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DEFORMATION SHAPE-MONITORING OF A PARABOLIC ANTENNA DISH USING ELECTRONIC CLOSE-RANGE SURVEYING TECHNIQUES

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ABSTRACT

Improvements in computer technology and electronic data communication have resulted in the better use of traditional geodetic surveying techniques in industrial engineering. The combination of close-range high precision surveying instruments with simple plane and spherical trigonometric functions have made it possible for industrial objects and surfaces to be accurately and remotely monitored for any form of deformation or misalignment. Fast data communication and data processing and modelling techniques via computers have made it possible to obtain results in real-time. This paper describes the surveying techniques and instrumentations used as well as the result of a deformation monitoring on a parabolic antenna dish. The prospects of the use of this low-cost technology are also explored.

1.0 INTRODUCTION

The shape of any geometric object can be monitored or determined if the three-dimensional co-ordinates of points on the object are known. The alignment of an object or the deformation of a body can be determined if the body is pre-defined by some known geometrical models. The classical geodetic surveying methods of triangulation, intersection and trilateration have been used to determine the geodetic coordinates of points on the surface of the earth. These methods require the measurement of horizontal/vertical angles and distances, and the inclusion of these measurements in mathematical models to compute 2-dimensions (2-D) or 3-dimensions (3-D) coordinates. These measurements are made using optical-mechanical theodolites, steel tapes, and electronic distance measurement (EDM) devices. The field procedure entails manual data read-out and recording which lend itself to reading and booking errors, and post-field data processing. These limitations are largely responsible for the lack of popularity of the geodetic surveying techniques beyond the land surveying needs.

Improvements in computer technology and electronic data communication have, however, improved the field use of theodolites and EDMs, beyond land surveying needs. Specific improvements include digital theodolites, with digital data display and data transfer to hand-held or desktop computers via a RS-232 interface cable. Reading errors are thereby significantly reduced, booking errors are eliminated and real-time data processing is now possible. The implication of these improvements in instrumentation is the expanded use of classical geodetic surveying techniques in the manufacturing and maintenance industries.

Using a configuration of two or more electronic theodolites, interfaced to a computer (as shown in figure 1), the 3-D coordinates of any point in space can be determined using close-range geodetic intersection techniques (Grist, 1991). Depending on the storage and speed of the computer, these coordinates can be obtained in real-time and subsequently used to quantify various geometric characteristics of an object. If the as-built dimensions of the object are stored on the computer, the

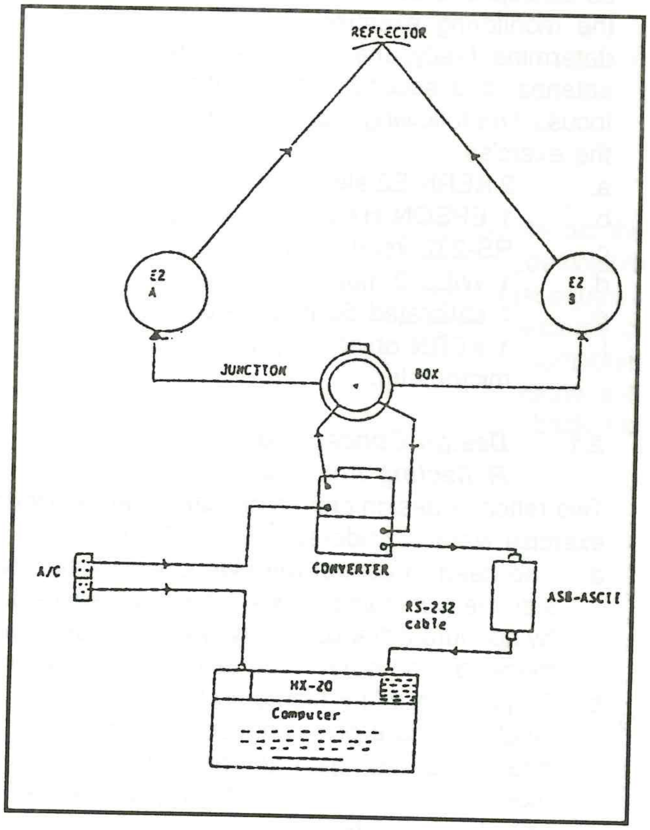

Figure 1 A Typical Theodolite, Object and Computer Configuration

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Pertinent discussion will be published in January observed dimensions can thus be compared, to determine any variation or deformation of the object. Standard models such as cylinders, spheres, simple arcs, planes or parabolas can easily be compared. The WILD CAT 2000, KERN ECDS2, Sokkia NET2 MONMOS, Wild/Leitz RMS 2000 are examples of commercially available instruments configured to perform these tasks. Apart from the use of electronic close-range geodetic surveying techniques, close-range photogrammetric surveying methods are also being used on a commercial scale (Fraser, 1986). Photogrammetry methods have the additional advantage of rapid and non-contact data collection, and non-tedious field work requirements. The advantages of these developments are: high accuracy as much as 1:2000,000; improved mobility, real-time measurement, fast data collection, repeatability, versatility, cost-effective and timeliness. Current industry applications of this technique include: surface profiling; antenna orientation; chassis alignment; guidance system alignment; robotics calibration; ship repair and construction; laser profiling of quarry rock faces; volumetric surveys of storage tanks and silos; and crane rail alignment and positioning (Range, 1993).

2.0 APPLICATION

A fairly flat parabolic reflecting antenna was chosen as an object to be monitored. The requirements for the monitoring exercise were two fold; namely to determine firstly, the shape and regularity of the antenna, and secondly, the location of its principal focus. The following equipment were assembled for the exercise:

a. 2 KERN E2 electronic theodolites;
b. 1 EPSON HX-20 microcomputer;
c. RS-232 interfacing cables;
d. 1 WILD 2-metre subtence bar;
e. 1 calibrated 50 metre steel tape;
f. 1 KERN objective parallel plate micrometer.

2.1 Design Concepts of a Reflecting Antenna

Two reflector design criteria critical to the monitoring exercise were considered (Ruze, 1966):

a. The need to control the side-lobe radiation outside the high-gain principal lobe or pattern caused by aperture diffraction, primary feed spillover, feed blocking, and other sources of spurious lobing;
b. To produce many high-gain beams from a single aperture or to change or scan the direction of high-gain antenna pattern by motion of the feed in the focal plane of the reflecting collection.

Aperture blocking causes a damaging effect in antenna design, leading to loss in gain of the received signal. Loss in gain, is the ratio of the aperture area and the feed blocking area. Blocking is caused by different sections of the parabolic surface having distinctly different focusing qualities due to irregularities of the surface (Sletten, 1969). The task is to detect areas on the reflecting surface where this blocking occurs.

2.2 Data Collection

Data collection was undertaken by obtaining three-dimensional coordinates of selected points on the surface of the antenna. Figure 2 depicts the geometric configuration of the data collection techniques employed. The actual instrument/equipment/computer interface is shown in figure 4. P is any point on the antenna whose x,y,z coordinates were determined from horizontal and vertical angle measurements obtained at theodolite positions A and B. Equations 1, 2, 3 were the intersection mathematical models used to compute the 3-dimensional coordinates.

$$X_{p_i} = \frac{[(Y_A - Y_B) + X_A Cot\beta_i + X_B Cot\alpha_i]}{(Cot\alpha_i + Cot\beta_i)} \qquad (1)$$

$$Y_{pi} = \frac{[(X_B - X_A) + Y_A Cot\beta_i + Y_B Cot\alpha_i]}{(Cot\alpha_i + Cot\beta_i)} \qquad (2)$$

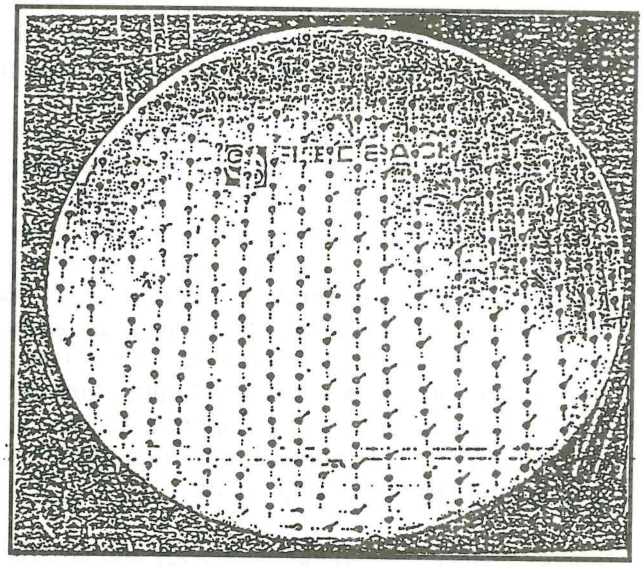

Figure 2: Targeted Surface of the Parabolic Antenna Dish

$$Z_{p_i} = \frac{(Z_A + Z_B)}{2} + [\frac{AB}{2}.\mathrm{Sin}(\alpha_i + \beta_i)][\mathrm{Sin}\alpha_i \mathrm{Tan}\phi_i + \mathrm{Sin}\beta_i \mathrm{Tan}\theta_i] \tag{3}$$

These equations provide a unique solution only. Iterative equations which will provide more accurate least squares solution are possible with recently manufactured electronic theodolites.

2.3 *Design of Targets*

Four characteristics of targets are critical to accuracy of results: pattern, shape, size and density. The concentric circle pattern with a 0.23mm dot in the center was chosen. The inner diameter is 4mm and the outer diameter is 10mm. This shape has the advantage of improving pointing and focussing accuracy of the observer. A grid pattern arrangement was used in the placement of the targets on the antenna (Figure 3). The grid pattern was adopted to aid the observers in the tracking of the targets. The density of the targets/points is directly proportional to the level of accuracy achievable. A total of 160 targets were placed on the antenna. A larger number of targets will result in longer time in field data collection, and therefore, higher cost.

2.4 *Accuracy Considerations*

The accuracy of the derived coordinates of the targeted points is a direct function of the theodolite measurement precision and to a lesser extent, the rigour of mathematical models used to compute the coordinates. The mean square error of a set of horizontal directions obtainable from the kern E2 theodolite is given as 0.3". The vertical angle mean square error is 1.0", bubble sensitivity is quoted to be 20" per 2mm. In carrying out a pre-analysis, therefore, the sum of the internal accuracy for one pointing of the telescope was deduced to be 2". This, for all practical purposes, is considered to be quite adequate for the accurate determination of the irregularities and principal focus of the antenna.

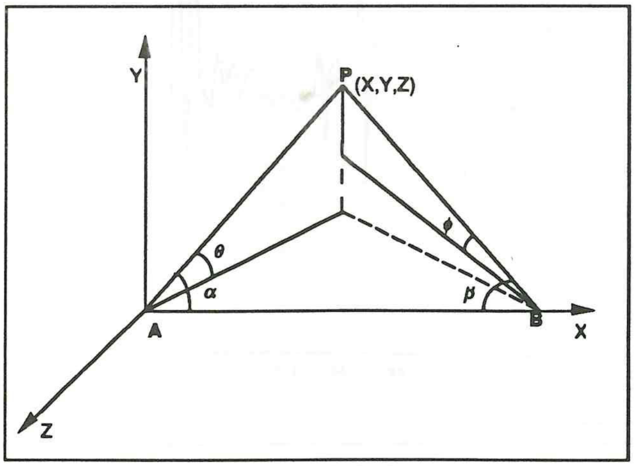

Figure 3 The Geometry of the Object and Theodolites Positions

2.5 *Data Modeling*

The next stage is the mathematical modeling of the computed coordinates to a chosen shape model. The standard form equation of an elliptic paraboloid was chosen as the most fitting model of the antenna. Equation 4 is the relevant mathematical model.

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = \frac{z}{c} \tag{4}$$

Since it is not possible to obtain the coordinates in the standard form, the general quadratic equation was used as shown in equation 5. This equation was later reduced back into the standard form:

$$ax^2 + by^2 + cz^2 + 2fyz + 2gzx + 2hxy + \alpha x + \beta y + \gamma z + k = 0 \tag{5}$$

in matrix notation:

$$[x,y,z]\begin{bmatrix} a,h,g \\ h,b,f \\ g,f,c \end{bmatrix}\begin{bmatrix} x \\ y \\ z \end{bmatrix} + [\alpha,\beta,\gamma]\begin{bmatrix} x \\ y \\ z \end{bmatrix} + k = 0$$

or

$$X^T AX + CX + K = 0$$

X contains the 3-D coordinates of points on the antenna; A, C and K are the 10 unknown coefficients of the equation to be determined using least-squares adjustment methods. This is possible because of the redundant measurements taken. The computed coefficients were subsequently used to rotate and translate the axes of the quadratic model back into the standard form as follows.

$$\overline{X} = X + \alpha/_{2a}$$

$$\overline{Y} = Y + \beta/_{2b}$$

$$\overline{Z} = Z - k/_{\gamma}$$

or (8)

$$a\overline{X}^2 + b\overline{Y}^2 + \gamma\overline{Z}^2 = 0$$

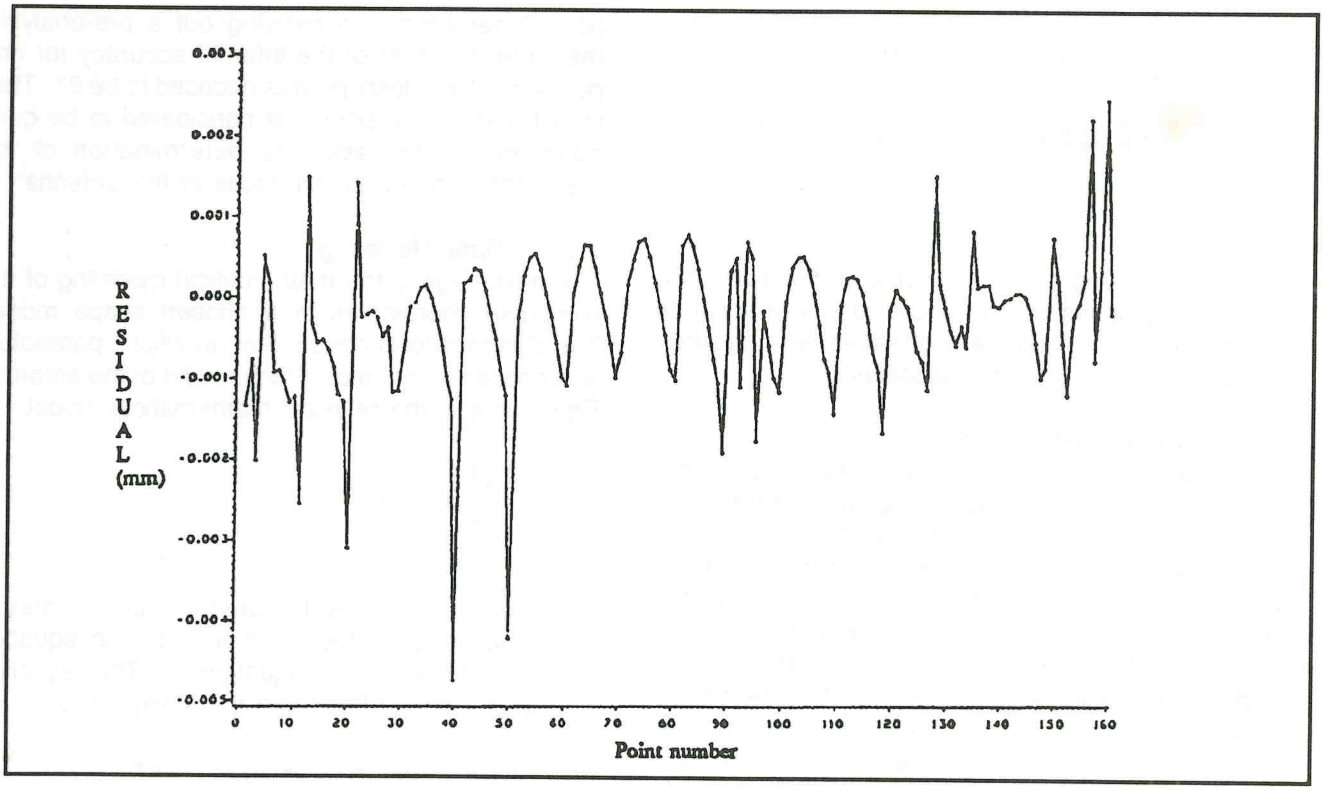

Figure 4 A Plot of the Residuals Along the X-Axis

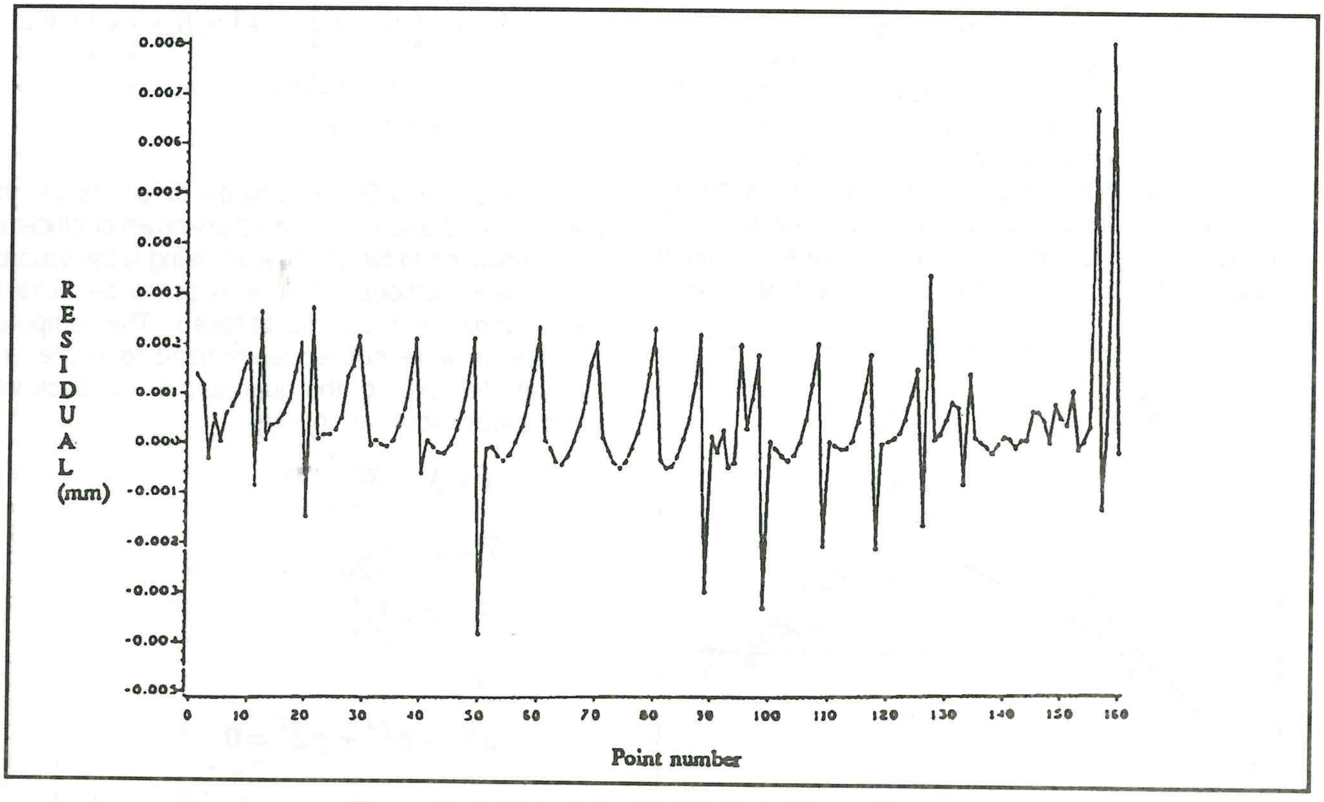

Figure 5 A Plot of the Residuals Along the Y-Axis

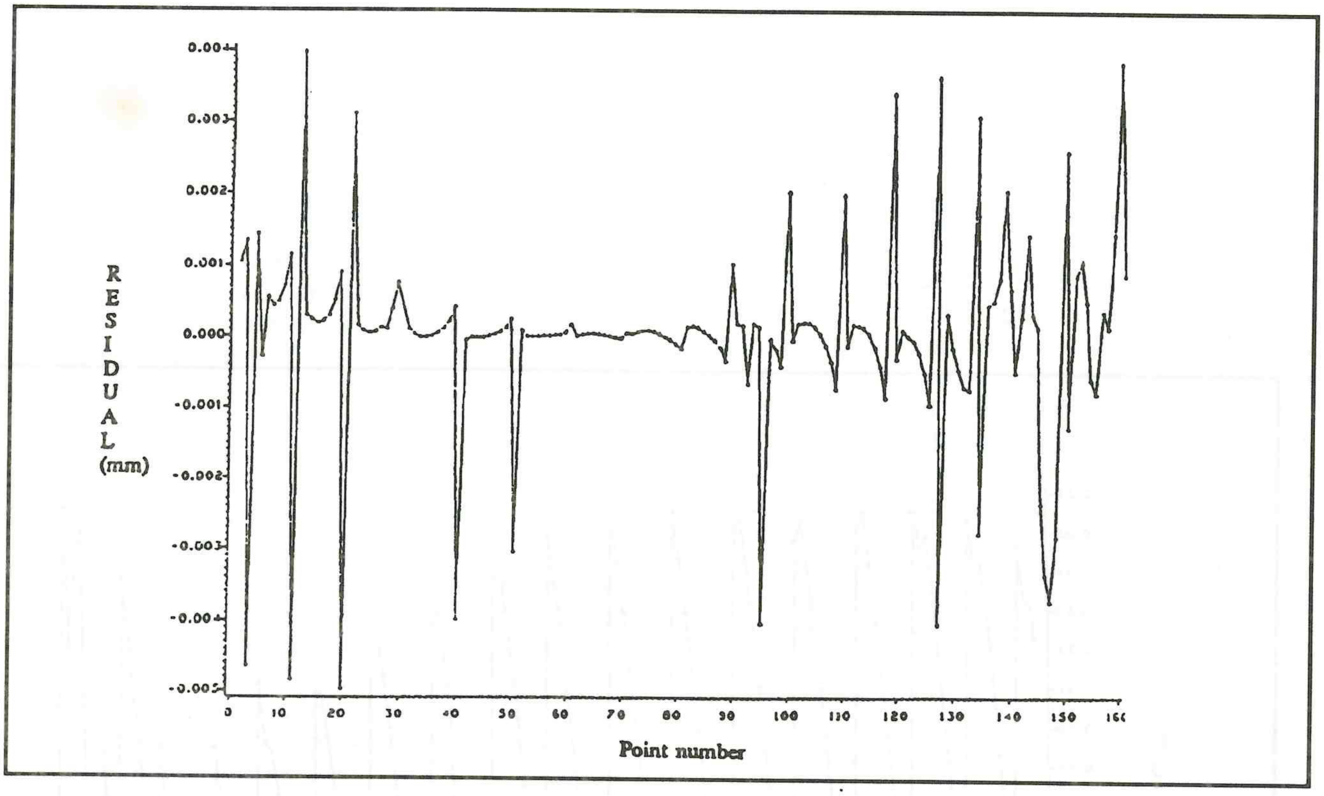

Figure 6 A Plot of the Residuals Along the Z-Axis

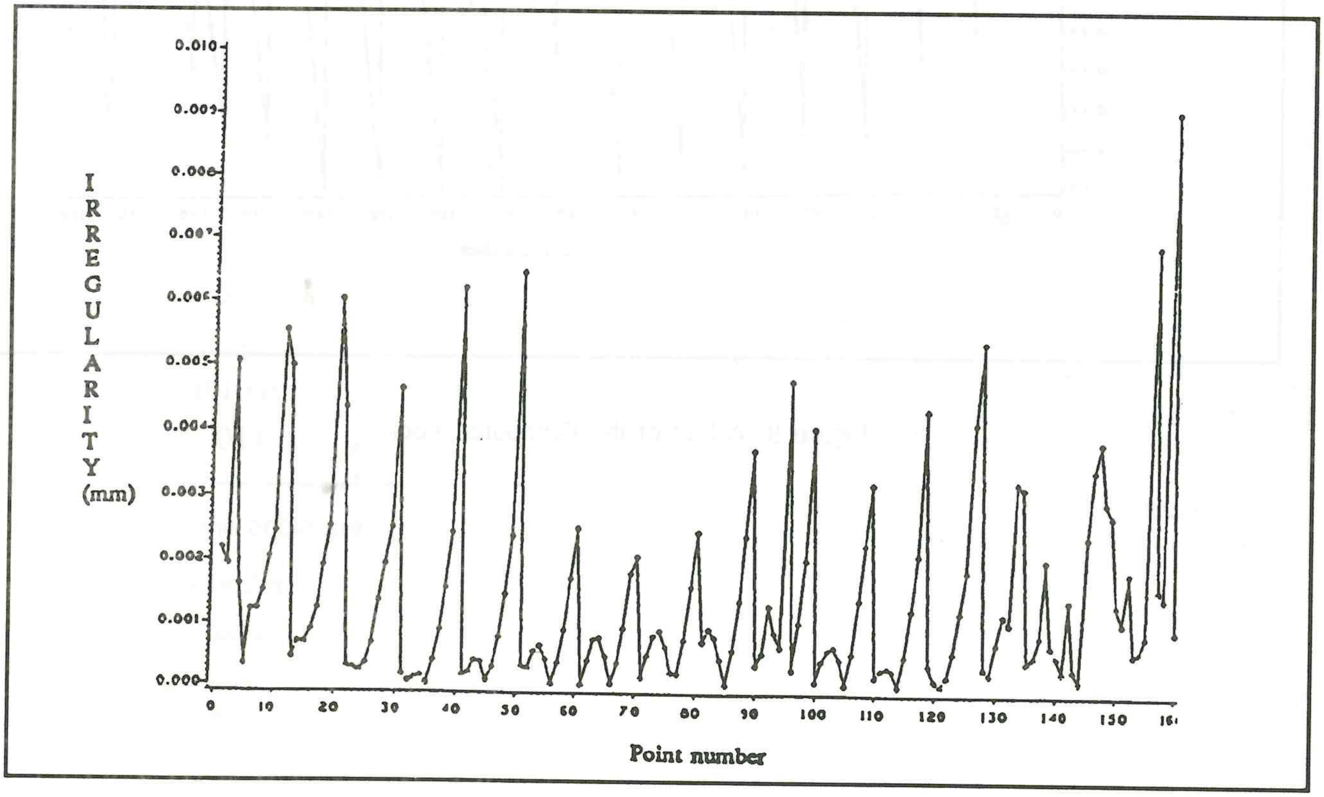

Figure 7 A Plot of the Irregularities on the Antenna Dish

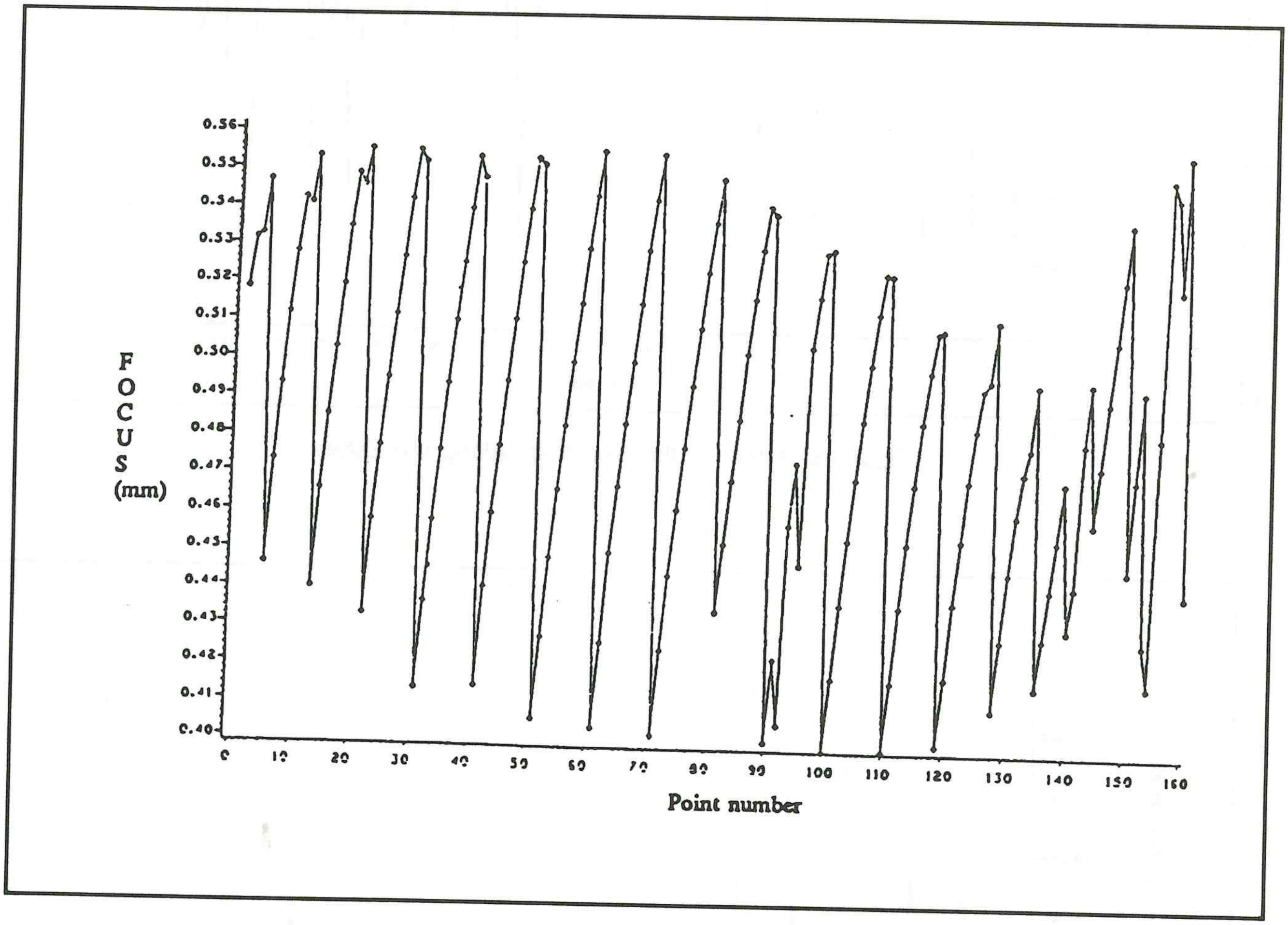

Figure 8 A Plot of the Computed Focii

with the coordinates of the origin

$$\left(-\frac{\alpha}{2a}, -\frac{\beta}{2b}, \frac{k}{\gamma}\right)$$

and the equation of the principal focus $f = \frac{\overline{X}^2}{4\overline{Z}}$.

The irregularities were derived from the weighted residuals of the measurements. It was assumed that the sum of squares of the residuals at each point on the surface of the reflector will provide a good indication of the surface roughness (n) i.e. $n^2 = Vx^2 + Vy^2 + Vz^2$ where Vx, Vy, and Vz are the residuals components at each target point.

2.6 Software Development

The major challenge of this project is software development. The suite of software developed is as follows: data transfer module; scale determination module; data verification module; coordinate determination module; least-squares fitting, axes rotation/translation module; and principal focus/ irregularities determination module. These software modules were developed using the BASIC language. The accuracy and efficiency of these software are vital to the success of the project; so also is data storage, quality control of results, and data management requirements.

3.0 RESULTS

The computed values of the coefficients of the paraboloid are shown in Table 1.

Table 1: Computed Values of the Coefficients

$a = 0.1195$ $h = -0.0036$

$b = 0.0996$ $\alpha = -0.6693$

$c = 0.0083$ $\beta = 0.5332$

$f = -0.1008$ $\gamma = -0.0625$

$g = 0.0043$ $k = 1$

Coordinates of the origin are

$$\overline{X} = -1.062m$$

$$\overline{Y} = -1.961m$$

$$\overline{Z} = -0.377m$$

Standard equation of the paraboloid is

$$\frac{x^2}{(11.2)^2} + \frac{y^2}{(10.98)^2} = 0.21z;$$

while the principal focus was computed to be 486mm.

4.0 DISCUSSION OF RESULTS

The electronic close-range surveying techniques require modular instruments / equipment which can be used alone for other functionalities, and at the same time interfaced for shape-monitoring functions. With the continuing decrease in the cost of computer hardware and electronic theodolites, the technology is becoming affordable especially to the developing countries. Manufacturing and standards organizations can quickly adopt these techniques/technology to undertake various monitoring tasks with little dependency on overseas partners.

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