Loughborough Anthropometric Shadow Scanner (LASS)

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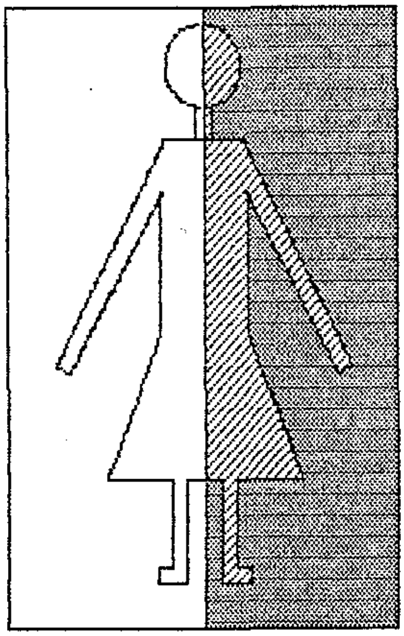
BY GORDON M. WEST



A Thesis Submitted in Partial Fulfillment of the Requirements for the Award of the Degree of Master of Philosophy of the Loughborough University of Technology
October 1987.

Declaration

This is to certify that the subject of this thesis is all my own work including the invention of the method (British patent no. 85.24473), design wiring and testing of the electronic circuitry of the camera interface and the design of the 24volt power supply. I also wrote the computer programs for the interface computer, the Macintosh computer and for the graph plotting.

Gordon M. West

Acknowledgements

It is here with grateful thanks that I wish to acknowledge the efforts of Dr P.R.M.Jones and Professor K.W.Brittan who so readily agreed to be my Research Director and Supervisor respectively. To David Harris and Philip Blake whose extra efforts in the normal work of the department allowed me time to work on this project, to my wife Rosemary who kept an eye on the grammar and the spelling mistakes and to Jeffrey Read who helped with some of the later experiments.

Gordon M. West

Abstract

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Traditional anthropometric methods are inadequate for both the amount of data collected and the time required to collect it. The subject of this thesis is a study of the feasibility of producing a socially acceptable whole body measuring machine capable of obtaining three-dimensional shape data of the human body. In particular the investigation of a novel idea (British Patent No. 85.24473) using television cameras and a particular form of structured light illumination. The geometry of the system is explained and some aspects of lens distortion investigated. A television camera interface has been designed incorporating a single card computer to capture the video image and to transfer it to a Macintosh computer. Programs written for both the computer and the interface allow measurements to be made of a significant part of the human body and have produced results in both tabulated and graphical form.

Compared with existing systems such as stereo-photogrammetry, Moiré topography, light slit scanning and rasterstereography which require sophisticated image analysis techniques, the new system provides a more direct read-out of data.

Body sway effects have been considered and the equipment has been used to measure the amount of sway in a small group of people.

CONTENTS

CONTENTS

Section. ....**Page.**

CONTENTS

Section. .... **Page.**

LIST OF FIGURES

Figure No's. ....**Page.**

LIST OF FIGURES

Figure No's. ....**Page.**

LIST OF TABLES

1.1 Automated Anthropometry

The measurement of human body size and surface shape is an important source of information, not only in textile manufacturing technology but also in medicine, human factors and biological sciences.

Traditionally, anthropometric measurements have been devised solely to describe human variation in body form, body proportions, and changes in size attributed to growth, race, and other variables of interest to anatomists and anthropologists. These anthropometric dimensions were taken to describe the linear distance between two landmarks, for example heights, breadth and depth, or around a body segment at a prescribed level such as circumference around the upper arm. In today's world, however, this classical approach to anthropometry is not sufficient to answer questions relevant to the interaction of man with a multitude of changing man-made environments. While the traditional measures are still important, as they describe differences between individuals and populations, the differences must also be considered as part of a 'man-machine system'. Thus, in anthropometric studies today, functional measurements which describe physical characteristics in relation to man's performance must be considered as well as the more traditional type of measurements. There is a need for a data bank of both classical and functional anthropometry on British men and women for application to product design and as an aid to the manufacture of uniformly better fitting garments.

The HUMAG research group in the Department of Human Sciences has, over the past few years, been involved in several size surveys of British boys and girls aged 5 to 16 years and British men aged 16 to 65 years. In all of these studies between 4,500 and 6,500 people were measured. Further studies of these magnitudes are not likely in the near future because they are costly, time consuming and labour intensive.

The traditional types of anthropometric survey take several measurements on every subject in the sample. Captive audiences for these types of survey can usually be found in the schools. However, there is increasing concern about the number of measurements that are now required which will extend the measuring time beyond that which is acceptable to pupils, teachers and parents. Thus, an alternative measurement strategy is needed. In essence this new strategy is to develop a fully automated system which is capable of measuring accurately and comprehensively the size as well as the shape of the human body in order to provide data for the garment manufacturing industry and others. It is envisaged that the final automated system will result in a piece of equipment that is readily transportable in order to collect survey data during, for example, the taking of a sample population survey.

Not all the applications of shape measurement are to do with the manufacture of clothing. Allied to clothing is the measurement of shoe lasts and of feet for the footware industry. Perhaps more important are the medical applications. It is reported in the Guardian newspaper (Rufford (1987)) that a Civil Engineer Dr. J. Boot and a Surgeon Mr. D. Sharp have used raster-stereography in order to help with the work of skin grafting during plastic surgery. Other applications include making measurements before and after surgery in order to improve the manufacture of artificial limbs and other protheses. In the treatmentof cancer the shape of parts of the body is required so that suitable masks can be made to regulate the dose of radiation in critical situations and also in the positioning of the radiation source so that the correct area is irradiated Sørenson(1968) and (Laursen,Andersen, and Hansen(1982)). The treatment of slow healing conditions, such as leg ulcers, can be investigated by doing a before and after treatment scan, so that a reduction in the area of the ulcer, or otherwise, can be detected in a reasonably short space of time.

Measurements of lung volume, body volume and surface area are also useful parameters in medical research and in the investigation of the effects of temperature and humidity on the human body.

2.1 Aim of Study.

The study was initiated by a request from Marks and Spencer Central Textile Technology to provide comprehensive shape data of the human body. These data were necessary to enable further work to be carried out in the field of computer aided design as applied to garment manufacturing technology. In particular the study is to investigate the possibility of manufacturing a socially acceptable non-contact measuring machine which is reasonably transportable and sufficiently speedy in operation to survey economically a large sample of the British population.

The study is required to answer the following.

1. Can a television camera be used as the non-contacting measuring transducer ?

2. Will the method of projecting a vertical shadow onto the body define the radius with sufficient accuracy ?

3. What are the problems associated with body sway ?

4. What are the problems associated with seeing round limbs etc. ?

5. How is the information to be interrogated in use ?

3. Review of Previous Work

3.1 Silhouette Measurement

One of the more obvious ways of measuring an object remotely is to measure the width of it when back lit or measure the shadow of it falling on to an array of photo cells. If this is done when the object is being rotated, or some other scanning mechanism is being used, then the solid form can, in certain special cases, be deduced. Such methods are described by Ito (1979), Takada & Esaki (1981), Vietorisz (1984) and are satisfactory for the measurement of non re-entrant objects such as are produced by many manufacturing processes. Because of its inability to measure re-entrant shapes it is an unsuitable method for this particular application, but the traditional measurements of the human form, taken by a tailor, with a tape measure also do not measure the true surface form.

3.2 Moiré Fringe Method

This method has been used, in various forms, in the engineering industry for many years but usually where the fringes are created over small or very small distances. An analysis of the method is given by Meadows, Johnson, and Allen (1970) in which they both illuminate and observe the object being measured through a 25 line/inch ruled grating which gave a resolution in the order of 0.25mm. Using finer grids resolutions up to 25μ were obtained. The interference fringes produced by the grating were photographed using a conventional film camera and the resulting pictures analysed later.

The depth of field using the above coarse grating was about 20cm. At distances greater than this the Moiré contours washed out due to diffraction effects. This method also produces extraneous noise-like terms due to the grid lines which may tend to obscure the contour pattern. Further work by Tokaski (1970) ,who used the Moiré system to measure a human torso, showed that these extraneous effects could be elliminated by moving the grating in its plane and taking a double exposure with the camera. He also mentions " too fine a grating causes diffraction of light which blurs the shadow. Even if the grating is coarse the shadow is blurred by penumbra caused by the width of the light source."

Further problems are caused by an object which has a surface inclined towards the light source since the width of the shadow lines increase.

In both of these applications of the Moiré method the object being measured and the equipment were both stationary, an all round view being obtained by taking a second shot from the rear and combining the results. Because the photographs so obtained were interpreted by a human observer the ambiguities which occurred where the photographs overlapped could be more readily resolved than might be possible with a computer controlled system.

3.3 Structured Light

In this context structured light refers to ilumination of the object to be measured by a pattern of light and shade. The measurement of the position of a point in space is essentially achieved by triangulation. The difficulty is to define a point on what is mostly a featureless surface. By projecting a pattern onto the surface to be measured, a measuring triangle is defined between the ends of the line joining the projector and the camera, and the point on the surface denoted by a feature of the pattern.

One such method by Gourlay, Kaye, Dennison, Peacock, and Morgen (1984) uses a pattern of parallel vertical stripes projected on to a human torso for the purpose of measuring the chest volume in lung function studies. Because the projector and the camera are mutually at right angles the contrasting edges of the light/dark stripes as viewed by the camera are a series of contour lines from which the surface coordinates can be calculated.

Again, with this method, a film camera was used to collect the data for later analysis and both the subject and the equipment were stationary. Information obtained in this way comprises a series of horizontal slices showing the form of the object being measured and spaced at convenient vertical intervals as scaled from the photographs.

A similar method by Laursen, Andersen, and Hansen(1982) uses a single strip of light to define a horizontal contour on the subject. The height of the contour is derived from a transducer mounted on the projector and a camera at right angles to the plane of the contour records the position of the contour of the body. By moving the projector and with multiple exposures of the camera a complete series of contours can be recorded.

Both the Moiré fringe systems described in 3.2 and the structured light system so far described require some human interpretation in order to analyse the results but the system of Lewis and Sopwith (1986) operates in a way that can be interpreted entirely by computer. A projector is used as above but this time a pattern of dots is projected in order to define particular points on the body surface. The dot pattern is viewed by two cameras simultaneously. The problem for the computer is unambiguously to match each spot in the image with the particular spot from the projector so that, by triangulation, its position in space can be calculated. This problem is not as easy as it first appears because not all of the spots are always visible, since some of them are obscured by projecting parts of the body or fall on steeply angled parts and are lost. By using the two cameras sufficient information is obtained to identify all the spots using only the computing power of a small stand alone computer.

Again this system produced only a view from one side. A second pattern of dots, projected further round in order to increase the viewing angle, was successfully tried and the second array of dots differentiated from the first by a marked difference in brightness. It was not considered feasible to produce a complete 360 degree view.

3.4 The Oxford Orthopaedic Centre (ISIS)

This method described by Turner-Smith (1982) is a highly successful device designed specifically to measure the shape of the human back. Essentially it uses structured light in the form of a single horizontal line of light. The projector and a television camera are fixed relative to one another in a swinging frame, which rotates at constant speed through a vertical arc, in order to scan the measuring area in one sweep. From a knowlege of the geometry of the system and the position of the image of the line as seen by the television camera, the three dimensional shape of the object being measured can be easily calculated by a computer. Again only one view is catered for and there would be some difficulty in combining several systems in order to achieve complete 360 degree measurement.

4.1 LASS Principle of Operation

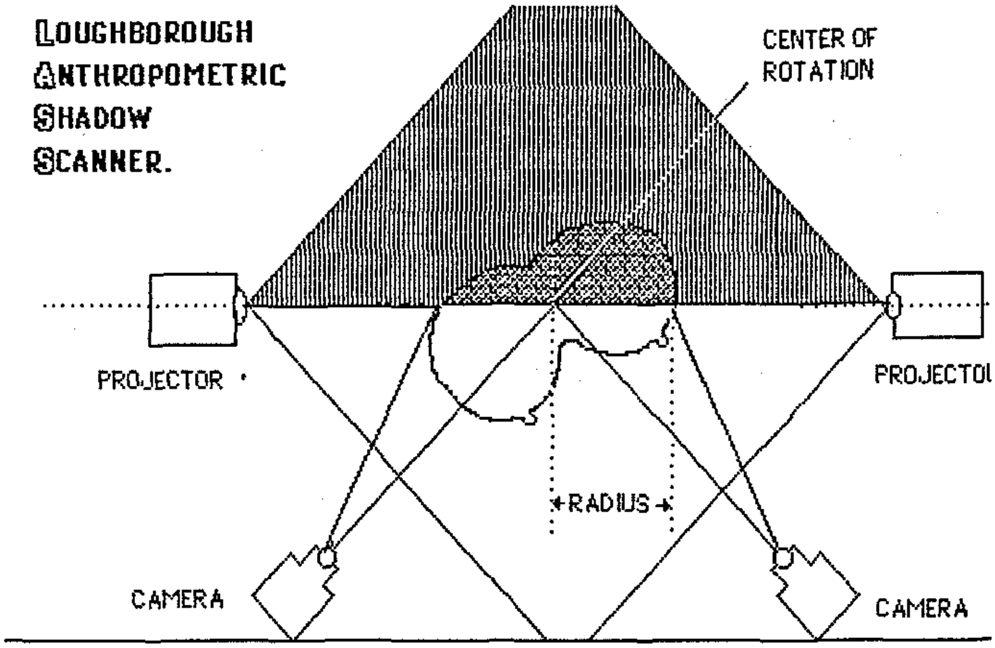


fig 4.1 General Arrangement of the System

The general arrangement is as shown in figure 4.1.

In this figure the person being measured is placed on a turntable such that they can be rotated through 360 degrees in measured angular increments. A shadow of a straight edge is projected from a slide projector to fall on the body in a vertical plane. This plane is arranged to pass through the center of rotation of the turntable. The whole scene is viewed by a television camera which is also aligned so that some known point at the edge of the field of view also coincides with the center of rotation of the turntable. Because the plane of the shadow passes through the center of the turntable, all points where the edge of the shadow falls on the body define the horizontal radii at points in the vertical plane. If one horizontal line of the scene viewed by the television camera is considered, the distance, from the reference point which coincides with the center of the turntable, to the shadow is accurately related to the radius of the body at that point. Clearly further TV lines will measure radii further down the body and information from a transducer mounted on the turntable will give the angle at which the radii were measured. In other words the full shape of the body is defined in cylindrical co-ordinates. If the TV camera is mounted at right angles to the plane of the shadow then any re-entrant parts to be measured will be obscured by other parts of the body. A more suitable angle between the camera and the projected shadow is 45 degrees which is a reasonable compromise between a good viewing angle for the re-entrant parts, and a sufficiently wide viewing angle to allow the radii to be measured with sufficient resolution.

From the television camera the video signals are processed by a special interface unit, so that numerical values are generated corresponding to the radii at any angle of the turntable. It is this information which is then passed to a main computer for storage and display.

4.2 The Television Camera as a Measuring Device

4.2.1 System Geometry

The television camera is a device for translating a view of an object into electrical signals in a reasonably high definition and linear fashion. With the use of modern electronics these signals can be translated into measurements which can be stored numerically in a computer. First the geometry of the optical system must be understood since, in this particular application, the camera will view the object to be measured at an oblique angle which will introduce a certain amount of distortion.

In order to make meaningful measurements the camera must first be calibrated. In fig 4.2 the plane of calibration is parallel to the image plane of the camera and is denoted by X*. A point X is on any other plane either nearer to, or further away from the camera than the X* plane.

The following relationships show that the size (MI) as seen by the computer will depend on the distance that the object being measured (X) is from the plane of calibration X*.

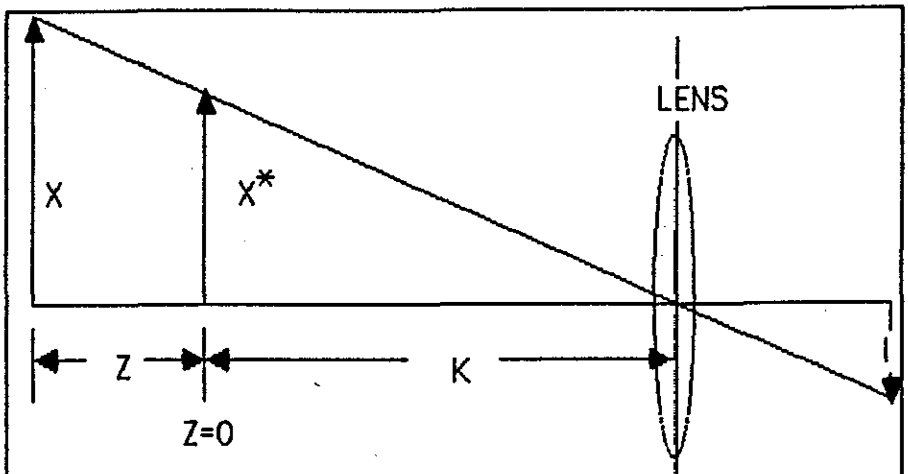


fig 4.2 Geometry of Normal system.

X^* = Measured value on the reference plane at Z = 0

By similar triangles -

$$\frac{X}{Z+K} = \frac{X^*}{K}$$

$$\frac{X^*}{X} = \frac{K}{Z+K} = \frac{1}{\frac{Z}{K}+1}$$

The computer readout = M x I where

M = The magnification of the camera/computer system.

M is adjusted during calibration so that MI = X^*

Then

$$MI = \frac{XK}{Z+K}$$

or

$$X = \frac{MI(Z+K)}{K} = MI(\frac{Z}{K}+1)$$

In fig 4.3 is shown the case where the object being measured (r) is inclined towards the camera. Since now the measurement involves the Z axis a non linearity is introduced as shown in the following calculation.

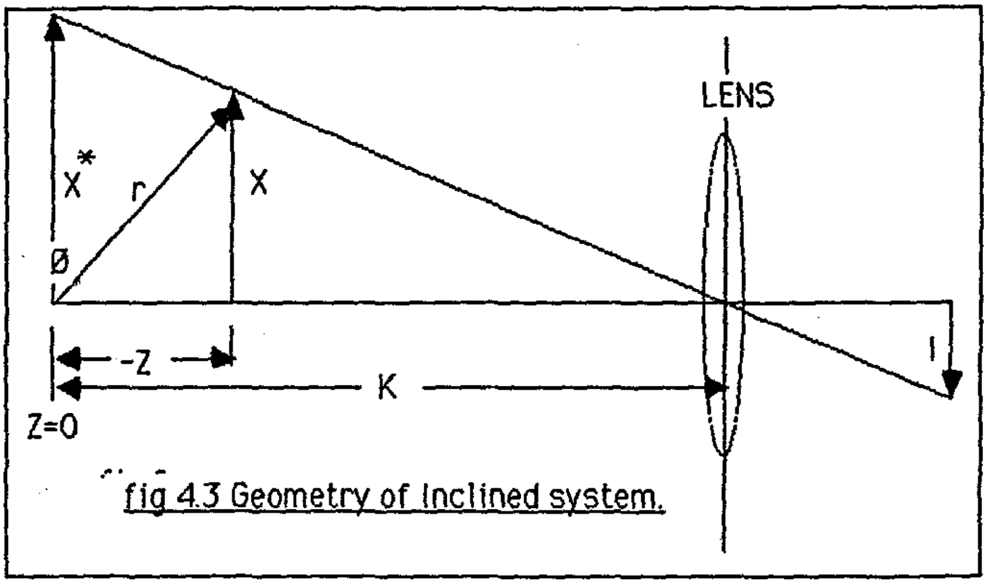


fig 4.3 Geometry of Inclined system.

$$X^* = MI \quad \text{(by calibration)}$$
$$X = r \cos ø$$
$$Z = - r \sin ø$$

and from previous calculation

$$X = \frac{MI(Z + K)}{K}$$

substituting for X and Z

$$K r \cos ø = -MIr \sin ø + KMI$$
$$r = \frac{KMI}{K \cos ø + MI \sin ø}$$
$$= \frac{MI}{\cos ø + \frac{MI}{K} \sin ø}$$

4.3 Details of the System

The system comprises;

a) Television camera

b) Interface unit containing the following.

1) Line synchronisation counter.

2) Voltage comparator.

3) Fast memory.

4) Computer/controller card.

5) Sync. driver circuits.

6) Video monitor driver circuits.

c) Slide projector.

d) D.C. Supply for the projector.

e) Rotary table.

f) Macintosh Plus computer.

4.3.1 Television Camera

Preliminary experiments were tried using a camera with a vidicon television tube. While these were fairly satisfactory better results were obtained from Pansonic WV-1550 cameras which use NEWVICON tubes. The NEWVICON tubes are more sensitive (0.3 lux) and do not bloom with high brightness.

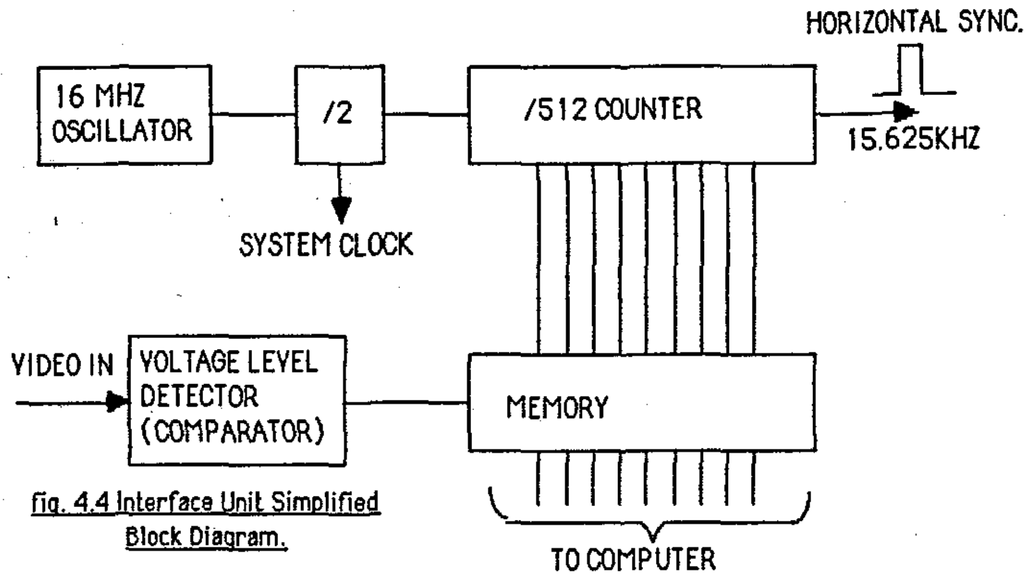


fig. 4.4 Interface Unit Simplified Block Diagram.

4.3.2 Interface Unit

A simplified block diagram to show the relationship between the line synchronisation counter, the voltage comparator and the fast memory is shown in fig 4.4 above. The 16 MHz crystal oscillator is divided by 2 to provide an 8 MHz clock signal. The division by 2 ensures an equal mark/space ratio in the resulting signal. Further division by 512 produces a pulse with a repetition rate of 15.625 kHz which is used as the line synchronising signal for the TV camera. When the camera recieves this signal a new line is started in the raster of lines forming the picture and, at any instant the number in the counter is a measure of how far the line has progressed, in time, from when it started. During the line scan a voltage comparator is monitoring the voltage level of the video signal from the camera. When there is a sudden change from bright to dark in the field of view of the camera, the voltage comparator detects the change in the video signal and causes the reading of the counter to be stored in the memory. With the camera set up as described above, the reading now stored in the interface memory is directly proportional to the radius of the body being viewed, at the height and angular position which pertain at that instant.

4.3.3 Computer/controller card

Associated with the interface memory is a single card microcomputer which performs most of the housekeeping functions of the interface. At the end of each line it reads the count from the fast memory into its own memory system. In addition it counts the lines and generates the frame synchronising pulse after 300 lines. Because of the time required to process the information by this computer the radius data is collected only every 15th line, giving 20 readings every frame of the picture. With the arrangement of lens and position of the camera normally used, this gives readings at approximately 1cm intervals in a vertical line. Having collected the data from one frame (20 readings) this is now transmitted by the interface computer to the main computer for storage or further processing. The cycle then repeats as necessary.

4.3.4 Sync. driver circuits & Video monitor driver circuit.

As is the normal practice the television camera and the video monitor accept signals via 75 ohm co-axial cables. The synchronising signals from the computer/controller card are at logic levels and are not sufficiently powerful to drive the cables. In addition the synchronising signals are required to be combined together to form a composite synchronisation signal for the camera. The monitor requires this composite signal combined with the video output of the camera. The circuitry to perform the above is shown in fig A1 in the Appendix.

4.3.5 Slide projector

A flourescent striplight was tried initially, shining against an opaque straight edge, but this was far from satisfactory owing to the width of the light source and the distance of the straight edge from the required position of the shadow. The best solution was to use a standard 35 mm slide projector (REFLECTA DIAMATOR AF) fitted with a slide made with a razor blade for the straight edge.

4.3.6 D.C.Supply for the projector

The television camera obviously responds to the light level of the scene being viewed. If the scene is illuminated from lights supplied from the 50 Hz mains supply then the illumination will vary in brilliance at 100 Hz rate, if incandescent lamps are used, since the lamp filament is heated equally by the positive or the negative half cycles of the mains supply. This variation in brightness will appear as modulation on the resulting video signal from the TV camera. By synchronising the integration time of the camera with the frequency of the mains supply this video modulation can be avoided or alternately the projector can be driven from an electrically smooth D.C. supply. This latter method was chosen and a suitable regulated 24 volt supply was constructed using the circuit of fig A2 in the Appendix.

4.4.1 Linesync counter, comparator and memory board.

Circuitry for two cameras to operate with common line synchronisation but with separate video comparators and memories is contained on the one circuit card (fig. A3 in the Appendix). Its purpose is to store the value of the line sync. counter into the appropriate memory when either video input signal indicates a transition from light to dark or from dark to light.

IC18 is the master clock for the system and is crystal controlled at 16.000 MHz. This signal is divided by 2 in the first stage of the 74HCT163 counter IC1to provide an 8 MHz waveform which now has an accurate 1:1 mark:space ratio. The 8 MHz waveform is used to sample the input waveform after the comparator. This part of the circuit will be described later.

Further division by IC1, IC2 and IC3 produce a pulse at 15.625 KHz. Fortunately the ripple carry output from IC3 is the correct length for the camera line synchronising pulse. Outputs from the counter chain are provided, in parallel, to both camera memories. The more significate 9 bits of the counter output, which effectively divide the period of one television line scan into 512 parts, are stored in the memory integrated circuits for either camera when the comparator signals that a shadow edge is being scanned at that moment. Camera A memory is contained in IC9, IC10 and IC11 while that of camera B is contained in IC12, IC13 and IC14. Each of these IC's is a 74LS189 which will store sixteen 4 bit words. As each camera memory comprises 3 of these IC's the total storage capacity of each camera memory is sixteen 12 bit words. Nine bits are used to store the line sync. counter data, one bit provides a black to white or white to black transition flag and the remaining two bits are not used. The memories are intended to store information gathered during the period of one line. It is possible to store the position in the line, as measured by the line scan counter, of up to sixteen light to dark transitions or vice versa. Camera A memory is addressed by the output of IC15 which is a 74LS197 4 bit binary counter and similarly camera B memory is addressed by IC16. Both counters are incremented by the appropriate memory write pulses which are inverted by part of the 74HCT04, IC17.

The video signal from camera A enters at SK1 connected to pin A4 where it is A.C. coupled by C1 and D.C. restored by D1 to 1.8 volts at the junction of R1 and R2. From the variable output of R2 is obtained the comparator reference voltage, which is the level above which the signal is regarded as white and below which the signal is regarded as black. The output of the comparator has now only two voltage levels corresponding to black or white and shown as waveform B in fig A4 in the Appendix. This waveform is connected to pin 2 of IC5 which is the D input of a 74HCT74 D type bistable. As the 8 MHz clock signal (waveform A) provides the clock input to the IC, any changes on the D input signal are now synchronised with the clock rising edge (waveform C). A second bistable circuit in IC5 is clocked by the 8MHz clock inverted by part of IC17 and which has its D input connected to the first bistable output. Because of the inversion of the clock signal this second bistable is triggered half of a clock cycle later to produce the waveform D in fig A4. Waveforms C and D are identical except that they are shifted in time by half of a clock cycle. When both of these waveforms are applied as inputs to the SN74HCT86 exclusive OR gate IC8 the output corresponds to the non overlapping parts of the two waveforms. When inverted by the second exclusive OR gate (its other input is tied to a logic 1 by resistor

R5) the waveform is shown at E. This waveform, which corresponds to a change from light to dark or from dark to light at the input, is used as the write signal to the memory so that the readings from the line sync. counter are stored in the memory every time the television camera line scan crosses a shadow boundary.

Since the memory is only capable of storing the readings taken during one line scan the information must be transferred to the main computer memory before more data can be obtained. In order to synchronise the data transfer, and to make sure that the data gathered during one linescan is not overwritten by the data from the next line before it is transferred to the main computer memory, the dual D type bistable I.C.19 is used. A pulse from the Computer/Controller card labelled "line grab" sets the first bistable as its D input is permanently connected to a logic one. The output of this bistable is the D input of the second which is now primed to set when the next line sync pulse, connected to its clock input, occurs. As soon as the second bistable is set it enables I.C.'s 5 & 6 which allows data to be collected and also resets the first bistable which removes the logic one on the second bistable D input. The next line sync pulse therefore resets the second bistable and the data gathering cycle for one line is complete.

The memory address lines are taken from the counter I.C.'s 15 & 16 which are capable of advancing the memory address one for every light/dark transition of the input. In this case, however, only the last transition in the line is required so the address counters remain permanently preset to zero. A "grab flag" signal from I.C.19 instructs the Computer/controller card to read the information from the fast memory into its own memory prior to sending it in serial form to the main Macintosh computer. Because of the time required to transfer the data it is only possible to read every 15th line of the television frame, and so give 20 readings per frame.

4.4.2 Sync.driver & Video monitor circuits

The raster scanning of the camera tube requires synchronisation pulses which determine both the start of a new line and the number of lines in one complete picture frame. Most cameras operate with an interlaced scan, where the first line of alternate frames is started at the centre of the picture so that the remaining lines fit between the lines of the previous frame. For this equipment it was decided that this was unnecessary and a simple 300 line non interlaced scan was chosen.

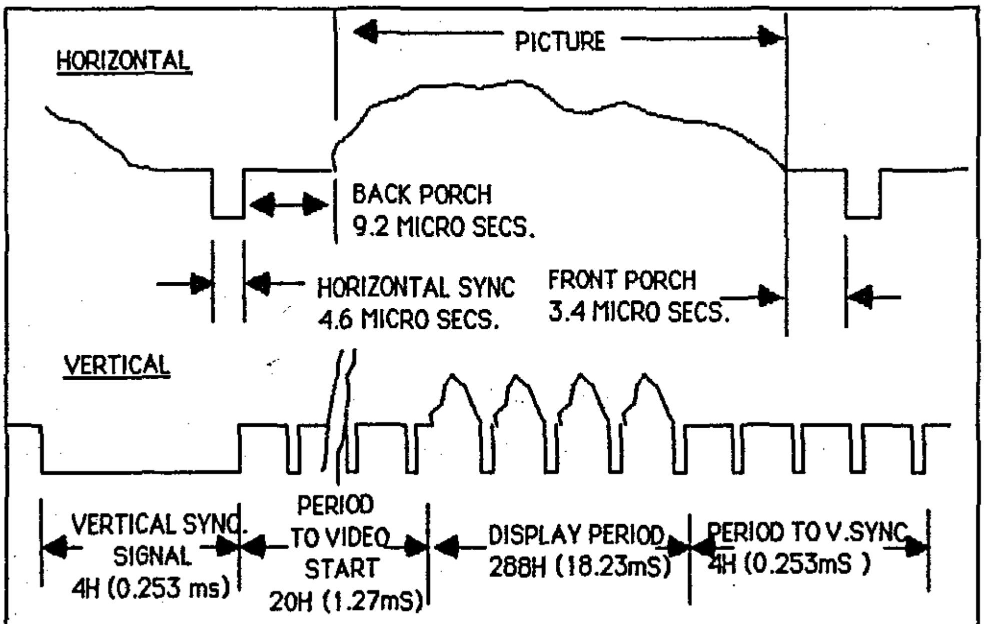


fig 4.5 Synchronising Waveforms.

Both the line sync. pulses and the frame sync. pulses are combined into a single composite synchronisation signal as shown in fig 4.5. The pulse lengths actually used are slightly incorrect but they were more readily obtained from simple electronics and operated very satisfactorily.

The line sync. pulse was 4 micro-seconds long and occurred at a frequency of 15.625 KHz while the frame sync. pulses were 256 micro-seconds long and occurred every 300 lines . No attempt was made to lock the synchronisation system to the 50 Hz mains supply.

4.4.3 24v D.C. Power Supply

This power supply is designed to give 0-24 volts at 12.5 Amps continuously. Referring to figure A2 in the Appendix a 35 volt transformer supplies a conventional bridge rectifier REC1 and a 10,000 uF smoothing capacitor C1, which on load provide 40 volts to the regulator circuit. For the regulator a standard 3 terminal regulator I.C. is used, shunted by 4 PNP3055 power transistors, which handle nearly all the output current. In fig A2 a voltage is developed across R1 as current is drawn through the regulator. This in turn increases the emitter base voltages of the 4 power transistors in parallel via the 5th PNP3055 transistor, used to boost the available base current. As a consequence of increased emitter base voltage the power transistors turn on and supply current to the load. Resistors R2-R5 are included to force the power transistors to share the current.

4.4.4 Heat sink calculations

Each PNP3055 is rated at a case temperature of 25 deg. C. and a maximum junction temperature of 200 deg. C.

Therefore the thermal resistance to case is

$$R_c = (200-25)/115 = 1.5 \text{ deg./watt.}$$

Assume 0.4 deg./watt for the mica washer

Therefore thermal resistance, junction to heat sink

= 1.5 + 0.4 = 1.9 deg./watt

Required 300 watts @ 24 volts

= 300/24 = 12.5 Amps per 4 transistors.

= 12.5/4 = 3.125 Amps per transistor.

Assume 3.5 Amps to allow for non-sharing and allow 15 volts drop across the regulator.

Therefore the power dissipation per transistor

= 3.5*15 = 52.5 watts.

Heatsink temperature = 200 -52.5*1.9 = 100.25 deg. C.

Total power dissipated by the heat sink

= 52.5*4 = 210 watts.

Required thermal resistance of heatsink for an ambient of 35 deg. C.

= (100.25 - 35)/210 = 0.31 deg.C/watt.

As a result of this calculation a commercially available heat sink having the nearest but lower thermal resistance was used.

4.5.1 COMPUTER and SOFTWARE

There are two computers in the system. A single board computer in the interface unit and an Apple Macintosh computer as the main system control computer. The single board computer is necessary because the Macintosh does not have a readily available parallel interface. Communication between the two is via an RS232 serial link. When using small single board computers, there are often difficulties in programming and, in particular, debugging the programs because this type of computer is generally too small to contain an Editor/Assembler program or sufficient RAM memory. The computer chosen for this project uses a Rockwell R65F11 microprocessor chip and the R65FR1 FORTH development ROM. Together these allow programs to be written and compiled in the FORTH high level language but still within the very small single board computer. The great advantage is that all the interface ports are available when testing the programs.

Since the FORTH language was necessary for the small computer, and since it is a very powerful high speed language, it was used for all the programs.

To get the programs into the single board interface computer the Apple Macintosh was used as a terminal and the programs downloaded from the Apple Macintosh disc drives.

Details of both the Apple Macintosh programs and the interface programs are in the Appendix.

4.6.1 Determination of Errors.

Measurements with the camera revealed a further distortion not accounted for by the calculations in 4.2.1. The following experiments were carried out in order to determine whether the error lay in the lens, the camera tube or some other cause.

The lens was first investigated as in fig 4.6.

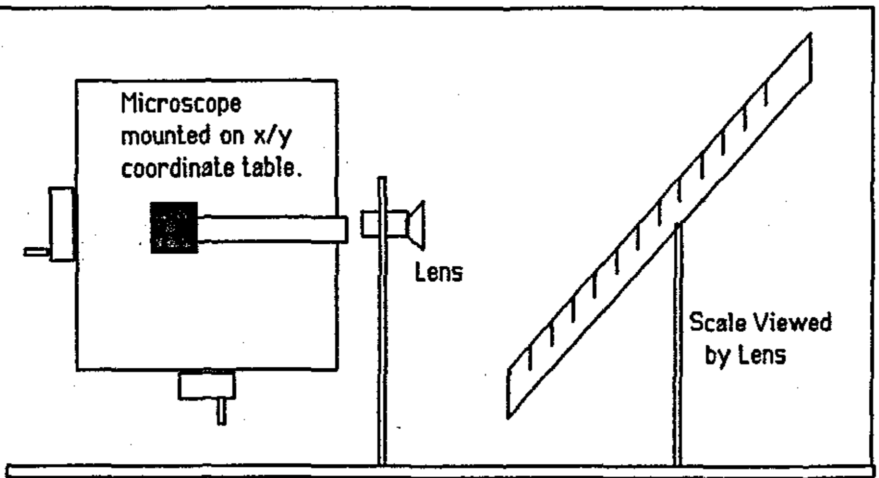


fig 4.6 Lens Test

A pocket microscope which had an eyepiece graticule was used to view the image of a linear scale (steel rule) produced by the lens. One particular line in the microscope eyepiece graticule was then aligned to the 1cm lines of the scale and a reading taken from the scale of the X axis of the co-ordinate table. This was repeated for every 1cm mark of the scale within the field of view of the lens. Because the same mark was used every time in the microscope, the effects of the microscope lens are constant and do not influence measurement. The results are shown in chapter 5. and indicate that there was no measurable error in the lens.

Further tests were made on the camera tube which was tested with the arrangement of fig 4.7.

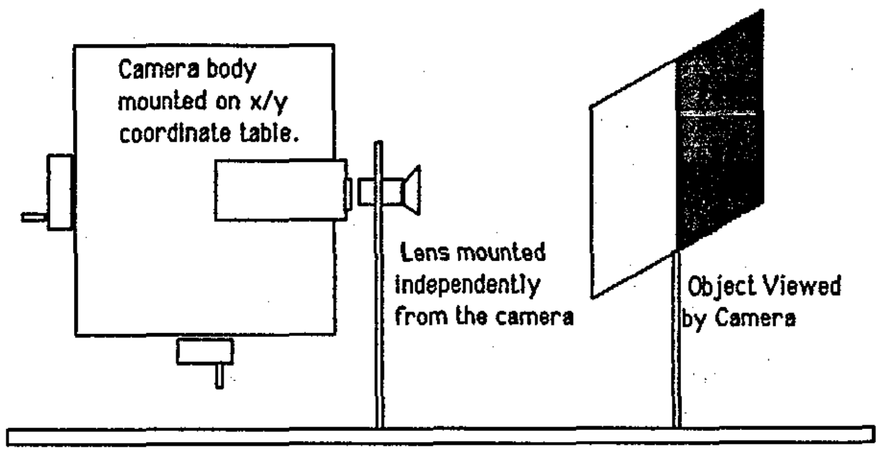


fig 4.7 Camera Tube Tests

This time the camera body was mounted on the co-ordinate table while its lens was mounted separately. The object being viewed comprised two contrasting areas with a vertical divide between them. As the interface electronics were designed to digitise the position of a change of contrast between bright and dark a numerical value was obtained which was related to the position of the image of the boundary between the contrasting areas on the camera tube. By traversing the camera on the co-ordinate table the response of the camera/computer to various positions of the pattern on the tube face could be determined directly. Again the results are tabulated in chapter 5. but no significant non-linearity was found.

4.6.2 Effect of Light Levels

With the camera pointing to a contrasting edge, created by projecting the shadow of the edge of a razor blade onto a plane surface, a reading of the position of this edge was obtained by the computer for different levels of the incident illumination. The illumination level was measured over the range of 500 to 2500 lux using a G.E.C. Minilux Photoelectric Photometer type P1.

4.6.3 System Calibration Method

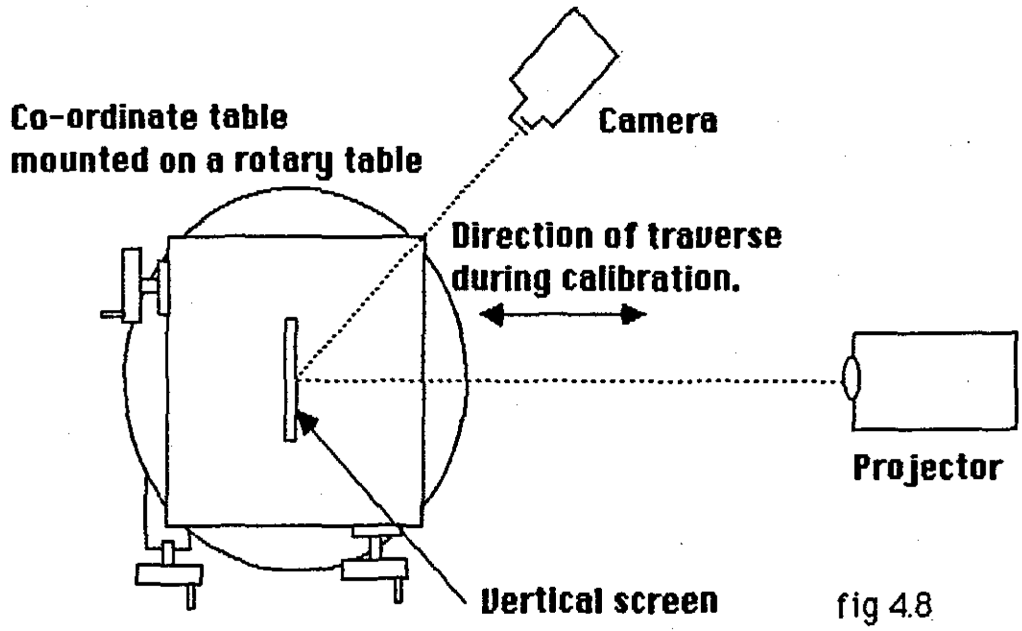


fig 4.8

Diagram to show Calibration Set-up

The above diagram shows how the calibration was carried out. At first the rotary table was set so that the co-ordinate table axis was parallel to the plane of the projector. This is easily verified by traversing the table so that the screen is moved towards or away from the projector. If the shadow projected onto the screen does not move across the screen during the traverse, then the axis of the co-ordinate table is parallel to the line to the projector.

The same technique is used to set up the angle to the camera. The rotary table was rotated through 45° and a mark on the screen was viewed by the T.V. camera. Again the co-ordinate table was traversed and the position of the camera adjusted so that the mark appeared stationary during the traverse.

Having set the relative positions of the projector and the camera the system was calibrated by first rotating the rotary table so that the screen was normal to the plane of the projector. Readings were then taken using the television camera/computer system to measure the position of the shadow for various settings of the co-ordinate table.

4.7.1 Body Measurement

The accuracy of the system is best investigated by the calibration method previously described, but it is necessary to demonstrate that the system will measure a shape corresponding to a human form. This study does not go as far as the measurement of a swaying human being, but the system was tested as far as was possible, by using a window dressers mannequin as the subject. The arms were removed for all of these tests as the computer program does not allow for interpolation behind them, but see page 68 for a discussion of this problem.

The mannequin was placed on a hand operated rotary table in front of the projector and television camera as described in 4.1. As the table was rotated at 5° increments, the Macintosh computer was instructed to take a measurement. This process was then repeated until 72 sets of measurements corresponding to the radii of 72 vertical slices covering the full 360° of rotation were obtained. Results were obtained in both numerical and graphical form.

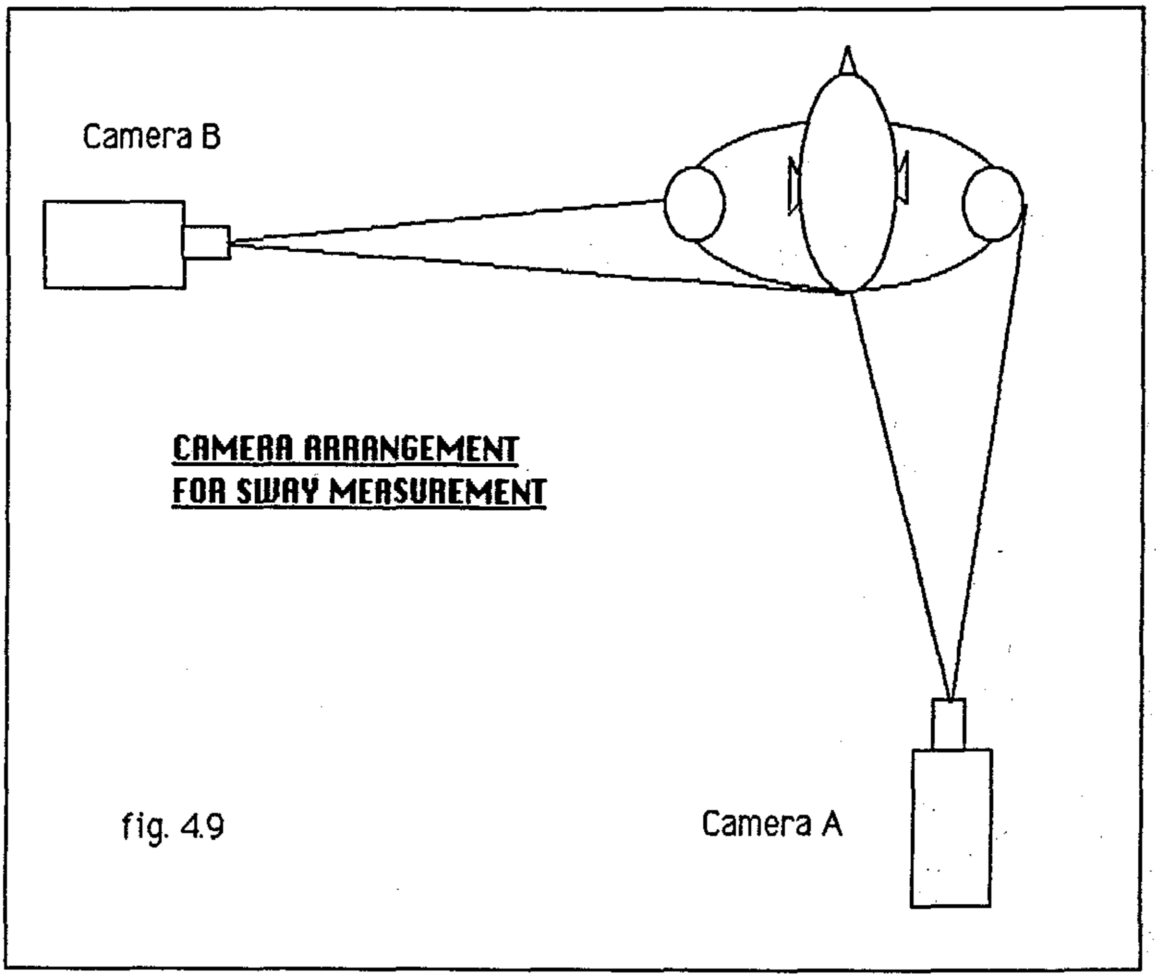
4.8.1 Measuring Body Sway

The method used by LASS to define a radius by projecting a shadow of a straight edge onto the subject in order to take measurements, is prone to errors if the subject sways while being measured. In order to make a proper assesement of the problem and to provide data to help in the design of a compensating solution, the equipment built during the study Phase of LASS was used.

As part of LASS, two cameras were interfaced to a computer such that the numerical value, proportional to the length of the TV horizontal scan line up to the point where the image in the camera changed from bright to dark, was fed to the computer for every 15th line of the scan. That is 20 readings were taken of the width of that part of the bright part of the image in the field of view. By viewing the subject with two cameras at right angles (see fig 4.9) against a dark background, it was possible to measure simultaneously the position of the right shoulder and the curve of the back. Processing by the computer took about 5 seconds for the 20 measurements by each camera.

4.8.2 Camera Alignment

To facilitate camera alignment the electronic interface is arranged so that the signal fed to the TV monitor is switched between the two cameras every time an active measuring line occurs. The effect is that the picture is divided into 20 horizontal stripes where alternate stripes display the scene from different cameras. The boundaries of the stripes are where the actual measurement takes place.



Camera A was first set up to view a plane surface where the subject would stand. By exploring with a pointer on the surface while looking at the monitor, it is possible to establish the field of view and the 20 individual measuring planes. In this experiment the measuring planes were approx 1.25cm apart. Adjustment of the scale was by means of the zoom lens of the camera. This was adjusted to give direct read-out from the computer in millimeters. The second camera was then adjusted in a similar fashion. To align the two cameras together the plane surface was angled at 45 degrees to each camera which could then both view two diagonal lines, in the form of a cross, on the surface. Whilelooking at the monitor the second camera was adjusted so that the cross, as seen in the stripes, was complete.

4.8.3 Sway Measurement

The subjects were then stood in place of the plane surface and the computer set to automatically scan for a period of 60 seconds. Because of the relatively long time between scans (5 secs.), it is possible to miss the higher frequency components of the sway profile, but then this experiment is meant to give a measure of the problem not as a definitive study on body sway.

5. Results

5.1 Experiment to determine the linearity of the lens

Lens Calibration

Scale	Traverse
0	93
10	129
20	157.6
30	184
40	214.6
50	245
60	268.6
70	295
80	327.6
90	354
100	379
110	408.5
120	441.6
130	467.6
140	496.8
150	537

The adjacent table of results were obtained by traversing a microscope across the image produced by the lens. The object seen by the lens was a linear scale.

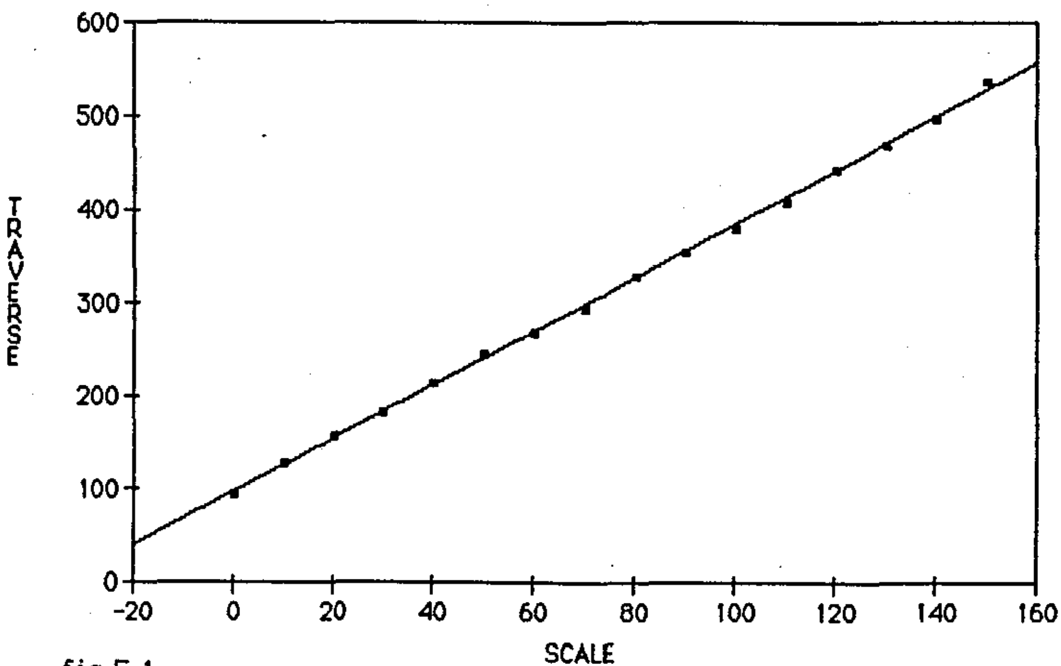


fig 5.1

Lens Calibration Curve

5. Results

The above data were analysed by a statistical program on a computer and the following results were obtained as a result of a linear regression calculation.

Data File: LENS CAL

Source	Sum of Squares	Deg. of Freedom	Mean Squares	F-Ratio
Model	279191.396	1	279191.396	17808.966
		14	15.677	
		15		

Durbin Watson Statistic

$$d = \frac{\sum_{i=2}^{N} (e_i - e_{i-1})^2}{\sum_{i=1}^{N} e_i^2}$$

Where e is the error (residual) for the ith case

ermination	0.999
relation	1.000
Estimate	3.959
atistic	1.464

	ent	Std. Err. Estimate	t Statistic
Constant	97.513	1.890	51.585
SCALE	2.866	0.021	133.450

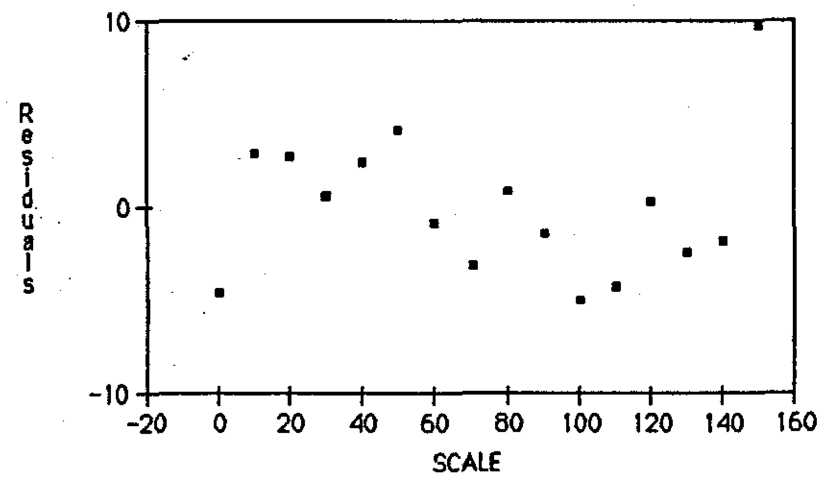


fig 5.2 Lens Calibration Residuals

The residuals now show a random scatter. Therefore the source of error is not due to lens distortion. The errors seem larger in this residual plot than the previous, but this is due to the finer resolution of the measurement.

5.2 Experiment to determine the linearity of the camera tube

Camera Calibration

Traverse	Computer
0	430
0.5	410
1.0	392
1.5	367
2.0	342
2.5	319
3.0	297
3.5	278
4.0	253
4.5	226
5.0	203
5.5	182
6.0	163
6.5	137
7.0	110
7.5	86
8.0	66
8.5	47

These results were obtained by traversing the camera body across an image produced by a stationary lens.

5. Results

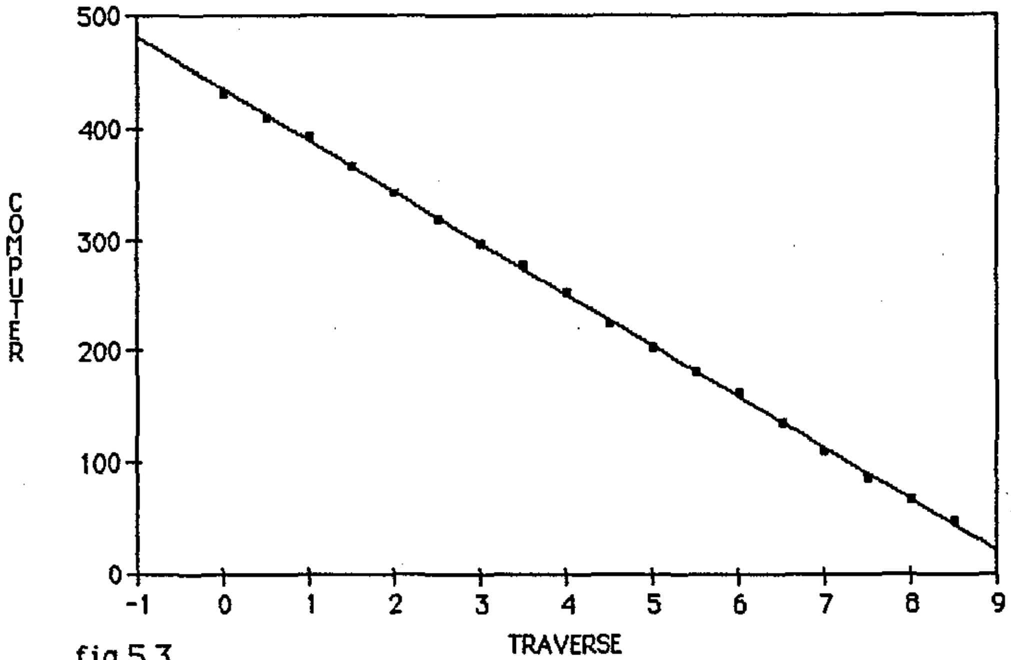


fig 5.3

Camera Calibration Curve

The following are the results obtained by analysing the above data using a statistical program on a computer to perform a linear regression calculation.

Data File: CAMERA CAL

Variable Name	Coefficient	Std. Err. Estimate	t Statistic
Constant	434.421	1.236	351.565
TRAVERSE	-45.903	0.248	-184.964

Data File: CAMERA CAL

Source	Sum of Squares	Deg. of Freedom	Mean Squares	F-Ratio
Model	255220.640	1	255220.640	34211.835
Error	119.360	16	7.460	
Total	255340.000	17		

Coefficient of Determination	1.000
Coefficient of Correlation	1.000
Standard Error of Estimate	2.731
Durbin-Watson Statistic	1.495

Again the residuals show a random scatter which means that the error was not due to the distortions introduced by the camera tube.

5.3 Effects of Illumination

With the length of one line of the television screen represented by a scale of 0 - 250 in arbitary units, the camera was pointed at a contrasting edge and its position measured with differing light levels. The experiment was carried out twice, once at each edge of the field of view, with the following results.

lux	1st Position	2nd Position
2500	71	244
2000	73	244
1500	74	245
1000	76	246
500	82	246

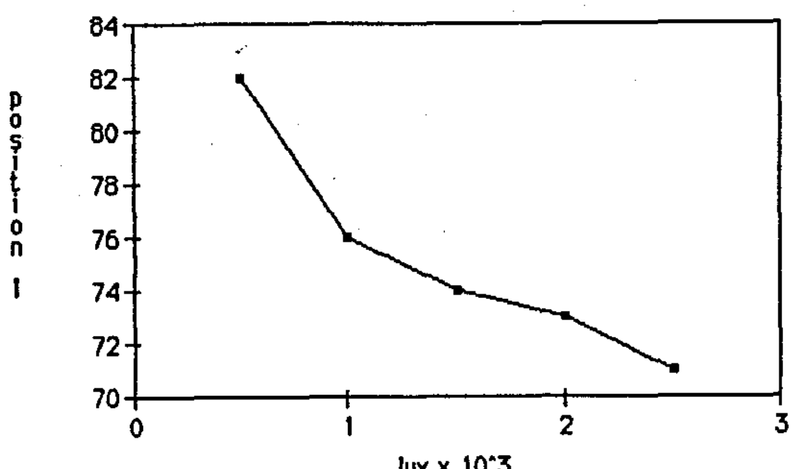


fig. 5.4 Effect of Illumination
Position A.

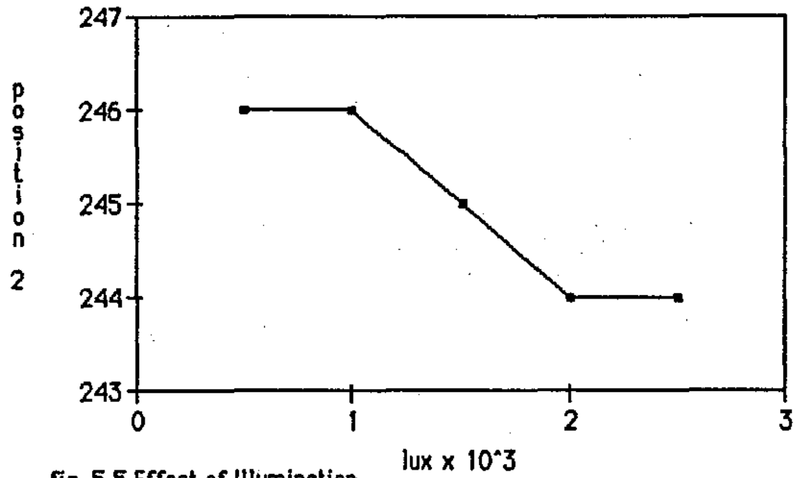


fig. 5.5 Effect of Illumination
Position B.

The apparent movement of the image is due to the fact that the electrical signal from the camera, in response to a contrasting edge, is not infinitely steep. The comparator, which is detecting a particular voltage level on this sloping waveform, will pick off a different point on the slope depending on the maximum amplitude of the slope. This amplitude is of course dependent on the light levels. More careful design of the comparator circuit may lessen this effect.

5.4 Results of Calibration

The following is the data from a series of calibration runs to determine the accuracy of the system and also where in the equipment any source of error may lie.

The conditions for runs 0 & 1 were :-

Camera aperture	f 8.0
Focal length of Zoom lens	70 mm approx
Focussing distance	1.9 Metres

The conditions for run 2 were :-

5. Results

Camera settings as above but the camera was moved so that the image was displaced relative to the camera tube.

The conditions for run 3 were :-

Settings were the same as 2 above but the projector lens was stopped down and the camera aperture adjusted to f 5.6 to compensate for the change of light level.

The conditions for run 4 were :-

For this run the Zoom lens was adjusted to a focal length of 30 mm in order to make the image, as seen by the camera, small compared to the width of the screen. The focus was set to 1.7 Metres.

5.5 Table 1. Results of 5 calibration runs.

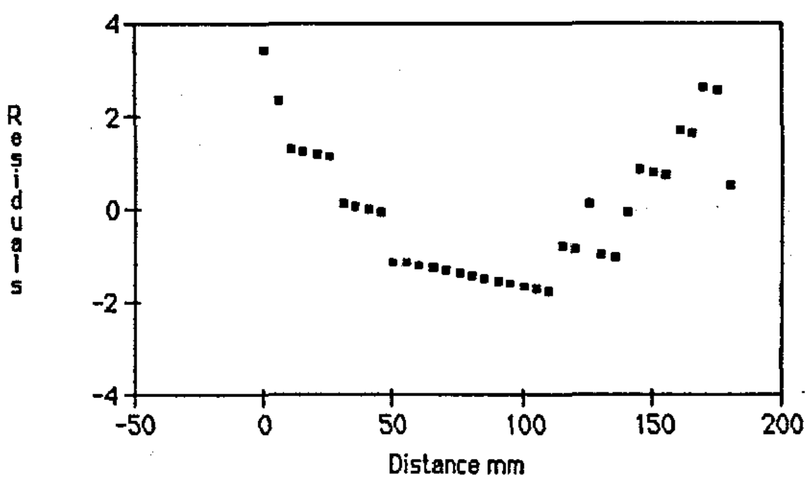
Dist.	Run 0	Run 1	Run 2	Run 3	Run 4
0	1	1	0	-1	0
5	5	6	4	3	4
10	9	10	9	8	8
15	14	15	13	13	14
20	19	19	17	17	18
25	24	24	22	22	23
30	28	29	27	27	27
35	33	34	31	32	33
40	38	38	36	36	37
45	43	43	41	41	42
50	47	48	45	45	47
55	52	52	50	51	52
60	57	57	55	56	56
65	62	62	60	60	62
70	67	67	65	65	66
75	72	72	70	70	71
80	77	76	75	75	76
85	82	81	79	80	81
90	87	86	84	85	87
95	92	91	89	90	91
100	97	97	94	95	97
105	102	102	99	100	101
110	107	107	104	105	107
115	113	112	109	110	111
120	118	117	114	115	117
125	124	122	119	120	121
130	128	127	125	126	127
135	133	132	130	131	133

Table 1. continued.

140	139	138	135	136	137
145	145	143	140	142	143
150	150	148	145	147	149
155	155	153	150	153	153
160	161	159	156	158	159
165	166	164	161	163	165
170	172	169	166	169	169
175	177	175	172	174	175
180	180	181	177	180	181

5.6 Analysis of calibration results

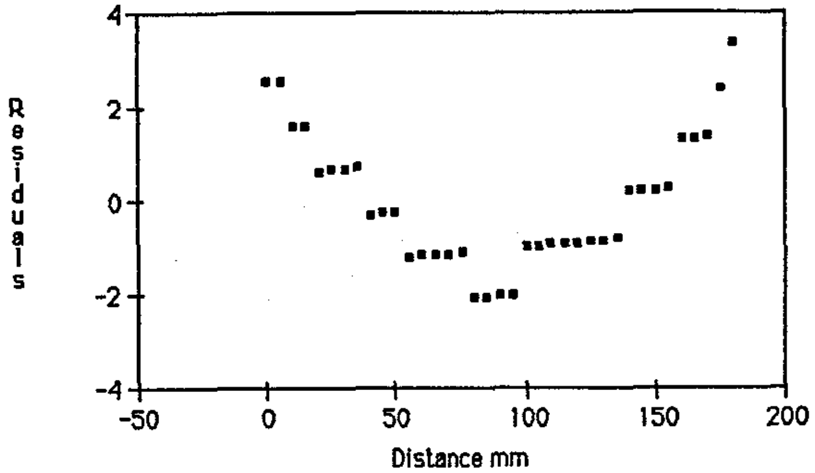
Obviously with each experimental arrangement there will be differences in zero offset and slope of the resulting readings. If we are to compare the results then these differences need to be excluded. A good way to achieve this is to calculate the linear regression on the results from each run. In this way accurate values of zero offset and slope are obtained. The important errors are the residuals resulting from the regression calculation since, in practice, errors in zero offset and slope can easily be corrected. It is interesting to see the plot of these residuals as shown below.



Plot of residuals of run 0

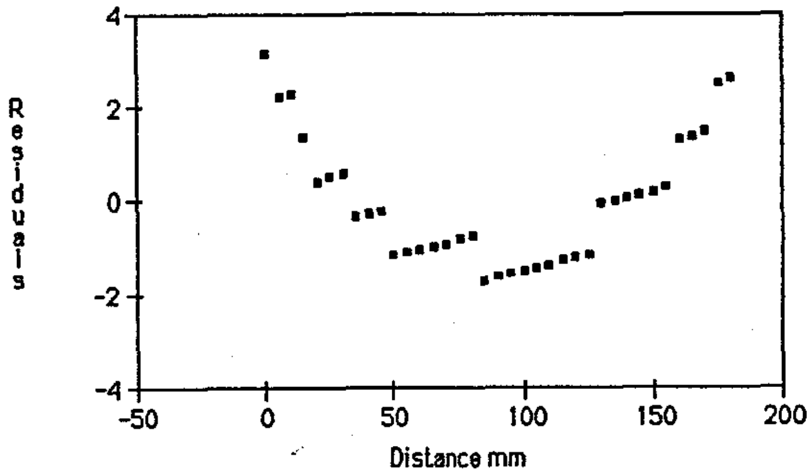
fig. 5.6 .

5. Results



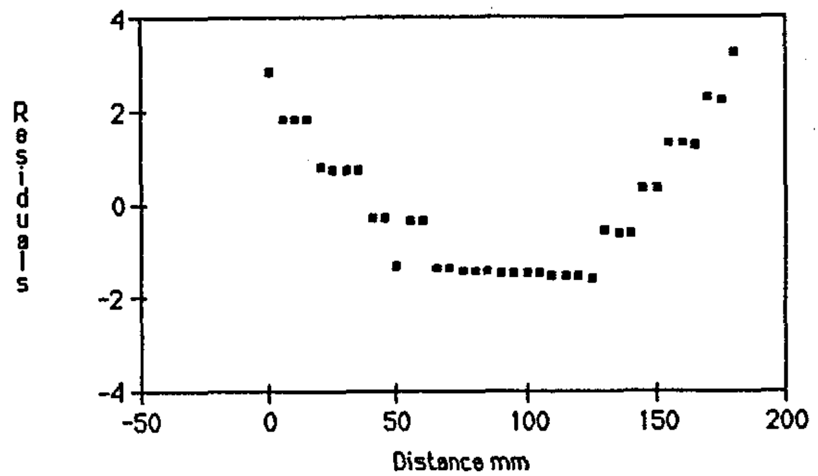
Plot of residuals of run 1

fig. 5.7



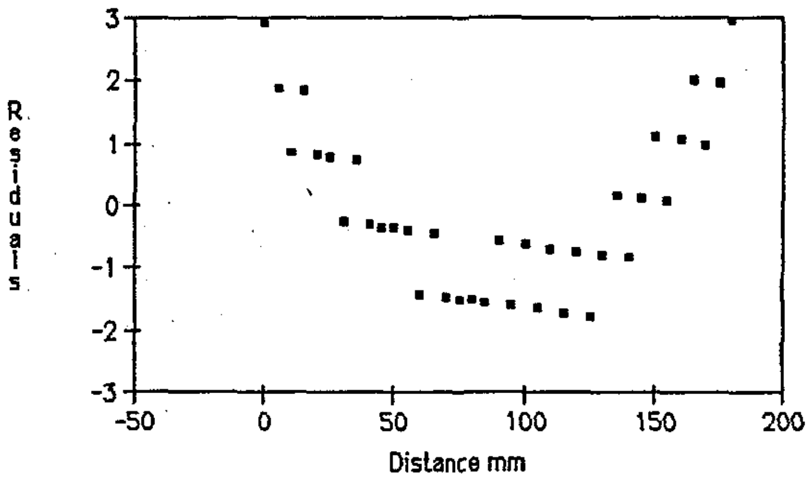
Plot of residuals of run 2

fig. 5.8



Plot of residuals of run 3

fig. 5.9



Plot of residuals of run 4

fig. 5.10

Clearly the changes in the experimental set-up had little effect on the error curve. The conclusion is that the error is due to the light output of the camera lens being less at the edges and this along with the effect of illumination on the comparator input is producing this error.

5.7 Results from the Prototype System

Having determined that the remaining slight non-linearity cannot be easily eliminated at source it was decide to use a non-linear calibration curve. To this end the five sets of results were subjected to a polynomial regression analysis with the idea that the resulting curve would define the relationship between the camera results and the actual measurements. The Standard Error of the Estimate from this is shown below in Table 2.

5. Results

Table 2. Accuracy of the Prototype System.

Calibration Run	Standard Error of the Estimate
Run 0	0.560
Run 1	0.513
Run 2	0.350
Run 3	0.365
Run 4	0.554

The above results indicate that the errors of 95% of the measurements will lie within + or - 2 times the standard error as given above, which in the worst case is within +- 2 x 0.560 = +- 1.12 mm.

5.8 Measurement of a Mannequin

The final output of the LASS equipment is of course the numerical values which define sufficient points, on the body being measured, to define its shape with the required accuracy.The following Table 3. is of the values of the radii of those parts of the mannequin shown graphically later. Each horizontal row contains the figures for 1 vertical slice and so there are 72 rows representing radial slices at 5 degree intervals. Numbers at the beginning of each row represent the top of the picture and of course those at the right of each row the bottom. Each number is the radius in mm.

5.8.1 Table 3. Radii for the Mannequin

82	88	95	102	108	110	107	96	76	77	78	78	77	77	77	77
101	99	98	97	95	93	91	88	86	83	80	77	73	70	67	65
99	99	97	96	94	93	90	88	86	83	80	77	74	71	68	67
108	109	112	117	123	126	127	123	103	99	97	103	94	94	92	93
95	95	95	94	93	91	90	88	86	83	80	77	75	73	71	70
93	93	93	93	92	90	90	88	86	84	81	78	76	73	72	71
90	90	90	90	90	90	88	87	86	84	81	79	76	74	73	73
89	89	90	90	89	88	87	86	84	83	81	79	77	75	74	74
88	88	88	90	89	88	87	86	84	82	81	79	77	75	75	75
88	88	90	91	91	90	87	84	83	82	80	79	77	75	75	75
88	88	90	92	95	95	93	86	82	81	80	82	79	76	75	75
88	88	90	94	97	99	99	95	84	80	80	78	81	77	75	75
88	89	93	97	101	104	105	100	86	79	78	78	77	77	76	76
88	90	95	100	105	108	108	104	89	78	78	78	77	77	76	75
86	89	94	99	105	110	112	110	100	78	77	77	77	77	76	76
86	91	97	103	109	114	115	111	100	77	77	77	77	77	77	76
82	86	93	99	107	114	117	114	103	77	77	77	77	77	77	77
80	84	90	97	105	112	115	112	101	77	77	78	77	77	77	77
77	82	88	95	102	108	110	107	96	76	77	78	78	77	77	77
75	80	86	92	97	102	104	101	90	76	77	77	77	78	78	79
73	77	82	88	93	97	98	95	84	76	77	77	77	78	79	80
71	75	80	84	88	90	91	87	77	75	76	77	77	78	80	80
69	72	75	80	82	84	84	80	74	75	75	77	77	78	80	81
67	69	72	74	76	77	77	73	73	75	75	77	77	79	80	81
65	67	69	69	71	71	71	72	73	75	75	76	77	78	80	81
65	66	67	68	69	70	71	72	73	75	75	76	77	78	80	80
67	68	69	69	70	71	72	73	74	75	76	77	78	79	80	81
71	73	74	75	73	73	73	75	76	77	78	79	80	80	82	82
75	78	82	85	86	79	77	77	79	80	80	82	82	83	84	84
81	85	89	94	97	97	80	80	82	83	84	84	85	86	86	87
86	90	96	102	107	109	104	85	84	86	87	88	88	88	89	89
90	96	102	109	115	119	115	79	88	89	90	92	92	92	91	90
95	101	108	115	123	127	124	115	92	93	94	95	95	95	94	93

Table 3. Continued.

99	106	112	120	128	134	131	122	97	95	97	98	99	98	97	95
104	109	116	123	130	133	132	124	102	99	99	101	101	101	99	98
107	112	117	123	129	132	130	123	104	102	102	103	103	103	102	101
109	112	117	122	127	129	127	119	105	105	105	105	105	105	104	103
110	112	115	120	124	125	122	113	107	107	107	107	107	106	106	105
110	110	113	117	119	119	114	109	109	108	108	108	108	108	107	106
109	110	112	114	114	112	110	110	110	110	110	110	109	108	108	107
109	110	111	112	112	112	112	112	112	112	111	111	110	109	108	108
110	110	112	113	114	114	114	114	114	113	113	112	112	110	109	108
112	112	113	114	115	115	115	115	115	114	114	113	112	110	108	107
115	115	116	116	117	117	116	116	116	115	114	112	111	109	107	106
119	119	119	119	119	119	119	117	116	115	114	112	110	107	105	103
122	121	121	121	120	119	119	117	116	114	112	110	107	104	101	99
122	122	121	121	121	119	118	116	115	113	110	108	104	101	98	95
121	121	121	120	119	118	116	115	113	111	108	105	101	97	94	90
119	119	119	118	117	116	114	113	110	108	106	101	97	93	89	86
115	115	115	115	114	113	112	110	108	105	101	97	93	88	85	81
111	111	111	110	110	109	108	106	103	100	96	93	88	84	80	77
106	106	106	106	105	103	102	100	98	95	91	87	83	80	76	73
99	100	100	100	99	98	97	95	93	89	86	82	78	75	72	69
93	93	94	94	93	93	91	89	87	84	80	77	73	71	68	64
86	86	87	88	87	86	85	83	81	78	75	72	69	67	63	60
80	80	81	82	81	80	79	77	75	73	70	67	64	62	59	56
75	76	76	76	75	75	73	71	69	67	65	62	60	58	55	52
73	73	73	73	73	72	71	69	67	65	62	60	58	56	53	50
72	72	72	72	71	71	69	68	67	64	62	60	58	56	53	50
71	71	71	71	71	71	70	69	67	66	64	62	59	57	54	51
71	72	73	73	73	72	71	71	69	67	65	62	60	58	55	52
73	74	75	75	75	74	73	73	71	69	67	64	62	59	56	53
75	76	77	77	77	77	75	75	73	71	68	65	62	60	56	54
78	79	80	80	80	79	78	76	74	72	69	66	63	60	57	54
81	82	82	82	82	81	80	78	75	73	70	67	64	60	58	55
84	85	85	85	84	83	82	80	77	74	71	68	64	61	58	55
88	88	87	87	86	85	83	81	79	75	72	69	64	62	58	56
90	90	90	89	88	86	84	82	80	77	73	69	66	62	59	56
93	93	92	91	90	88	86	84	81	78	74	70	67	63	60	57
95	95	94	93	92	90	88	85	82	80	75	72	68	64	60	58
97	97	96	95	93	91	89	86	84	80	77	73	69	65	62	59
99	98	97	96	95	93	90	88	85	82	78	74	71	67	64	61

These results have been plotted on the following pages.

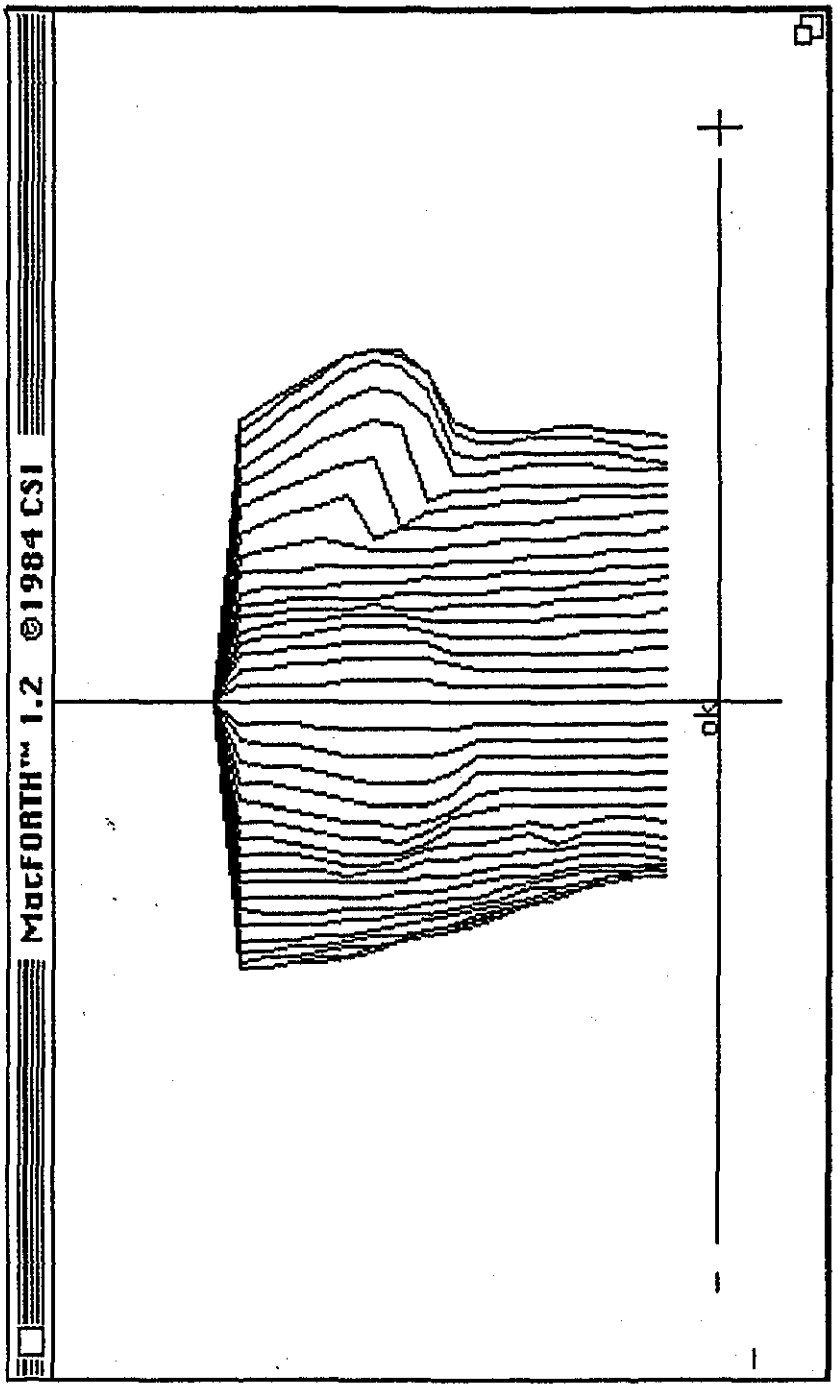


fig. 5.11 Plot of Manequin View A

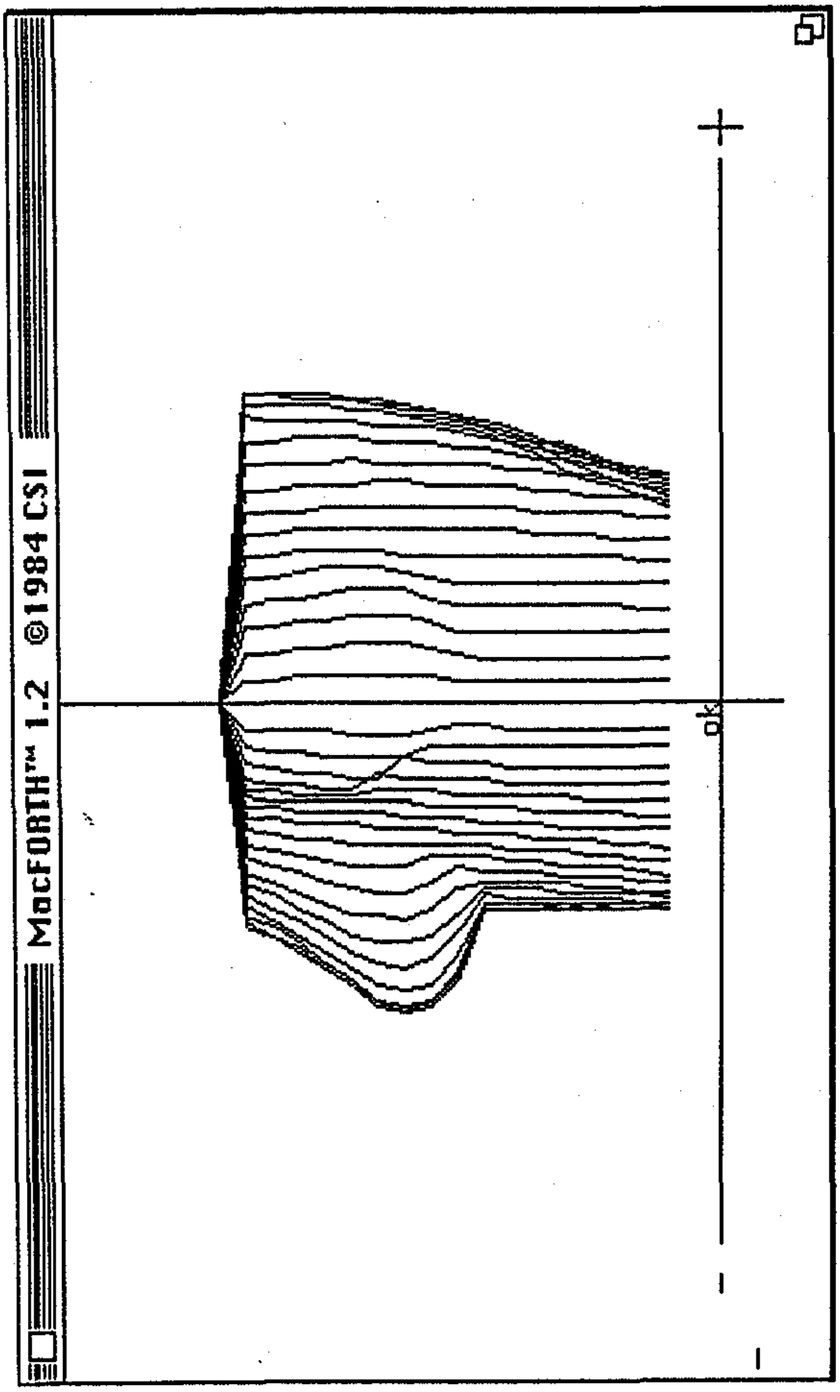


fig. 5.12 Plot of Manequin View B

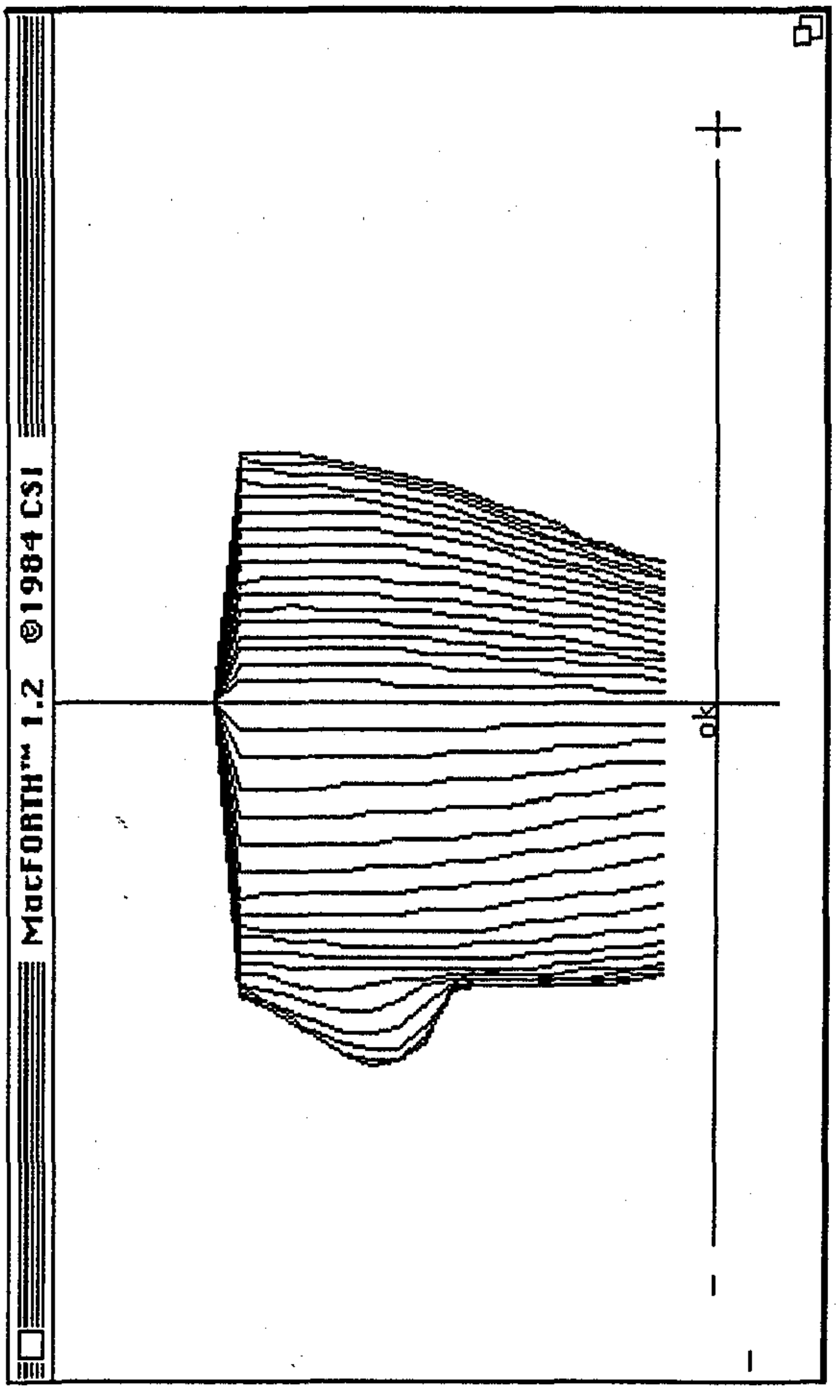


fig. 5.13 Plot of Manequin View C

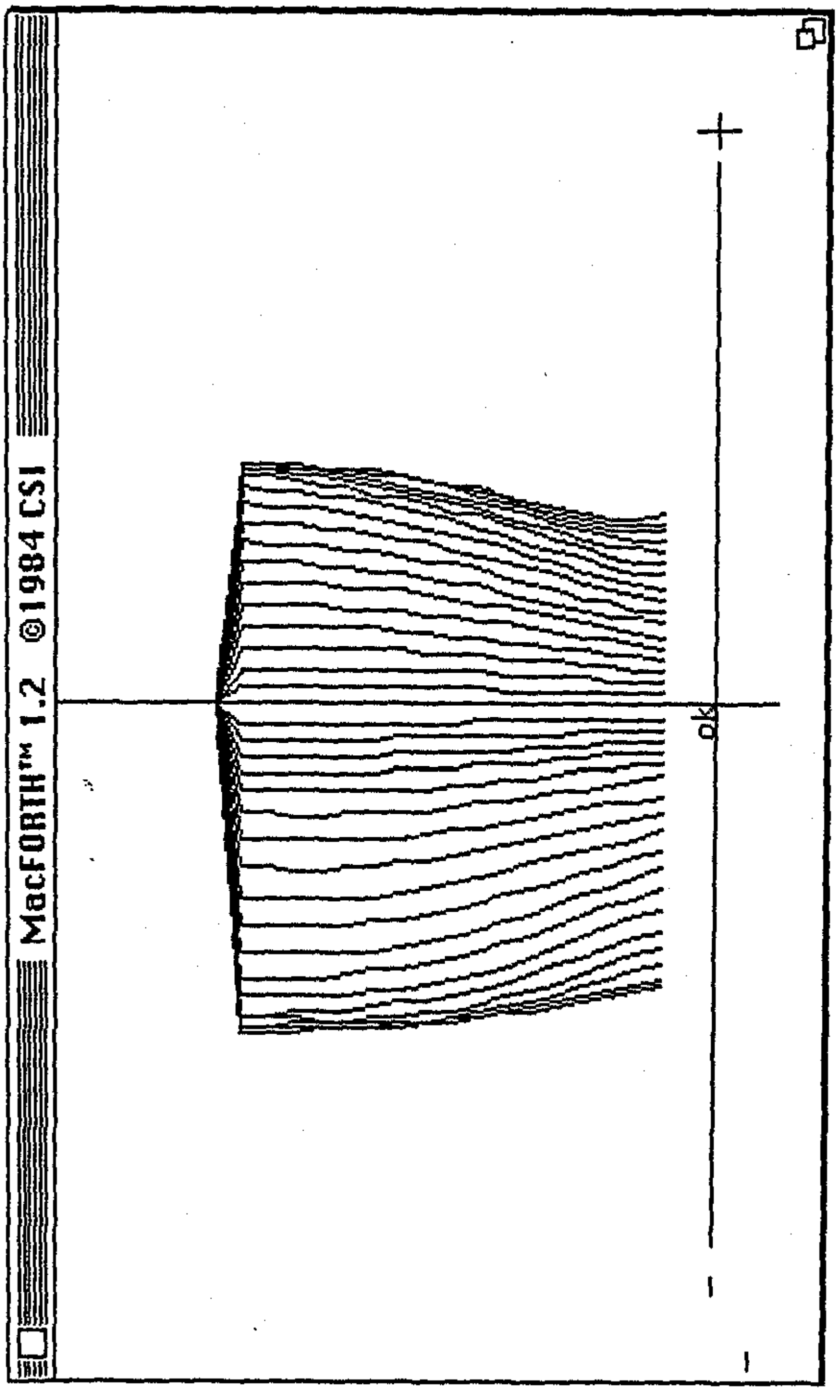


fig. 5.14 Plot of Manequin View D

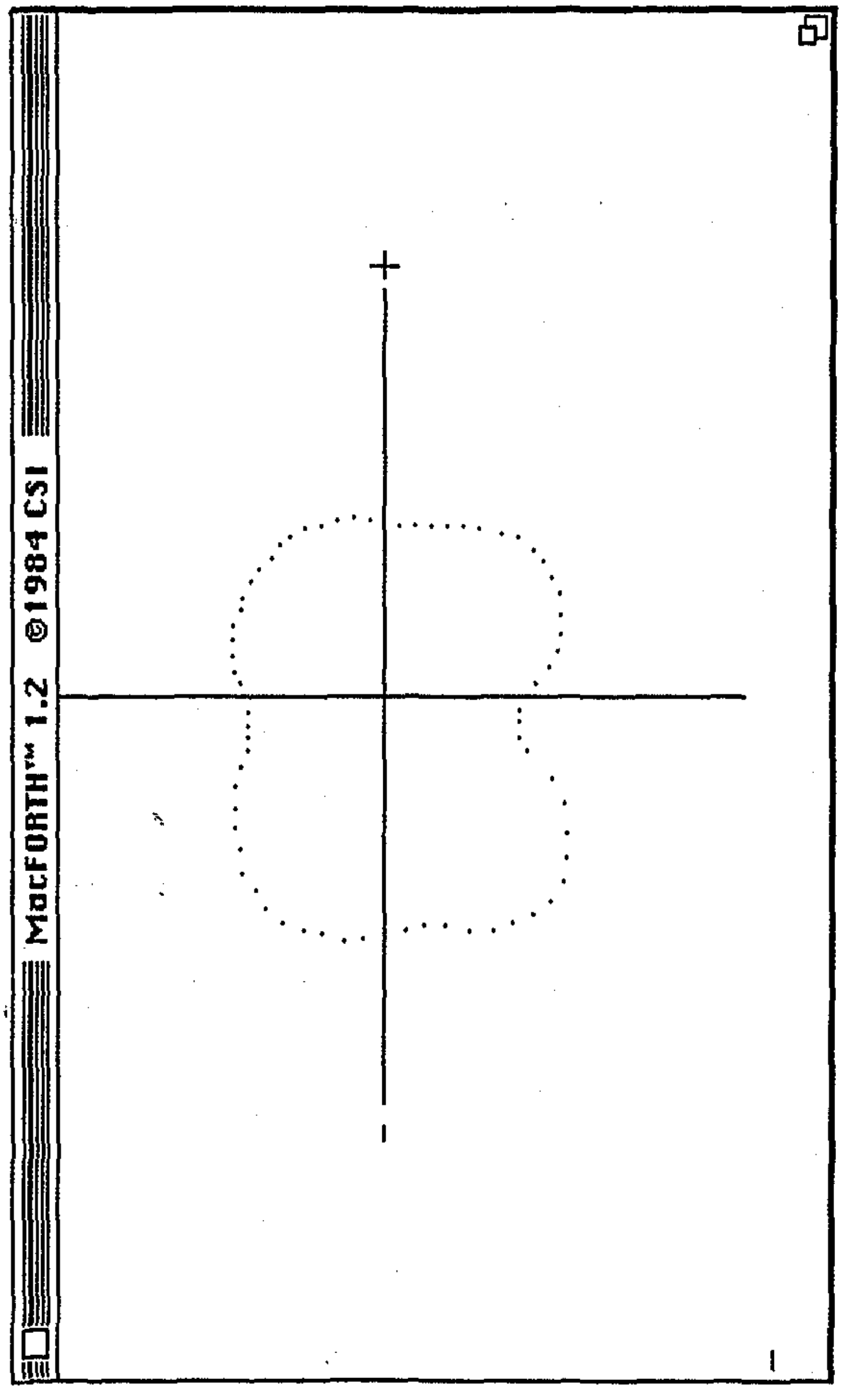


fig. 5.15 Plot of Manequin Showing a Horizontal Slice

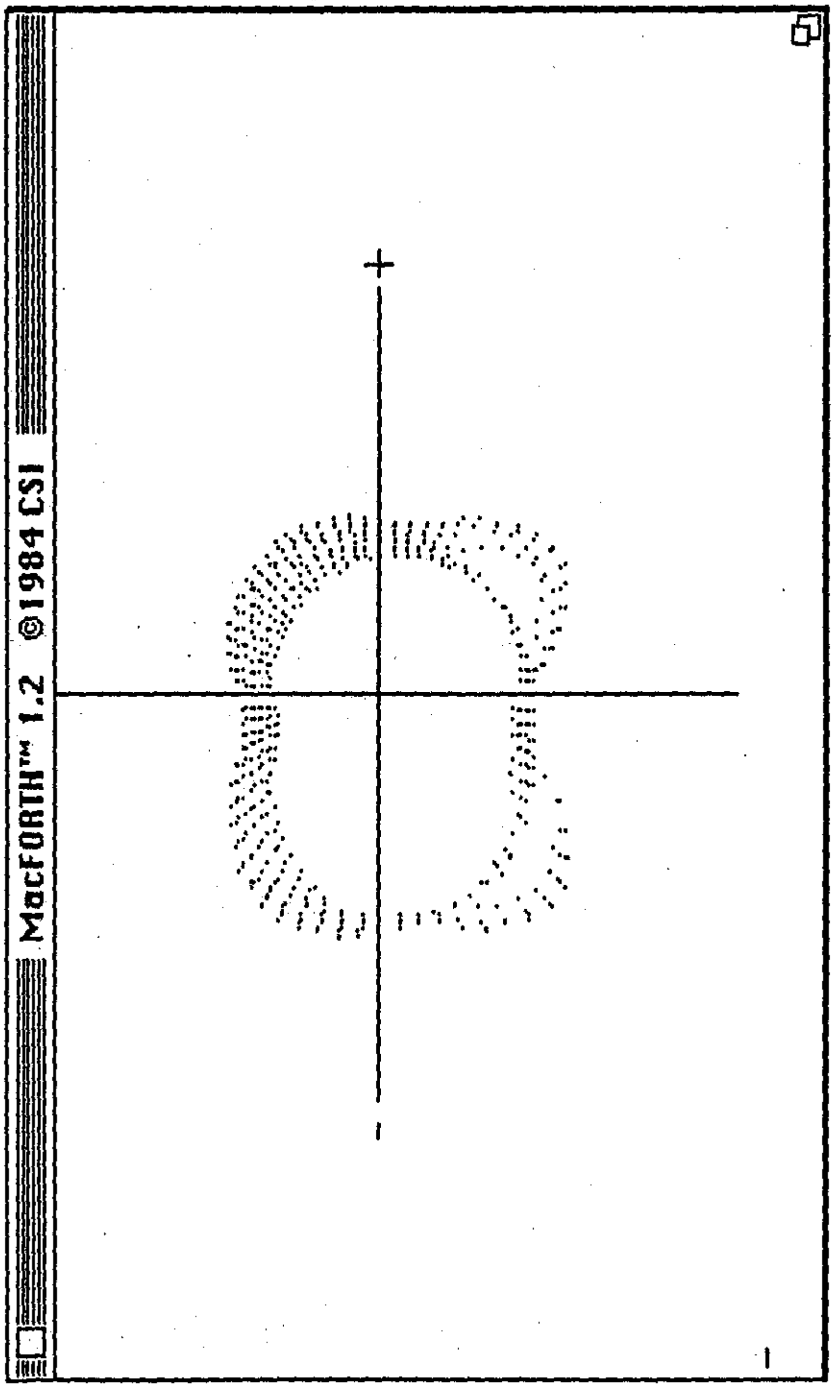


fig. 5.16 Plot of Manequin Showing Multiple Horizontal Slices

5.9.1 Results of the Sway Measurement

Measurement of sway was taken on 16 subjects, 8 male and 8 female. Details of the subjects are shown below in Tables 4 & 5.

Table 4. Details of the Male Subjects used for Sway Measurements.

Subj.No.	Height.cm.	Weight.kg.	Age.years.
1	179.8	73.0	55
2	185.1	91.0	56
3	173.5	77.0	24
4	189.2	70.5	42
5	175.7	71.5	35
6	180.4	88.0	47
7	170.9	61.5	38
8	178.9	60.0	45

Table 5. Details of the Female Subjects used for Sway Measurements.

Subj.No.	Height.cm.	Weight.kg.	Age.years.
1	162.5	52.5	38
2	154.8	61.5	50
3	162.0	65.0	34
4	150.5	55.0	28
5	171.2	64.0	42
6	165.5	58.0	37
7	173.3	73.5	26
8	155.5	50.0	46

Although 20 measurements were taken by each camera these data were reduced to a point at the top and a second point 19 cms beneath, which with approximately 11 frames times 2 cameras gives 44 readings in total for each subject (all readings are scaled in millimetres). While not strictly true the two planes of measurement are now referred to as 'shoulder' and 'waist'.

A preliminary examination of the results showed a fairly random movement in any direction. In the particular context of movement while the subject is being measured, it was decided that the amount of movement during any measuring interval is the important factor. Therefore the results were converted to directional vectors for both the shoulders and the waist. As there seemed to be no way of predicting the direction from one moment to the next the direction of the vector was ignored.

Because the distribution of the vectors show a positive skew the logarithm of the results were taken and were found to have a more normal distribution. The statistical analysis for both males and females is shown below.

Table 6. Analysis of the Male Shoulder Vector

Data File: MALE SWAY	
Variable: LOG.SH.VEC.	Observations: 141
Minimum: 0.000	Maximum: 3.186
Range: 3.186	Median: 1.498
Mean: 1.489	Standard Error: 0.067
Variance:	0.631
Standard Deviation:	0.794
Coefficient of Variation:	53.336
Skewness: -0.294	Kurtosis: -0.640

5. Results

Table 7. Analysis of Male Waist Vector

Data File:	MALE SWAY		
Variable:	LOG.W.VEC	Observations:	141
Minimum:	0.000	Maximum:	3.097
Range:	3.097	Median:	1.498
Mean:	1.426	Standard Error:	0.068
Variance:		0.661	
Standard Deviation:		0.813	
Coefficient of Variation:		57.011	
Skewness:	-0.316	Kurtosis:	-0.616

Table 8. Analysis of Female Shoulder Vector

Data File:	FEMALE SWAY		
Variable:	LOG.S.DIF.VEC	Observations:	64
Minimum:	0.001	Maximum:	2.780
Range:	2.779	Median:	1.445
Mean:	1.485	Standard Error:	0.085
Variance:		0.459	
Standard Deviation:		0.677	
Coefficient of Variation:		45.618	
Skewness:	-0.164	Kurtosis:	-0.720

Table 9. Analysis of Female Waist Vector

Data File: FEMALE SWAY	
Variable: LOG.W.D.VEC	Observations: 64
Minimum: 0.000	Maximum: 2.840
Range: 2.840	Median: 1.350
Mean: 1.326	Standard Error: 0.087
Variance:	0.487
Standard Deviation:	0.698
Coefficient of Variation:	52.637
Skewness: -0.054	Kurtosis: -0.760

5. Results

To return from the lognormal distribution to the normal distribution the following formulae apply.

If μ and o_ are the mean and standard deviation of y = loge x. then, it can be shown that the mean and standard deviation of x are :-

Mean = eμ+1/2o-2

Standard Deviation = eμ+1/2o-2(eo-2- 1)1/2.

The conversions then are :

Male shoulder

Mean = 6.077 mm.

Standard Deviation = 5.699 mm.

Male waist

Mean = 5.792 mm.

Standard Deviation = 5.605 mm.

Female shoulder

Mean = 5.553 mm.

Standard Deviation = 4.238 mm.

Female waist

Mean = 4.804 mm.

Standard Deviation = 3.805 mm.

6. Discussion

6.1 Errors due to Camera Angled View

It is necessary to incline the camera to view the subject being measured at an angle to the normal to the projector. This is so that re-entrant parts of the body can be measured. As shown in section 4.2.1 this produces distortion of the image. The results given in section 5, while taking into account the major distortions due to the angle, have assumed that all horizontal lines of the T.V. picture represent the same distance on the the scene being viewed. In fact all the calibration figures given refer to the central line of the picture. For any future implimentation of this system it will be desirable to incorporate some form of compensation into the computer program in order to correct the resulting measurement.

6.2 Dealing with the Sway Problem

Although the amount of sway of a person has been measured (sect 4.3) there has been no attempt to allow for it in the measurements so far. In a final version of the system either some form of support or restraint could be used to eliminate the sway altogether, or the amount of sway could be independently measured (say with cameras, or other type of sensor, which rotated with the person being measured). Having measured the sway simultaneously with measuring the radii of the body the latter measurement can be corrected by subtracting the former. When the body sways the actual point on the surface being measured will not be the point where the measurement was intended to take place but, providing a sufficiently large measuring point density is achieved, this will not be a problem.

6.3 Masking by Arms and Legs

The measurement of radius will result in a single value for any one point. Clearly when the measurement reaches a point obscured by an arm then the radius being measured will be that of the outside of the arm not

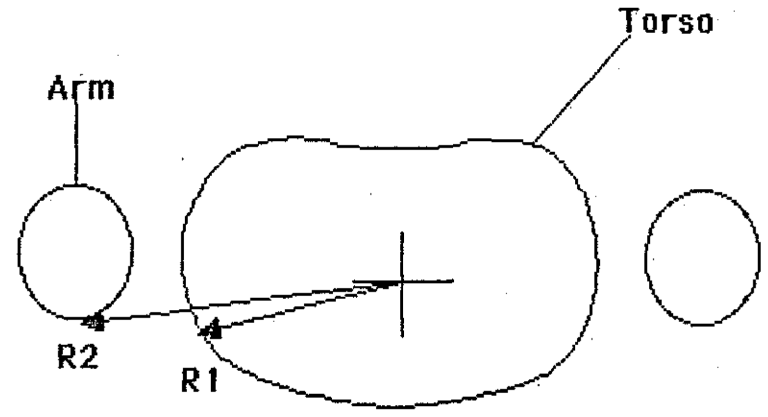


fig. 6.1 Change of Radius Due to an Arm.

that of the torso. Fortunately as shown in fig. 6.1 the value of the radius as the measurement proceeds from the point R1 to the point R2 will suddenly increase in value. This increase can be detected by the computer and the value of the radius at R1 used to extrapolate the torso radius for the parts obscured by the arm. The curve of the outside of the arm will be measured and these data can be used to create an approximate shape for the unmeasured part of the arm.

The legs also present a similar problem and some computer extrapolation will have to be used to fill in the missing data. Extra information can be obtained to help with the extrapolation by causing the camera to take silhouette views at particular angles during rotation. From such views an indication of arm, leg, and also torso, diameter can be obtained.

6.4 Using the Information

The results obtained so far either as a series of numbers in the computer, or as plotted graphs, while looking fairly impressive are not of immediate use to a garment designer. Traditionaly tape measures have been used by tailors in order to make proper fitting clothes. The tape measure is very suitable in that it usually does not measure the true surface distance, but stretches across indentations, in the manner that cloth does (modern stretch fabrics excepted). First then it is necessary to define what sort of measurement is required, whether a surface distance or a tape measure distance or perhaps a direct distance as required generally in engineering.

The second problem is to define exactly the end points of the measurement. Even for the more obvious measurements such as waist or chest it is not easy. Where is a waist ? On some people it is the narrowest part around the middle but on others it is the widest. Even if we know exactly where we want to measure, how do we interrogate the data. An obvious way is to produce a plot of the data on the computer screen and then with a light pen or some similar technique, indicate the end points of the measurement. This method will probably be satisfactory but, unless done with care on a high resolution screen, could introduce errors at least as great as the original measuring errors.

If the LASS system is to be used, as expected, to measure large numbers of people with subsequent computer analysis of the data then standards, such as the definition of the position of a waist, will have to be defined or computer analysis will be impossible.

6.5 Relationship with other methods.

Although the subject of this thesis is only a feasibility study, the achievements made indicate strongly that the method surpasses the previous methods in several ways.

It is capable of measuring re-entrant shapes (to a limited extent) and is therefore superior to the silhouette measuring technique.

The results of the LASS method are suitable for unambiguous computer interpretation, which makes this technique superior to the Moiré fringe method, which requires a human operator to interpret the fringe patterns. The amount of computation required is also less.

Compared with the Structured Light method, and LASS is of course one form of that method, the whole surface of the body has been measured, whereas previous methods have only been capable of taking one view of the body at a time.

The Oxford Orthopaedic Centre (ISIS) equipment is also limited by taking only one view of the subject.

Clearly the methods which take one view at a time, such as ISIS, could be used to take several views and so digitise the whole surface of the body. The problem is that the several views could not be taken simultaneously because of the mutual interference between their light projectors, and so the separate views would probably require human intervention for their interpretation in order to achieve a 'best fit' where the views overlap.

There are disadvantages to the LASS method. A single television camera, if the system is to have a reasonable resolution, does not cover a very large area of the subject. Typically 400 X 300 mm. for 1 mm. resolution. Seven cameras are required then, to cover the two metre height of a tall subject. More cameras than this could be needed if compensation for sway is taken into account.

While various mechanical scanning techniques could be used to cover a larger field of view than a single television camera a bank of television cameras is likely to provide a cheaper solution because they are a standard mass produced product. A bank of television cameras will also provide a better vertical resolution than is likely to be achieved by a single mechanical scanning system.

It is not very desirable to have to rotate the subject because it can exagerate the sway problem and perhaps cause the subject to stand in a less than relaxed posture. The difficulty with keeping the subject still and rotating the cameras and projectors about them is largely one of safety because of the fairly large rotating mass that would be required.

7.Conclusions

7.1 Conclusions

There is little doubt that the questions posed in Section 2 " Aim of Study" can all be answered positively.

The television camera is a suitable measuring device with a resolution of 1 in 512 approx. Unfortunately the aspect ratio of the field of view of the camera which is 4 : 3 is widest in the horizontal direction while the human body is of course taller than it is wide. Perhaps the cameras can be used rotated through 90° but at worst it simply means using more cameras.

From the results so far obtained the method using the projected shadow works as expected, and because of its simplicity, gives very rapid results. With a standard error of the estimate of 0.56 mm. is shown to be sufficiently accurate.

The remaining problems to do with body sway, effects of limbs and dealing with the final result have been discussed in the previous section and are also the subject of future research under a program sponsored by the SERC/ACME Directorate (Ref. GR/E 04097 Dr. P R M Jones and Mr G M West. 1986).

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9.Appendix.

Appendix Contents.

9.Appendix.

A.1 Interface Computer Software

The following programs were all designed to run in the interface computer.

```
( PROGRAM PAGE 1 )
HEX 1E CONSTANT ULB         (  Input/output buffer addresses
1C CONSTANT LLB             (
15 VARIABLE LINCNT          ( Storage area for the T.V.line count

( PROGRAM PAGE 2 )                          ( 111585 GMW)
ASSEMBLER HERE
PHA,
LINCNT LDA, 0= NOT IF,
0F * LDA, LLB STA,          ( Set active lines to every 15th
00 * LDA, ULB STA,          (
LINCNT DEC,
PG LDA, BF * AND, PG STA,
ELSE,
03 * LDA, LLB STA,          ( Sync pulse width
00 * LDA, ULB STA,
14 LDA, LINCNT STA,         ( Set no of active lines to 20 )
PG LDA, 40 * ORA, PG STA,
THEN, LLB LDA,              ( Clear timer IRQ )
PLA, RTI, 0040 ! ( SET VECTOR )
```

```
( PROGRAM PAGE 3 )
FORTH
: INTRPT E8 MCR C!              ( Set interrupt vector
     20 IER C! ;
0 VARIABLE ADATA
C8 ALLOT         ( B44 )
0 VARIABLE BDATA
C8 ALLOT         ( B44 )
0 VARIABLE AYSTORE
0 VARIABLE BYSTORE
0 VARIABLE LINE.FLAG
CODE LFIND BEGIN,
LINCNT LDA, LINE.FLAG CMP,
0= UNTIL, NEXT JMP, END-CODE

( PROGRAM PAGE 4 )
CODE GRAB1                   ( Here to "GRAB" data from camera A
0 # LDA,
PE STA,
0 # LDA, PG STA,
20 # LDA, PG STA,
BEGIN, PA LDA,
0C # AND,
0= UNTIL,
NEXT JMP, END-CODE

( PROGRAM PAGE 5 )
```

```
CODE GRAB2                    ( Here to "GRAB" data from camera B
30 # LDA,
PE STA,
0 # LDA, PG STA,
20 # LDA, PG STA,
BEGIN, PA LDA,
0C # AND,
0= UNTIL,
NEXT JMP, END-CODE

( PROGRAM PAGE 6 )
HEX
CODE A1STORE                  ( Here to store camera A data

AYSTORE LDY,
80 # LDA, ( SELECT ACAM )
PE STA, PF LDA,
ADATA ,Y STA, INY,
PA LDA, 01 # AND,
01 # EOR, ( INVERT LSD )
ADATA ,Y STA, INY,
TYA, AYSTORE STA,
NEXT JMP, END-CODE

( PROGRAM PAGE 7 )
HEX
CODE A2STORE
AYSTORE LDY,
```

```
PB LDA, 0F # AND,
CLC, 9F # ADC, PE STA,
PF LDA, ADATA ,Y STA, INY,
PA LDA, 01 # AND,
ADATA ,Y STA, INY,
A1 # LDA, PE STA,
PF LDA, ADATA ,Y STA, INY,
PA LDA, 01 # AND, 01 # EOR,
ADATA ,Y STA, INY,
TYA, AYSTORE STA,
NEXT JMP, END-CODE

( PROGRAM PAGE 8 )
HEX
CODE B1STORE                    ( Here to store camera B data
BYSTORE LDY,
40 # LDA,
PE STA, PF LDA,
BDATA ,Y STA, INY,
PA LDA, 01 # AND,
01 # EOR,
BDATA ,Y STA, INY,
TYA, BYSTORE STA,
NEXT JMP, END-CODE

( PROGRAM PAGE 9 )
HEX
CODE B2STORE
```

```
BYSTORE LDY, PB LDA,
.A LSR, .A LSR, .A LSR, .A LSR,
CLC, 4F # ADC, PE STA,
PF LDA, BDATA ,Y STA, INY,
PA LDA, 01 # AND,
BDATA ,Y STA, INY,
51 # LDA, PE STA,
PF LDA, BDATA ,Y STA, INY,
PA LDA, 01 # AND, 01 # EOR,
BDATA ,Y STA, INY,
TYA, BYSTORE STA,
NEXT JMP, END-CODE

( PROGRAM PAGE 10 )
HEX
: AMEM ." ;" AYSTORE C@ 0 DO
ADATA I + C@ .
LOOP ;

: BMEM ." ;" BYSTORE C@ 0 DO
BDATA I + C@ .
LOOP ;


( PROGRAM PAGE 11 )
: NEWSTART 0 AYSTORE ! 0 BYSTORE ! ;
: SNAP1 13 LINE.FLAG C!
BEGIN LFIND
```

```
 GRAB1 A1STORE B1STORE
LINE.FLAG C@ 1-
DUP LINE.FLAG C!
0< UNTIL ;
: SNAP2 13 LINE.FLAG C!
BEGIN LFIND
GRAB2 A2STORE B2STORE
LINE.FLAG C@
1- DUP LINE.FLAG C!
0< UNTIL ;

( PROGRAM PAGE 12 )
: ACAM1  NEWSTART SNAP1 AMEM ;
: BCAM1  NEWSTART SNAP1 BMEM ;
: ACAM2  NEWSTART SNAP2 AMEM ;
: BCAM2  NEWSTART SNAP2 BMEM ;
: BAUD HEX 000C 18 ! ;
  DECIMAL
  INTRPT
: ALIGN BEGIN 19 LINE.FLAG C!
BEGIN LFIND
 GRAB1
LINE.FLAG C@ 1-
DUP LINE.FLAG C!
0< UNTIL  AGAIN ;
```

A.2 Control Programs which run in the Apple Macintosh

```
( GET CAMERA INFO ) HEX
CREATE ACAM1$ ," ACAM1"
CREATE BCAM1$ ," BCAM1"
CREATE ACAM2$ ," ACAM2"
CREATE BCAM2$ ," BCAM2"
CREATE INTRPT$ ," INTRPT"
CREATE ALIGN$ ," ALIGN"
CREATE FILENAME$ ," 01234567890123456789"
400 CONSTANT R.STORE.SIZE
CREATE R.STORE R.STORE.SIZE ALLOT
CREATE R.BUF R.STORE.SIZE ALLOT
CREATE R.DISC.BUF 1770 ALLOT  ( 6K )


( GET CAMERA INFO ) DECIMAL
VARIABLE C.NT
VARIABLE R.ZERO
VARIABLE R.SCALE
VARIABLE R.DIFF
 -684 R.SCALE !  423 R.ZERO !
VARIABLE CON.COUNT
VARIABLE R.DISC.POINT
VARIABLE RECORD.COUNT
VARIABLE CAMDATA NEXT.FCB CAMDATA !
VARIABLE R.ANGLE
VARIABLE THETA
```

9.Appendix.

```
0 R.ANGLE ! 0 THETA !
VARIABLE KK    16650 KK !



( SERIAL INPUT )
: HSHAKE
    BEGIN  S.?TERMINAL 10 > UNTIL
    BEGIN S.?TERMINAL 2000 0 DO LOOP S.?TERMINAL = UNTIL ;
: R.GET   ( GET DATA FROM SERIAL I/P INTO R.BUF )
      HSHAKE  S.?TERMINAL R.BUF 2DUP  C!
        1+ SWAP S.EXPECT ; ( S.EXPECT RESETS S.?TERMINAL ! )
HEX
: R;SAVE  ( SAVES R.BUF IN R.STORE AFTER ";" )
       1 C.NT ! R.BUF DUP C@ OVER + SWAP 2DUP DO IC@
       SWAP 1+ SWAP 7F AND 3B = IF LEAVE THEN LOOP
       DO IC@ 7F AND R.STORE C.NT @ + C! 1 C.NT +!
        LOOP C.NT @ 1- R.STORE C! ;


( GET CAMERA INFO )


  DECIMAL
: R.CON ( CONVERTS R.STORE TO BINARY IN R.DISK.BUF )
     0 R.STORE CON.COUNT @ 0 DO CONVERT SWAP I 2 /MOD DROP
     0= IF 2* C.NT ! ELSE C.NT @ +
     R.ZERO @  - R.SCALE @ 1000 */  THETA @
     0= NOT IF DUP 10000 KK @  */ THETA @ DUP ROT SWAP
     SIN  10000 */  SWAP COS + 10000 SWAP */  THEN
     R.DISC.BUF 2 - I 2 * + ! THEN
```

```
    0 SWAP LOOP 2DROP ;

( GET CAMERA INFO ) HEX

: R.CON1 28 CON.COUNT ! R.CON ;
: R.CON2 50 CON.COUNT ! R.CON ;
: R.DISC.PRINT1 ( PRINTS DATA IN SINGLE EDGE SENSING FORMAT )
    CR 50 0 DO I 28 /MOD DROP 0= IF CR THEN
    R.DISC.BUF I+@ 5 .R 4 +LOOP CR ;
: R.DISC.PRINT2 ( PRINTS DATA IN DOUBLE EDGE SENSING FORMAT )
    0 R.DIFF ! CR R.DISC.BUF DUP 140 + SWAP 4+
    DO I@ DUP 8 .R C.NT @ 0= IF R.DIFF ! 1 C.NT !
    ELSE R.DIFF @ - 12 .R CR 0 C.NT ! THEN 4 +LOOP ;
: DISC.PRINT1 ( NO. OF RECORDS --- )
    CR 50 * 4 DO I 50 /MOD DROP 0= IF CR THEN
    R.DISC.BUF I+@ 4 .R 4 +LOOP CR ;

( GET CAMERA INFO ) HEX

: ACAM1 ( GETS DATA FROM CAMERA A )
    ACAM1$ COUNT S.TYPE 0D S.EMIT
    R.GET R;SAVE R.CON1 2 SYSBEEP ;
: R.ACAM1 ( GETS DATA FROM CAMERA A & PRINTS IT )
    ACAM1 CR R.DISC.PRINT1 ;
: BCAM1 ( GETS DATA FROM CAMERA B )
    BCAM1$ COUNT S.TYPE 0D S.EMIT
    R.GET R;SAVE R.CON1 ;
: R.BCAM1 ( GETS DATA FROM CAMERA B & PRINTS IT)
```

```
     BCAM1  CR R.DISC.PRINT1 ;
: ALIGN ( ALTERNATELY SWITCHES CAMERAS )
     ALIGN$ COUNT S.TYPE 0D S.EMIT  ;


: R.INTRPT ( STARTS INTERRUPT PROGRAM IN CAMERA INTERFACE )
     INTRPT$ COUNT S.TYPE 0D S.EMIT ;
: R1 BEGIN R.ACAM1 AGAIN ;
: S1 BEGIN R.BCAM1 AGAIN ;
: RY BEGIN R.ACAM1 KEY DROP AGAIN ;
: RT BEGIN 3 @CLOCK + R.ACAM1 BEGIN @CLOCK OVER =
    UNTIL DROP AGAIN ;


( CAMERA INFO. TO DISC )
DECIMAL

: R.SAVE ( RECORD NUMBER IN RECORD.COUNT )
     R.DISC.BUF RECORD.COUNT @ CAMDATA @ WRITE.FIXED
     ?FILE.ERROR ;
: R.READ ( RECORD NUMBER --- )
     R.DISC.BUF SWAP CAMDATA @ READ.FIXED
     ?FILE.ERROR  ;
: READ.MAX ( NUMBER OF RECORDS --- )
    1+  1 DO R.DISC.BUF I 80 * + I CAMDATA @ READ.FIXED
   ?FILE.ERROR LOOP ;
```

9. Appendix.

```
( PLOT ROUTINES )
: CLEAN
     PAGE CARTESIAN ON LOWER.LEFT 250 250 XYOFFSET
     200 250 XYSCALE XYAXIS ;
: R.PLOT1 0 76 MOVE.TO 76 8 DO
      R.DISC.BUF I+@ R.ANGLE @ SIN 20000 */ 80 I - DRAW.TO
      4 +LOOP -10 0 MOVE.TO  ;
: R.PLOT2
       CLEAN 20 0 DO 20 I - R.DISC.BUF I 16 * + 2DUP
       @ 100 250 */ 100 SWAP - SWAP 6 * MOVE.TO 8+
       @ 100 250 */ 100 SWAP - SWAP 6 *  DRAW.TO
       LOOP -10 0 MOVE.TO  ;

DECIMAL
: DUMP ( ADDRESS COUNT --- )
    OVER + SWAP DO IC@ . I 40 /MOD DROP 0= IF CR THEN LOOP ;
: Z   ( REPEATS R.ACAM1 EVERY 3 SECS & SAVES TO DISC. )
    1 RECORD.COUNT ! BEGIN 3 @CLOCK + ACAM1  R.SAVE
    1 RECORD.COUNT DUP @ . +! CR BEGIN @CLOCK OVER =
    UNTIL DROP AGAIN ;
: PLOT ( RECORD NO. --- PLOTS +- 18 RECORDS EITHER SIDE )
     CLEAN  90 54 DO DUP I DUP 5 * R.ANGLE !
     + BEGIN DUP  72 > IF 72 - THEN  DUP 73 < UNTIL
     R.READ R.PLOT1 LOOP  DROP  ;
: ZZ   ( REPEATS R.ACAM1  & SAVES TO DISC. )
    1 RECORD.COUNT ! BEGIN ACAM1 2 SYSBEEP R.SAVE
    1 RECORD.COUNT DUP @ . +! CR  AGAIN ;
```

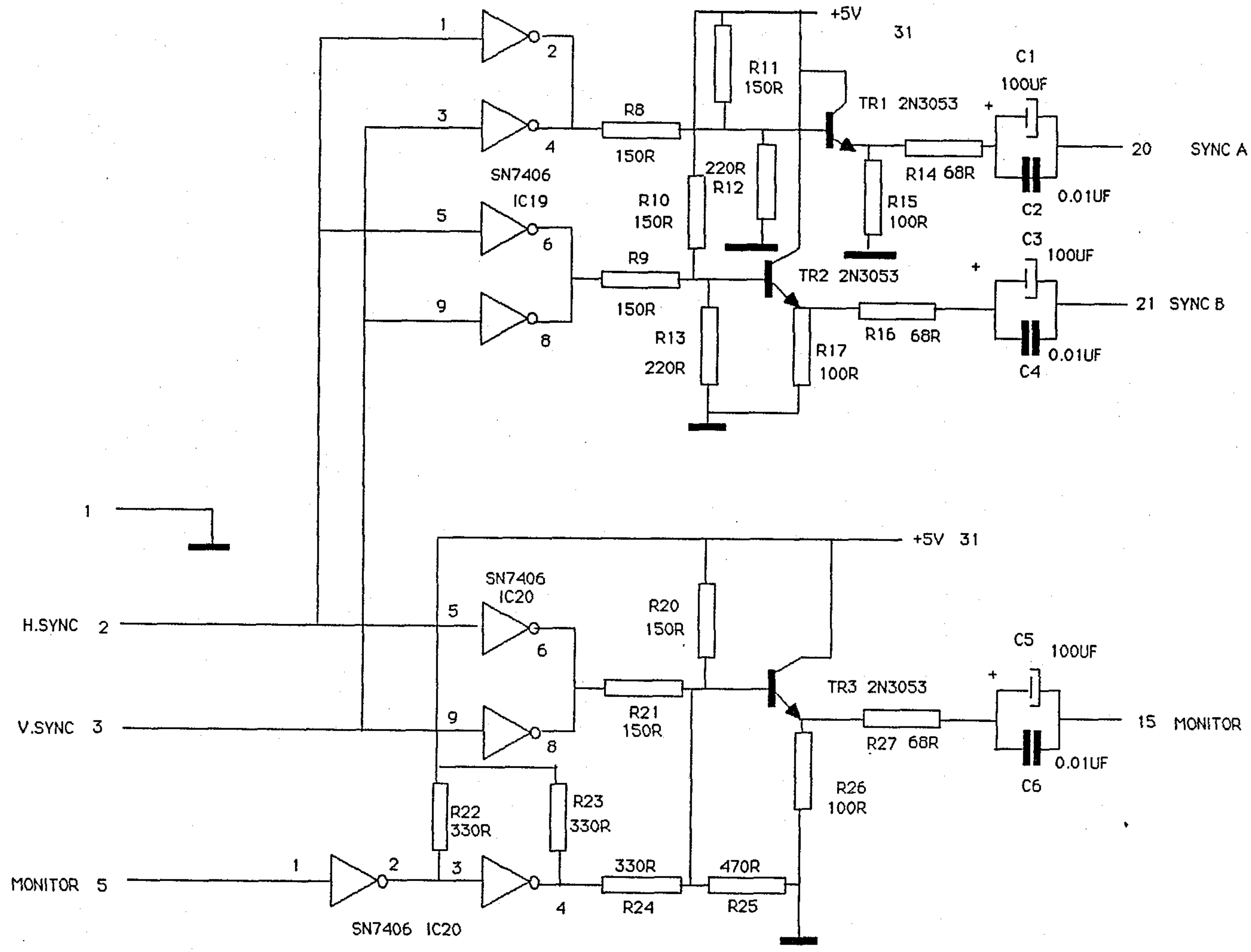
9.Appendix.

```
( SLICE PLOT )

: SPLOT ( 72 READ.MAX )
    4 * 8 + 72 1 DO DUP R.DISC.BUF I 80 * +  + @  2 /
    DUP I 5 * SIN * 10000 / SWAP I 5 * COS * 10000 / DOT
    LOOP DROP ;
: SLICE.PLOT ( 1ST SLICE * LAST SLICE * --- )
    PAGE CARTESIAN ON 150 150 XYSCALE CENTER XYAXIS
    SWAP DO I SPLOT LOOP -150 -150 MOVE.TO ;
: CIRC ( CALCULATES CIRCUMFERENCE : SLICE* --- )
    0 C.NT ! 4 * 8 + 72 1 DO DUP R.DISC.BUF I 80 * +  + @
   C.NT +! LOOP  DROP C.NT @ 50000 572958 */ . CR ;




( DISC SORT )

: NEW  CR  ( SETS NEW FILENAME FOR DATA )
      ." ENTER NEW FILE NAME - " FILENAME$ 20 INPUT.STRING
      CR  1600 FILENAME$ NEW.FILE CAMDATA !
      160 CAMDATA @ SET.REC.LEN  ;
: OLD  CR ( READS FROM OR RE-WRITES INTO OLD FILE )
      ." ENTER OLD FILE NAME - " FILENAME$ 20 INPUT.STRING
      CR  FILENAME$ CAMDATA @ ASSIGN
      160 CAMDATA @ SET.REC.LEN CAMDATA @ OPEN ?FILE.ERROR ;
( DATA IN Y X FORMAT )
VARIABLE YSCALE  1 YSCALE !
```

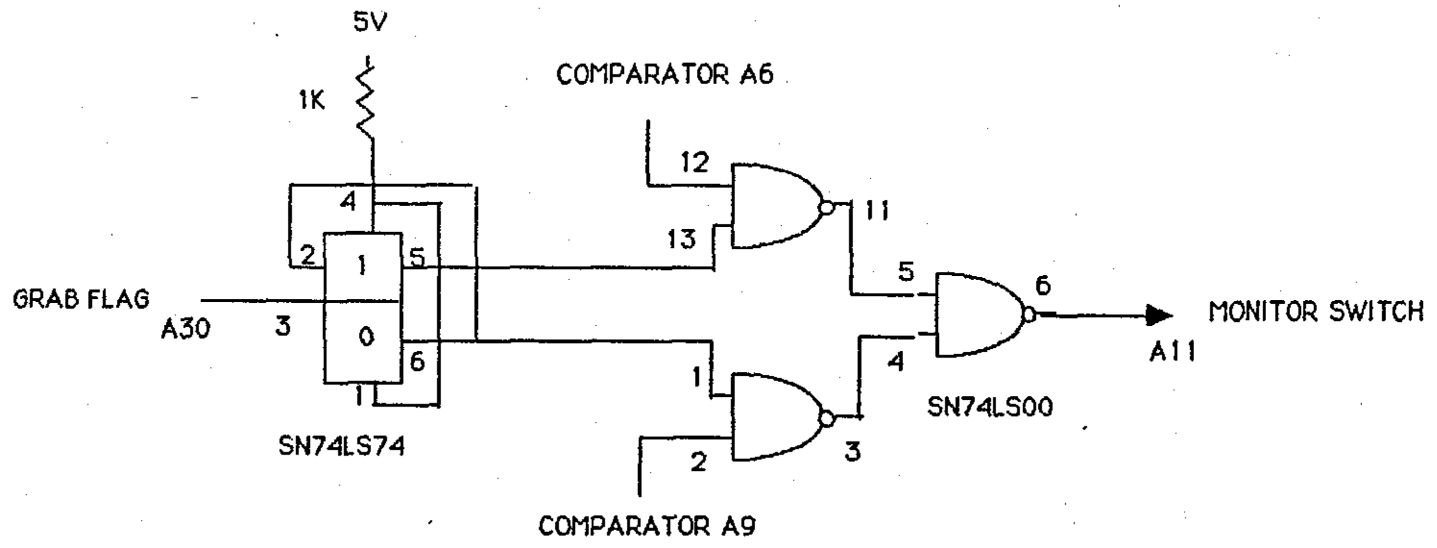
9.Appendix.

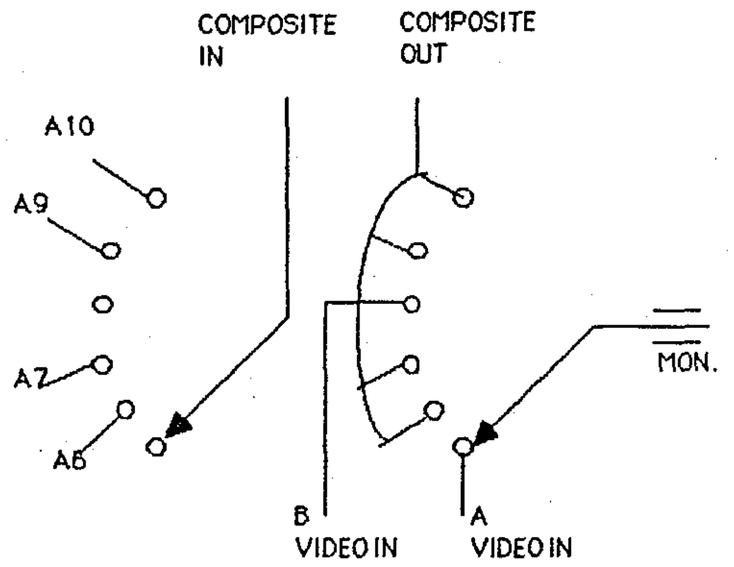
```
: YGET ( LINE NO. --- LINE DATA STARTING FROM BOTTOM )
      76 SWAP 4* - R.DISC.BUF + @ ;
: XYPRINT ( PRINTS DATA IN Y X FORMAT )
      1 18 DO I 2 /MOD DROP 0= IF CR ELSE 5 SPACES THEN
      18 I - DUP 8 - YSCALE @ * 5 .R 1+ YGET 5 .R -1 +LOOP ;
: XY ( GETS DATA & PRINTS IN XY FORMAT )
    BEGIN  KEY DROP ACAM1 XYPRINT CR CR AGAIN ; -->
 ( DATA IN R H FORMAT )

: RGET (  NNN --- CALCULATES RADIUS FOR 45 DEGREES )
      DUP 7071 KK @
      */ 7071 + 1000000 SWAP */ SWAP OVER ABS
    <# # # 46 HOLD #S SIGN #>
      TYPE  ;
: HRPRINT ( PRINTS DATA IN H R FORMAT )
      1 18 DO I 2 /MOD DROP 0= IF CR ELSE 5 SPACES THEN
      18 I - DUP 8 - YSCALE @ * 5 .R 5 SPACES 1+ YGET DUP 5 .R
      4 SPACES RGET
      -1 +LOOP ;
: HR ( GETS DATA & PRINTS IN HR FORMAT )
    BEGIN  KEY DROP ACAM1 HRPRINT CR CR AGAIN ;

( CALIBRATE )
: SETUP ( SET ZERO AND FULL SCALE )
      0 R.ZERO ! 1000 R.SCALE !  0 THETA ! CR
      ." SET TARGET PATTERN TO ZERO & PRESS ANY KEY " CR
      KEY DROP ACAM1 9 YGET R.ZERO ! BEGIN CR
." SET TARGET PATTERN TO FULL SCALE AND ENTER THE FULL SCALE
```

```
VALUE" CR 5 INPUT.NUMBER UNTIL ACAM1 1000 9 YGET */
R.SCALE ! BEGIN CR ." ENTER CAMERA TO ZERO DISTANCE "
 5 INPUT.NUMBER UNTIL KK ! BEGIN CR ." ENTER MEASURING ANGLE"
 5 INPUT.NUMBER UNTIL THETA ! CR ." CALIBRATION COMPLETE" CR ;


HEX
: ALIGN ( ALTERNATELY SWITCHES CAMERAS )
      ALIGN$ COUNT S.TYPE OD S.EMIT ;
```



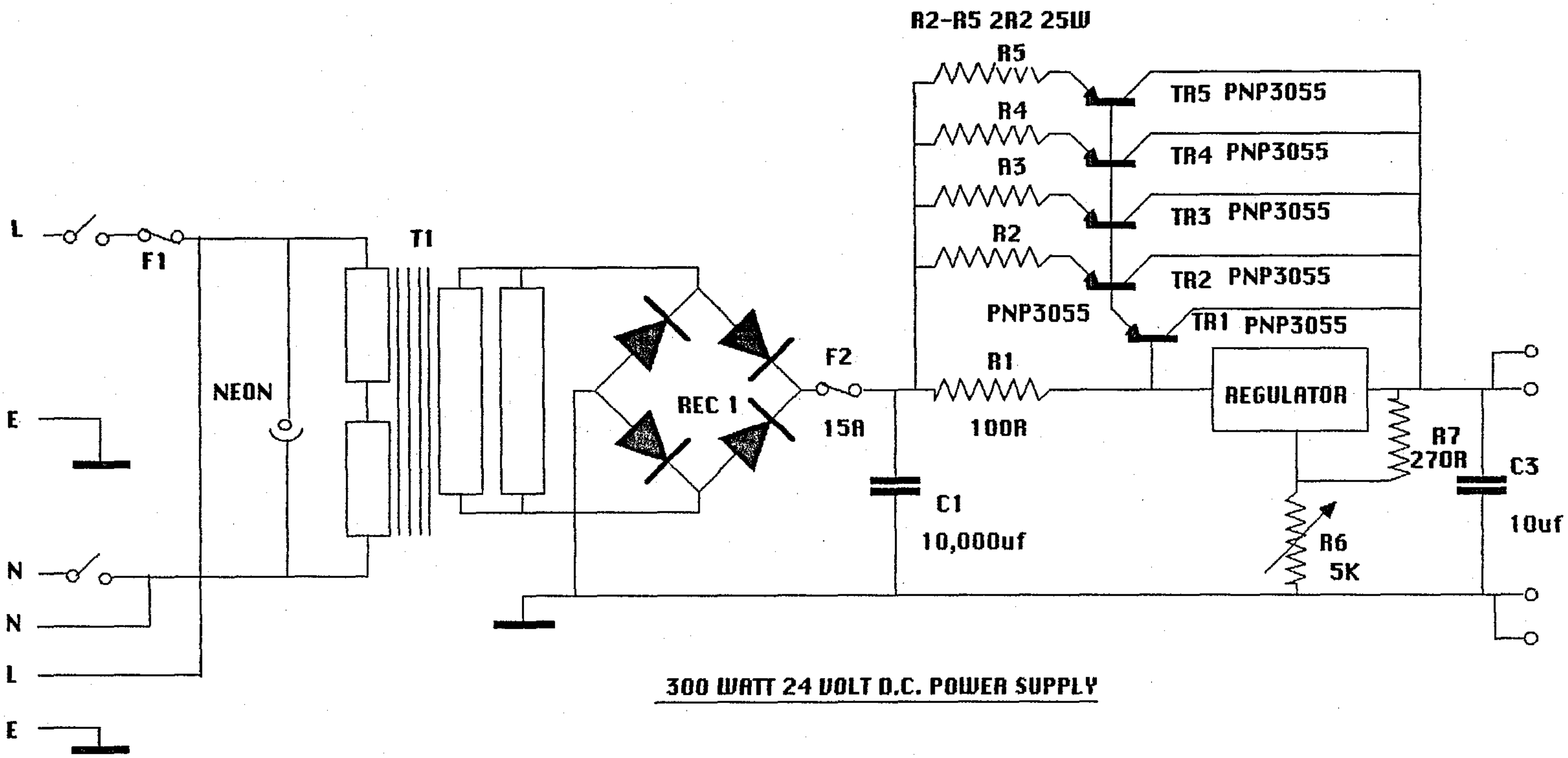
<u>**Synchronisation Driver Circuit. fig.A1 (sheet 1 of 2)**</u>





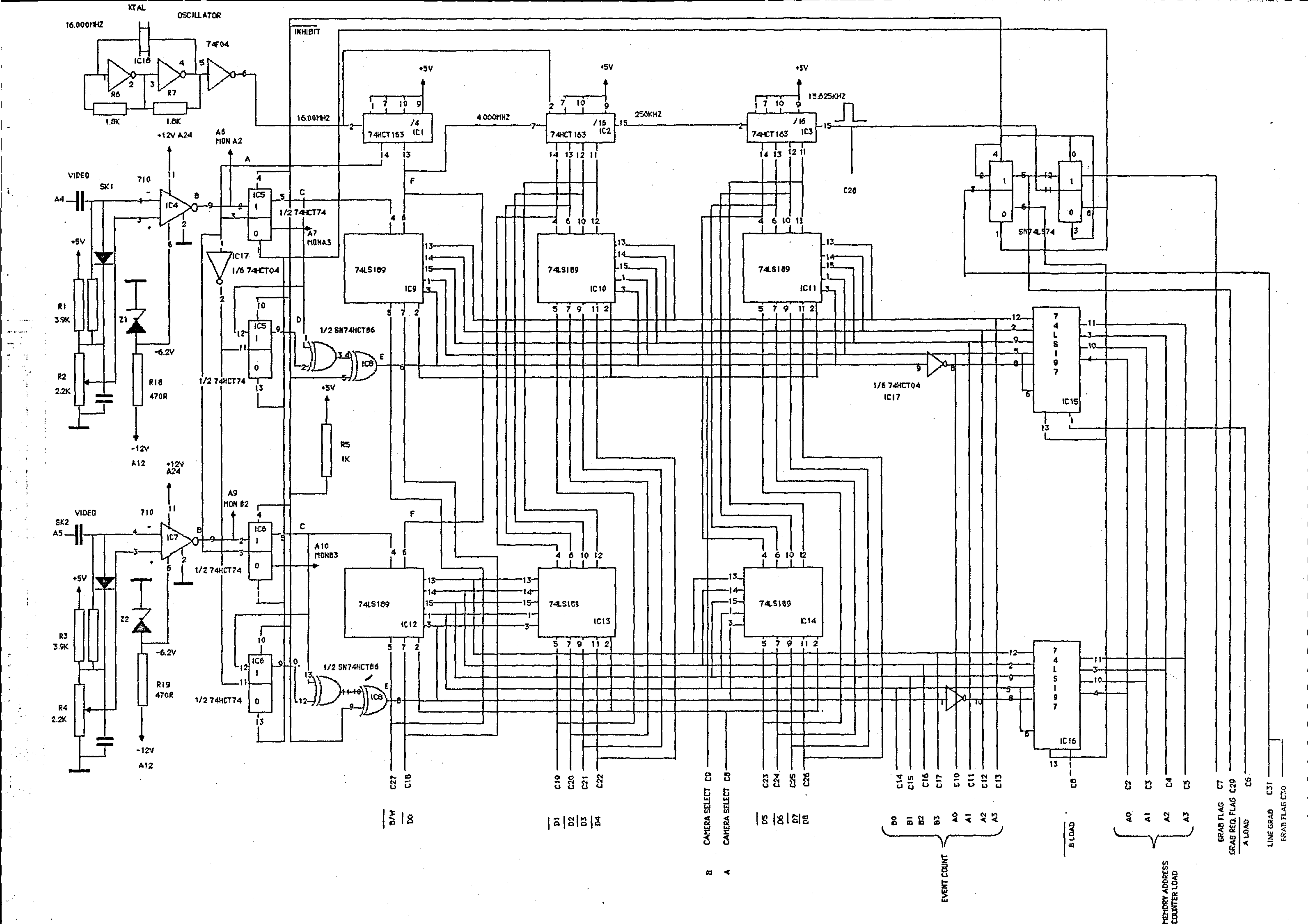
MONITOR SWITCH

Synchronisation Driver Circuit. fig.A1 (sheet 2 of 2)

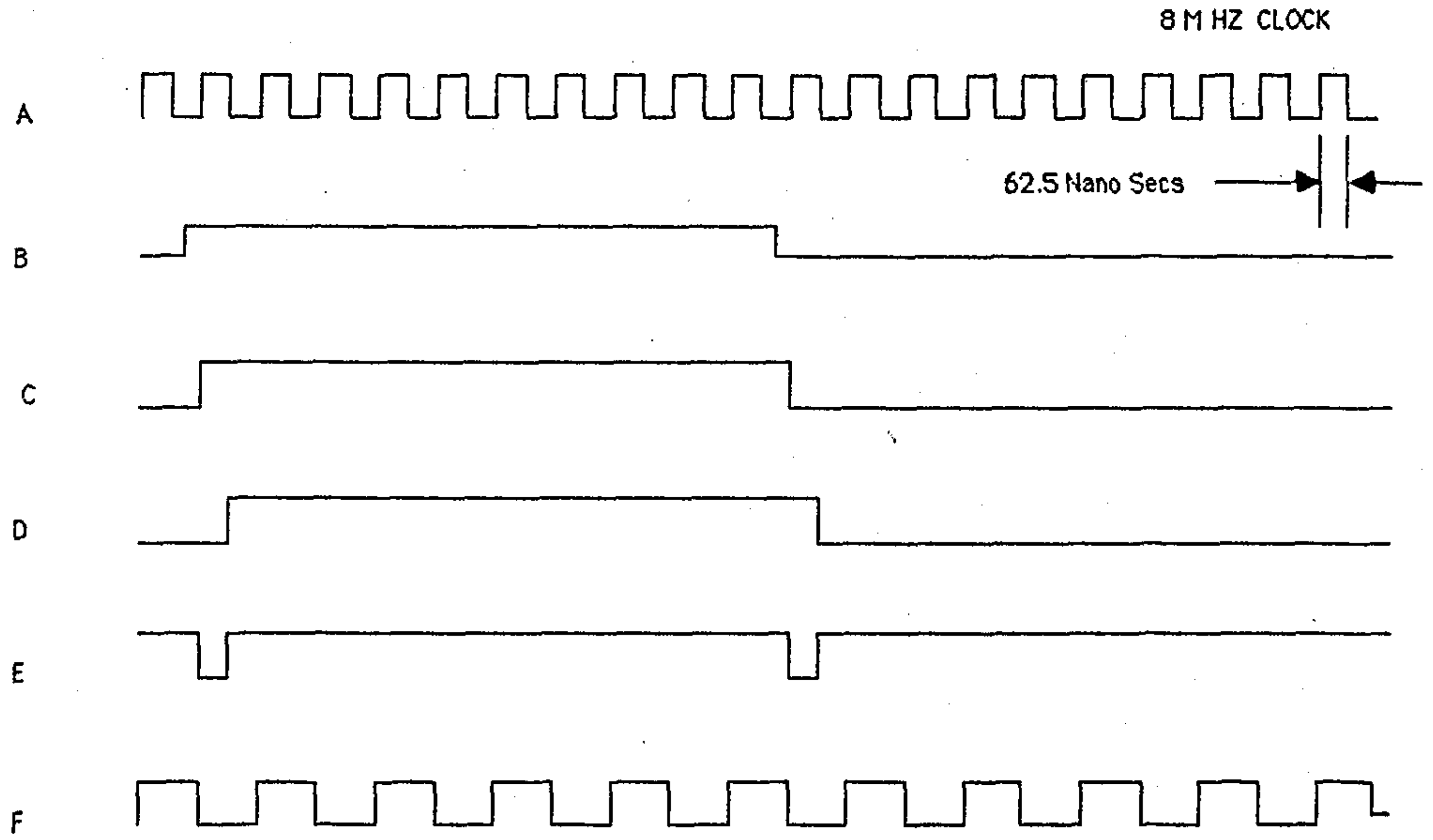


300 WATT 24 VOLT D.C. POWER SUPPLY

fig. A2.



Interface Circuit Diagram **fig. A3**



INTERFACE CIRCUIT WAVEFORMS fig. A4