative conditions:

a) Ground control points, which have accurate 3D coordinate.
b) Scale distance on object field, which is needed in absolute orientation.
c) Interior orientation procedures, which are performed previously.

These restrict conditions should be removed for ideal convenient photogrammetry. With this motive, Image Based Integrated Measurement (IBIM) System was developed by the authors. The most remarkable point of this IBIM is its ability to calculate both exterior and interior orientation parameters simultaneously without scale distance, GCP and previous interior orientation procedures. After describing the IBIM, performance evaluation is investigated in this paper.

2. IMAGE BASED INTEGRATED MEASUREMENT SYSTEM

Image Based Integrated Measurement (IBIM) System developed by the authors consists of 5 parts: mirrors, amateur digital camera, laser range finder, personal computer and monitor. Figure 1 shows the appearance of this system, and Figure 2 shows the configuration. The IBIM is able to rotate in vertically and horizontally so that precise space distance from the center of a camera to feature points on object field can be measured, and images are taken through the capture device with real-time. Therefore, onsite camera calibration and 3D measurement are achieved. The specifications of this system are as follows.

+Mirrors

Both axes for laser range finder and amateur digital camera are adjusted by two mirrors (mirror and half mirror).

+Camera

OLYMPUS C-3040 (3.14 mega pixels)

+ Laser profiler

Leica LDS-1 (accuracy is ±3mm to 40m)

+ PC

Pentium Ⅲ 850Hz

Laser range finder and amateur digital camera are controlled by personal computer, and captured image data and measured distance data are recorded on hard disk (mounted on 10GB).

+ Monitor

6.4-inch display is used as a finder and PC monitor.

Figure 1. Appearance of the IBIM

3. CAMERA CALIBRATION

In order to perform camera calibration, at least 6 space distances for the points, which show feature on object field from the center of a camera, have to be measured by laser profiler. These feature points are defined as temporal GCP in this paper. Then, 36 unknown parameters such as exterior orientation parameters for both camera {(X_{OL}, Y_{OL}, Z_{OL}, ω_L, φ_L, κ_L), (X_{OR}, Y_{OR}, Z_{OR}, ω_R, φ_R, κ_R)}, interior orientation parameters {f (focal length), x_0, y_0 (principal points), a_1, a_2, (scale factor), k_1 (lens distortion)} and 3D coordinates for the 6 temporal GCPs should be calculated. However, X or Y-axis and 2 points, which have the same height value or height values for 2 points, are required to prevent rotations. Therefore, origin point and the point, which define the X-axis direction, are selected. 3D coordinates for the origin point and the point are assumed (0, 0, 0) and (X_2, 0, 0) respectively. As a result, 30 parameters become unknowns, and these unknown parameters are calculated by collinearity condition and space distances simultaneously. Detail calibration procedures are as follows.

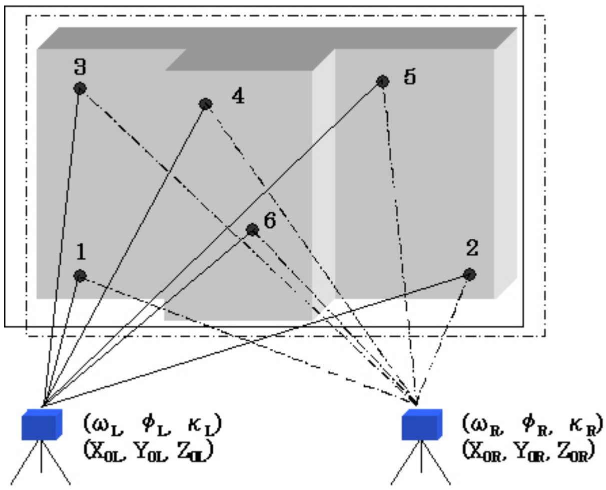

Figure 3. Concept of measurement by the IBIM

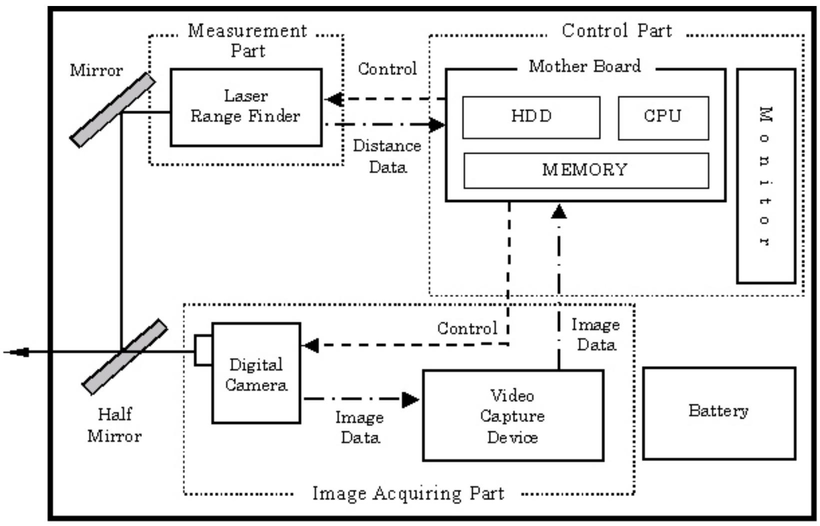

Figure 2. Configuration of the IBIM

3.1 Initial Value

3.1.1 Initial Values of Camera Position

Initial values for the temporal GCPs are required as same as orientation parameters in calibration procedures. Figure 4 shows the concept of computation of initial values for the temporal GCPs, and initial values for the temporal GCPs are computed as follows.

In Figure 4, D_1, D_2 and D_3 are space distances, angle α is computed with respect to focal length (f) and image coordinate using following equation (1).

$$\cos\alpha = \frac{x_{p1}\cdot x_{p2} + y_{p1}\cdot y_{p2} + f^2}{\overline{Op_1}\cdot\overline{Op_2}} \quad (1)$$

$\overline{Op_1}$ and $\overline{Op_2}$ are length from the camera position to image points, and the lengths are computed following as equation (2).

$$\overline{Op_1} = \sqrt{\left(x_{p1}^2 + y_{p1}^2 + f^2\right)},\ \overline{Op_2} = \sqrt{\left(x_{p2}^2 + y_{p2}^2 + f^2\right)} \quad (2)$$

Therefore, initial X_2 value of the point P_2 for the origin coordinate (0, 0, 0) is computed as D_{12} from equation (3).

$$D_{12} = \overline{P_1P_2} = \sqrt{D_1^2 + D_2^2 - 2\cdot D_1\cdot D_2\cdot\cos\angle\alpha} \quad (3)$$

On the contrary, relationship between focal length and flying height (distance from exposure position to the object field) is simply expressed as follows using image distance d to the corresponding ground distance D_{12} under the assumption that vertical photo was taken over flat terrain.

From the following relation, initial Z coordinate for exposure position is estimated as H .

$$f/H = d/D \quad (4)$$

Furthermore, let make ground coordinate for the camera position O (X_0, Y_0, Z_0), P_1 (X_1, Y_1, Z_1) and P_2 (X_2, Y_2, Z_2), space distance D_1, D_2 is expressed as follows,

$$D_1^2 = (X_0 - X_1)^2 + (Y_0 - Y_1)^2 + (Z_0 - Z_1)^2 \quad (5)$$

$$D_2^2 = (X_0 - X_2)^2 + (Y_0 - Y_2)^2 + (Z_0 - Z_2)^2 \quad (6)$$

where: $(X_1, Y_1, Z_1) = (0,0,0)$, $(X_2, Y_2, Z_2) = (X_2, 0, 0)$

By equations (5) and (6), initial value for camera position is obtained as follows.

$$X_0 = \left(D_1^2 - D_2^2 + X_2^2\right)/2X_2$$
$$Y_0 = \sqrt{\left(D_1^2 - H^2 - X_0^2\right)}$$
$$Z_0 = H$$

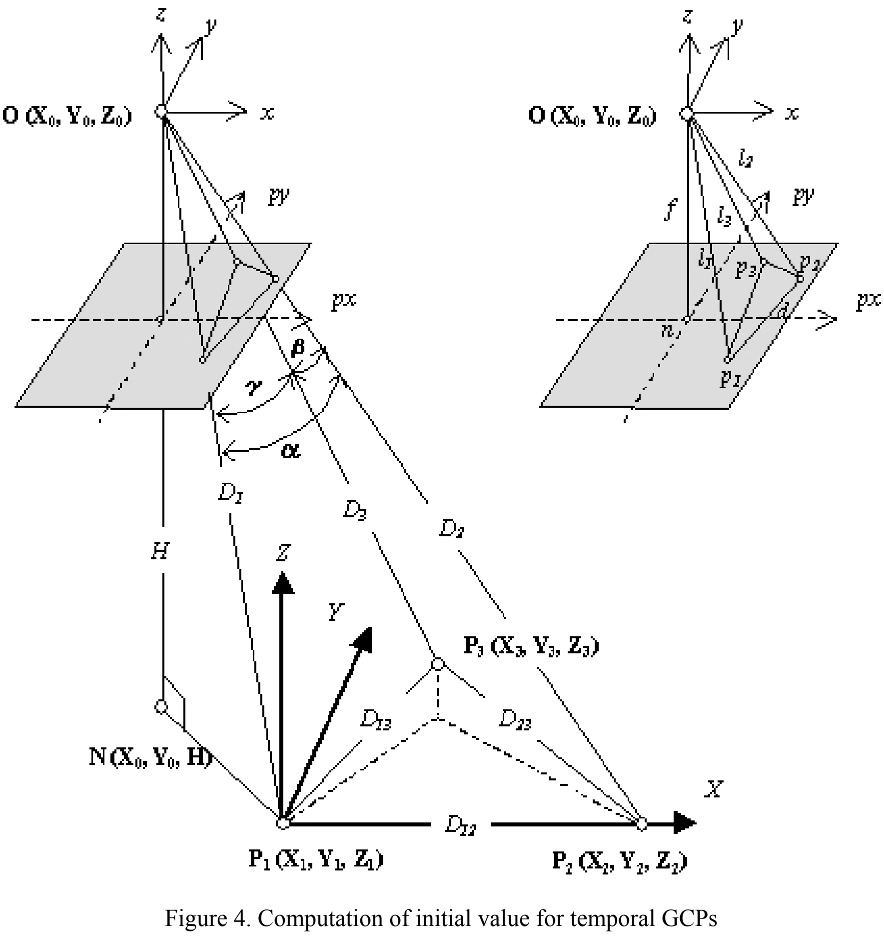

Figure 4. Computation of initial value for temporal GCPs

3.1.2 Initial Value of the Temporal GCPs

The Church method is one of methods to calculate exterior orientation parameters, and exterior orientation parameters of a tilted photo are calculated using 3 GCPs which have accurate 3D ground coordinates (Wolf, 1983).
In Figure 4, images p_1, p_2 and p_3 of GCPs P_1, P_2 and P_3. Angle α, β, γ are

$$\cos\alpha = \frac{K_\alpha}{\overline{OP_1}\cdot\overline{OP_2}}$$

$$K_\alpha = (X_0 - X_1)(X_0 - X_2) + (Y_0 - Y_1)(Y_0 - Y_2) + (Z_0 - Z_1)(Z_0 - Z_2) \qquad (7.1)$$

$$\cos\beta = \frac{K_\beta}{\overline{OP_2}\cdot\overline{OP_3}}$$

$$K_\beta = (X_0 - X_2)(X_0 - X_3) + (Y_0 - Y_2)(Y_0 - Y_3) + (Z_0 - Z_2)(Z_0 - Z_3) \qquad (7.2)$$

$$\cos\gamma = \frac{K_\gamma}{\overline{OP_3}\cdot\overline{OP_1}}$$

$$K_\gamma = (X_0 - X_3)(X_0 - X_1) + (Y_0 - Y_3)(Y_0 - Y_1) + (Z_0 - Z_3)(Z_0 - Z_1) \qquad (7.3)$$

where:

$$\overline{OP_1} = (X_0 - X_1)^2 + (Y_0 - Y_1)^2 + (Z_0 - Z_1)^2$$
$$\overline{OP_2} = (X_0 - X_2)^2 + (Y_0 - Y_2)^2 + (Z_0 - Z_2)^2$$
$$\overline{OP_3} = (X_0 - X_3)^2 + (Y_0 - Y_3)^2 + (Z_0 - Z_3)^2$$

On the other hand, $\cos\alpha$, $\cos\beta$, and $\cos\gamma$ are expressed with respect to focal length and image coordinates using the following geometry equations:

$$\cos\alpha = \frac{x_{p1}\cdot x_{p2} + y_{p1}\cdot y_{p2} + f^2}{\overline{Op_1}\cdot\overline{Op_2}} \qquad (8.1)$$

$$\cos\beta = \frac{x_{p2}\cdot x_{p3} + y_{p2}\cdot y_{p3} + f^2}{\overline{Op_2}\cdot\overline{Op_3}} \qquad (8.2)$$

$$\cos\gamma = \frac{x_{p3}\cdot x_{p1} + y_{p3}\cdot y_{p1} + f^2}{\overline{Op_3}\cdot\overline{Op_1}} \qquad (8.3)$$

In equation (8), $\overline{Op_1}$, $\overline{Op_2}$, and $\overline{Op_3}$ are length from the camera position to the respective image point, and $\cos\alpha$, $\cos\beta$, and $\cos\gamma$ in equation (7) are given by equation (9). Therefore, equation (7) consists of 3 unknowns (X_0, Y_0, Z_0), and equation (7) are solved with respect to unknowns using Taylor's theorem.
However, X_3, Y_3, and Z_3 are unknowns in this paper. Therefore, in order to obtain these unknowns, the Church method was used inversely under assumption Z_3 coordinate equal 0, and solved unknowns are given as initial values for the temporal GCP of P_3.
Similarly, initial values for the other temporal GCPs are obtained by repeating the same procedures.

3.1.3 Initial Values of Orientation Parameters

The initial values of exterior orientation parameters are given as calculated values from the space resection using initial values for the temporal GCPs, which were obtained by the above procedures.

3.2 Calibration Procedures

In the above procedure, initial values for the exterior orientation parameters and 3D coordinates for the 6 temporal GCPs are given. Therefore, unknown parameters for the interior/exterior orientation parameters and 3D coordinates for temporal GCPs are calculated by the resection using collinearity conditions and space distances.
equation (9) shows collinearity conditions, and equation (10) shows distance conditions, and these equations for the both images are used simultaneously in calibration procedures. Consequently, 36 observation equations are acquired for 30 unknown parameters, and unknown parameters are calibrated as the values that make the following function H minimum under the least-squares method (equation (11)). Furthermore, 3D coordinates for additional feature points are able to compute simultaneously.

Collinearity condition:

$$\left.\begin{aligned} F &= (x - x_0)(1 + k_1 r^2) + f\frac{m_{11}(X - X_0) + m_{12}(Y - Y_0) + m_{13}(Z - Z_0)}{m_{31}(X - X_0) + m_{32}(Y - Y_0) + m_{33}(Z - Z_0)} \\ G &= (y - y_0)(1 + k_1 r^2) + f\frac{m_{21}(X - X_0) + m_{22}(Y - Y_0) + m_{23}(Z - Z_0)}{m_{31}(X - X_0) + m_{32}(Y - Y_0) + m_{33}(Z - Z_0)} \end{aligned}\right\} \qquad (9)$$

where: x, y are image coordinates of temporal GCPs, r is distance from principal point to image point, k_1 is lens distortion parameter, and m_{ij} are rotation matrixes.

Observation condition for the space distance:

$$D_i = \sqrt{(X_i - X_0)^2 + (Y_i - Y_0)^2 + (Z_i - Z_0)^2} \qquad (10)$$

Function with weight:

$$H = \sum_{i=1}^{n=2}\sum_{j=1}^{n=6} p_1\left(\Delta x_j^2 + \Delta y_j^2\right) + \sum_{i=1}^{n=2}\sum_{j=1}^{n=6} p_2\left(\Delta D_j^2\right) \rightarrow \min \qquad (11)$$

where: $\Delta x, \Delta y$: residual for the image coordinates, ΔD : residual for space distance.

Weight values in equation (11) should be carefully considered under statistically or measurement accuracy, and calibration results were investigated using various weights. However, calibration results don't show any significant improvements compared with various weight values. Therefore, equal weight ($p_1 = p_2 = 1$) was adopted in this paper.

4. PERFORMANCE EVALUATION

In order to evaluate an accuracy of the IBIM, experiment was performed. Figure 5 shows test site, 20 circular points in Figure 5 are temporal GCPs and check points. A stereo image was taken with 21.790m (left side), 21.957m flying height (right side) respectively and 8.44m base line under the fixed focal length. The 3D coordinates for all circular points and

Figure 5. Test field

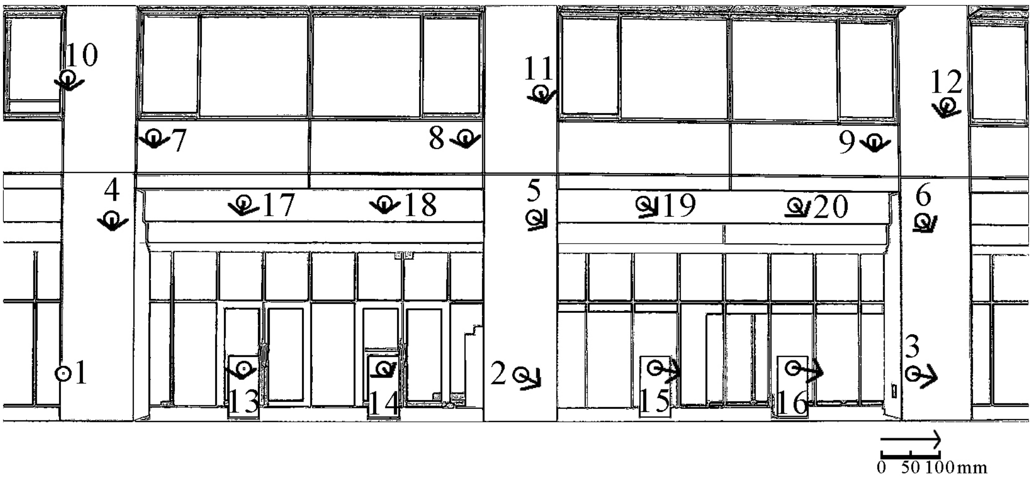

Figure 6. Error distribution of XY coordinates by the IBIM

space distances were measured by the motorized total station (SOKIA MET2NV; distance accuracy: ±1mm, angle accuracy: ±2″).

Image coordinates for each point were given as the center of area gravity by image processing. Accuracy for 3D coordinates of check points was compared with space resection using 9 GCPs.

In Figure 6, No. 1,3,10,11,12,14 points are temporal GCPs, and No. 1,3,10,11,12,14,15,24,25 are GCPs for the resection method. Therefore, No. 2,4,5,6,7,8,9,13,16,23,26 are common check points for the both method. Table 1 and 2 show calibration results. Table 3 shows the RMSE for X, Y, XY and Z coordinates regarding 11 check points.

Table 1: Calibration result of exterior orientation parameters

	Left	Right
X_0	2743.047 mm	11145.012 mm
Y_0	565.820 mm	601.626 mm
Z_0	20903.188 mm	20941.344 mm
ω	1° 33′ 44.4″	1° 50′ 55.6″
ϕ	11° 21′ 42.0″	- 11° 21′ 00.4″
κ	0° 00′ 35.9″	- 0° 16′ 14.2″

Table 2: Calibration result of interior orientation parameters

x_0	1024.045 pixels
y_0	759.183 pixels
f	7.216 mm
a_1	288.830
a_2	1.319
k_1	0.3996E - 07

Table 3: The R.M.S.E. for X, Y, XY, Z coordinates

	IBIM	Space resection
X	21.434 mm	4.182 mm
Y	10.424 mm	6.055 mm
XY	16.624 mm	5.204 mm
Z	9.504 mm	9.388 mm

From Table 3, it can be seen that the accuracy of Z coordinate shows the same values that was computed resection method using 9 GCPs. However, the accuracies of X, Y, XY show lower values. In particular, X accuracy show quite lower.

On the other hand, Figure 6 shows error distribution of XY coordinates by the IBIM (residual values of XY coordinates were magnified 10 times). From Figure 6, though it can be

found larger error on the lower right points. It may be supposed that X coordinate is sensitively influenced by initial values since the initial 3D coordinate are estimated using the X value for the No.2 point which define X-axis.
However, because of the IBIM doesn't need any surveying on an object field nor previous interior orientation procedures, it is concluded that flexible 3D measurement is achieved by the IBIM.

5. CONCLUSION AND FURTHER WORK

The Image Based Integrated Measurement (IBIM) System, was developed by the authors for a convenient digital photogrammetry using digital cameras, and performance evaluation were performed in this paper. It is concluded that the IBIM is expected to become a useful measurement system for the various close range application fields since interior orientation parameters and exterior orientation parameters are calibrated simultaneously without any scale distances nor GCPs on object field. In particular, the remarkable point of the IBIM is its ability to perform onsite camera calibration.
However, investigation has come up with some issues which need to be resolved before this system may become more operational. These problems are improvement accuracy aspects, acceleration of downsizing/handling.

Reference from Book:
Paul R. Wolf, 1983, ELEMENTS OF PHTOGRAMMETRY, McGraw-Hill Book Company, pp.240-245.

Reference from Other Literature:
Y. KUNII and H. CHIKATSU, 2001, On the Application of 3 Million Consumer Pixel Camera to Digital Photogrammetry, Proceedings of SPIE (Videometrics VII), Vol.4309, pp.278-287

H. CHIKATSU and Y. KUNII, 2002, Performance Evaluation of Recent High Resolution Amateur Cameras and Application to Modeling of Historical Structure, International Archives of Photogrammetry and Remote Sensing, Vol.XXXIV, Part5, pp.337-341, Corfu

R. NAKADA and H. CHIKATSU, 2003, Generating 3D Model of "Meguro Residence" using Digital Armature Camera, International Archives of Photogrammetry and Remote Sensing (CD-Rom), Vol.XXXIV-5/W10, ISSN 1682-1777, Vulpera

Reference from website:
CAMERA & IMAGING PRODUCTS ASSOCIATION, http://www.cipa.jp/english/index.html (accessed on 30 April 2004)