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EVALUATION OF POSTURAL MECHANISMS UNDER DYNAMIC CONDITIONS

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by

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ABSTRACT

A stimulus delivery and data acquisition system for assessment of human posture has been developed based on a digital computer and a translating platform. The movement of the platform acts to displace the subject's base of support while the computer tracks the corrections which are made by the subject to maintain balance. Various stimuli are used ranging from fast transients to sine waves.

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I. SUMMARY

This report concerns the development of an instrumentation system which has potential clinical usefulness for the assessment of postural stability. In particular, our interests lie in the human postural response to controlled dynamic disturbances of the subject's base of support. To investigate such situations we have developed a stimulus delivery and response measurement system involving a microcomputer, a moving platform, a pair of digital line scan cameras, and other necessary support electronics. The majority of this report describes the configuration of our system; the remainder of the document will be recommendations for further development and application.

II. REPORT ON CLINICAL POSTURAL ASSESSMENT SYSTEM HARDWARE DEVELOPMENT

A. Final Computer Configuration

Stimulus delivery and data acquisition and analysis for our experiments is done by a Digital Equipment Corporation (DEC) LSI-11 microcomputer with a total of 20 K words of semiconductor memory. 4 K of the memory is made up of onboard memory and 16 K of additional memory supplied by EMM Memories. The computer includes floating point hardware. The software being used is DEC's RT-11 software package with FORTRAN IV. Peripheral storage is provided by a Data Systems Design dual floppy disc; each diskette is capable of storing 122,880 data words. Other peripheral devices include 16 channels of A/D conversion, 3 channels of D/A conversion, both from ADAC Corporation, and one DEC VT-55 graphics terminal with a hard copy unit supplied by the University of Michigan.

B. Final Moving Platform Configuration

The moving platform is mounted on two parallel stainless steel rails with ball bushings. The drive mechanism is a .25 inch/revolution lead screw with a nut attached to the moving platform. The enclosure for the motor and drive mechanism is a 2 feet by 5 feet aluminum box 2/3 foot high. Three slots on the top of the enclosure which allow movement of the platform supports are covered with sliding teflon sheets. The torque motor used to drive the lead screw is an Electrocraft Corp. E703 permanent magnet DC motor which operates at a maximum of 3000 RPM for our application. An Electrocraft Corp. M110 tachometer is integrally mounted on the torque motor to provide velocity feedback to the servo amplfier (Electrocraft Corp. 6200 AP) controlling the motor. A ten turn potentiometer is geared to the platform, sending an electrical feedback signal to the computer about the position of the platform with respect to the center of its allowable excursion. The signal from the potentiometer is used to calibrate the platform, and then center it before stimulus delivery. The servo amplifier converts velocity commands from the computer into drive current for the DC motor controller. The system functions off 115v at a maximum of 13 amps. The maximum linear range of the moving platform is 17" due to the microswitch stops located three inches inside the mechanical range extremes on each end.

Two problems were encountered when the system began functioning. The first of these was vibration and noise. The vibrations could be felt through the plywood foot base, providing cues to the rider about platform movement speed. This distraction was somewhat alleviated by the insertion of a vibration absorbent lead impregnated material between the plywood foot base and the aluminum portion of the moving platform. The noise problem was approached from the point of view that the aluminum enclosure for the system acted as a sound box, amplifying any mechanical noise inside it. We covered the interior surfaces of the enclosure with a sound absorbing material, and achieved improved noise levels. We also changed our nut for the lead screw from a preloaded ball bearing net, which had no backlash and required only moderate torques, to a solid nut which has a small backlash, but none of the ball bearing noise. This lowered the noise level considerably.

The other problem we encountered was a motor shaft to lead screw eccentricity which caused mechanical binding and thus a distortion of sinusoidal stimuli. This problem required careful realignment of the motor and lead screw, and may require periodic readjustment.

Figures 1 and 2 show some details of the platform design.

C. Signal Conditioning Electronics

1. Anti-alias Features:

We use four Freq. Devices, Inc. anti-alias low pass filters on the 4 active A/D data accumulation channels. The cutoff frequency is set at 30 Hz.

2. Digital Line Scan Camera System:

The basic operation of this system is such that the number of photodiode positions in the Reticon horizontal scan is counted at 2 counts/pulse until the leading edge of the silhouette is reached, then until the trailing edge is passed the positions are counted by ones. The average between the leading and trailing edge positions is then left in the counter. A D/A converter is loaded with this average count which is then displayed on a Tektronix SC 502 oscilloscope. This analog position voltage is then passed into the computer by an A/D converter for sampling and storage.

3. Signal Testing Module:

A digital voltmeter (DM 502 multimeter) is combined with the SC 502 oscilloscope in a Tektronix TM 505 rack mount power module along with a blank plug-in kit of double width which houses the camera controller. This equipment provides for direct readout and review of the various signals under test.

D. Power Supplies

1. Power for the computer (LSI-11) comes from two Lambda power supplies (LJS-10-12-OV 12v, LJS-11-5-OV 5v), and the anti-alias filters' power comes from a Datel Inc. ±15v supply. The power supplies are mounted on the rack chassis which houses the computer, the floppy disc, a Tektronix RM 503 oscilloscope for X-Y display, and a special panel which houses the 16 phone jacks for A/D inputs, the single phone jack for D/A output which controls platform motion, two banana plugs for the D/A outputs to the X-Y scope, the anti-alias filters, and an entire system power up toggle switch. Figure 3 shows the racks of instrumentation in relation to the clinical set-up.

E. Clinical Environs

1. Camera Configuration:

The two Reticon LC-600 digital line scan cameras are situated on a specially constructed tripod (shown in Figure 4) which can be broken down for travel. The cameras are mounted at different heights so that their scans are parallel to each other and horizontal. The tripod is capable of being levelled, to remove the error due to improper tripod alignment. The cameras are situated (on the tripod) 81.5 inches from the backdrop, and 48.5 inches from the center of the platform (see Figure 5). Since the viewing angle is 40 degrees total the cameras will view peak-to-peak movement with respect to the center of the platform of 35.3 inches perpendicular to the line of sight. Since the platform motion is only 17" peak-to-peak when the safety stops are operational, the subject can sway another 9" beyond the end of the platform's travel and still not leave the field of the cameras. The camera resolution at this distance is to .0689 inches.

2. Backdrop:

The backdrop for providing our dark on light silhouettes is a white painted cement block wall of about 64 square feet in area.

3. Lighting:

Backdrop lighting is provided by six 75 watt incandescent bulbs housed in utility light clamps which in turn are clamped to tripods located laterally next to the wall (backdrop).

III. REPORT ON SOFTWARE DEVELOPMENT

A. General Considerations

The RT-11 software system supplied by DEC is a real-time operating system which will allow numerous external events to proceed with the main program in such a way that they will not interfere with the running of the main program. This facility is extended to the FORTRAN IV programming system. As the software development proceeded, we determined by experimentation with the software that no assembly language programs were necessary to make the various non-standard hardware components work in real time. This has been a great simplification of the original concept of how the various modules were handled in the system. That is, all interrupt handlers could be written in FORTRAN. As the program now operates, the stimulus and data transactions with the test hardware, the storage of data and the on-line display all operate with independent program segments running under interrupt controls.

This organization makes the overall program very plastic in nature. New developments can be inserted without undue consideration for past developments.

B. Generation and Delivery of Stimuli

1. Physical Constraints:

Subjects stand erect on the footbase made of plywood to provide a high friction interface. These subjects are required to maintain their postural stability while the platform moves within its 17" peak-to-peak range. To insure against injury from falling due to an irrecoverable postural instability, a guard railing, which can be adjusted for each subject, has been installed on the platform's enclosure (see Figure 3). With motion induced by the .25 inch/revolution lead screw powered by the 410 oz.-in. torque motor at a maximum angular velocity of 3000 RPM, the linear maximum velocity, after correcting for motor derating and efficiency, is approximately 1 ft/sec, with a maximum available force of 450 lbs. Mechanical resolution is .003 inches/foot with a slight backlash due to the use of a nut that is not preloaded on the lead screw. Electrical resolution is .1% of full scale on both position and velocity. Commands to the system are deliverd by a 10 bit D/A converter at an update rate of 100 samples/sec.

2. Platform Checkout and Centering:

A small section of a FORTRAN program has been developed to run the platform at a constant, user specified velocity to one end of its effective linear range, where the microswitch stop is activated. When the platform reaches close to zero velocity the velocity command is reversed, sending the platform to the stop at the other end of the travel. At each stop the position of the platform is read from the potentiometer providing position feedback; then the average position, or center, is calculated. The platform velocity is again negated automatically, moving the platform back towards center. When within a specified position range around center, the platform stops and is ready for stimuli.

3. Software Considerations (all software is in FORTRAN IV):

a. Stimulus Delivery: The desired stimulus, whether a sinusoid, impulse or pseudorandom sequence is first precalculated in a 1024 point buffer. This buffer forms the velocity commands that are sent to the platform at the rate of 100 commands per second through a programmed interrupt routine. The first point of the period is zero to assure a smooth start. When the end of the buffer is reached, it is repeated until the total stimulus duration is achieved. Only integer multiples of the complete buffer are allowed.

b. Progress: We have been using sinusoidal velocity command buffers primarily during our preliminary hardware checkouts. These sinusoids are harmonics of the 1024 point base period, and the frequencies used to date have ranged from .1 Hz to 2 Hz. Amplitude scaling is another feature included in the sinusoidal stimulus software.

An impulsive type stimulus is needed for some aspects of the testing and as a first attempt, an all-pass digital filter has been designed to provide a peak amplitude limited impulse stimulus. This signal may be of too short a duration to be useful. As a substitute, we are trying the impulse responses of several low pass filters as the transient stimulus. This design is in the preliminary stages of being implemented, and has not yet been used extensively with the platform.

Several alternative approaches to generating a pseudorandom stimulus were under consideration. The choices included a periodic signal made up of a number of harmonics of the base frequency all with random phases or the output of a digital low-pass filter driven by the FORTRAN random number generator. We have selected and implemented the latter, with a cutoff frequency of 10 Hz. This stimulus has not been extensively utilized to date.

C. On-line Display of Data

While the platform is being stimulated with velocity commands and the four data channels are being sampled and stored, our stimulus program provides us with the capability to display two of the incoming data channels on-line. Two of the four data channels (the velocity feedback, the position feedback, the output of camera 1, and the output of camera 2) are selected for display before the stimulus is applied to the platform. The displayed data scrolls from the right to left on our X-Y oscilloscope (Tektronix RM 503), with one hundred points of each channel being displayed simultaneously. These displays provide the experimenter with a means of monitoring system performance during an experiment in much the same way as if a strip chart were running.

D. Sampling and Storage of Data

The four data channels mentioned above are each sampled at 100 Hz by the same interrupt routine that sends the velocity commands to the platform. The resulting data points are sorted and then double buffered so that while one buffer is being written to the diskette by a direct memory transfer, the other buffer is being filled. This technique insures that no data is lost during the storage operation.

The data are written onto the diskette in 256 word blocks consecutively, so that the first block is the tachometer feedback, the second is the position feedback, the third is camera 1 feedback, block 4 is camera 2 feedback data, and so on. This data structure is convenient for analysis purposes. Since our sampling frequency is 100 Hz, each block of data represents 2.56 sec worth of data. Because four blocks are required to write 2.56 sec of data from all four of the data channels, the capacity of one diskette (480 blocks) is 2.56 X 120 = 307.2 sec of continuous data, or 5.12 minutes of data/diskette. This figure will be important to our recommendations for a final test battery.

E. Analysis Programs

The first requirement for each of our analysis programs is to be able to access the data records stored on the diskettes. A small program has been completed which can read data from the diskettes and display that data on the graphics screen for perusal. This enables us to look at the data before further analysis, to ascertain that the data collection process was completed satisfactorily.

The program to read data becomes one component of the analysis program that is currently being developed. A program is being implemented to perform autocorrelation and autopower spectral density analyses with frequency domain techniques. The core of this analysis is a complex discrete Fourier transform implemented as a Fast Fourier Transform (FFT) routine. The autocorrelation is a result of sectioning the input data records into two 128 word sections for each 256 word block, adding 128 zeroes on the end of each of the 128 word sections, FFTing the 256 point sequences, and forming the complex sum:

Taking the 256 pt. inverse FFT of and dividing this result by the number of total points processed yields an estimate of the complex autocorrelation. This much of the analysis program has already been coded, and credit is due to Rader for the algorithm (CM Rader,"An improved algorithm for high speed autocorrelation with applications to spectral estimation," IEEE Trans. Audio Electroacoust., Vol. AU-18, Dec.1970, pp.439-441). The power spectral density estimate portion of the program involves smoothing the correlation estimate with an appropriate data window (the Hamming raised cosine window is currently being used) and then taking the FFT of this smoothed spectrum estimate.

Once this autocorrelation package has been completely tested, the development of a similar crosscorrelation package will be trivial. At that point a package of programs will be composed to perform a coherence analysis.

Another common factor of the analysis programs in their anticipated form will be the need for plotting analysis results. To this end a set of plot routines have been developed to utilize the full capabilities of the VT-55. The VT-55 is an alphanumeric and graphics display which operates as the console device under RT-11. We are using it to generate the final records of our data system in both numeric and graphic form.

IV. RECOMMENDATIONS FOR A FINAL EQUIPMENT CONFIGURATION

A. Introduction

We have learned a great deal about our hardware and software in the 5 months it has been operational. In evaluating the equipment we should examine its intended use with respect to its known performance. The primary reason for the construction of a new platform would be to make a more portable and easy to use measurement system for the evaluation of postural mechanisms. It is hoped that opportunities will arise to test shuttle crews with the idea of using the performance of their postural mechanisms as a method of evaluating re-adaptation to a 1G environment after an extended period of zero G. To obtain our baseline data we envision shipping the platform to an area where the crews are taking their other medical examinations during the pre-flight period. The equipment will then be shipped to the landing site so that post-flight data can be obtained as soon as post-flight operations allow. The shipment will involve:

1. LSI-11 Computer with interfaces
2. Camera system and lights
3. Moving platform
4. Terminal

When the immediate post-flight tests are complete, the equipment can then be shipped to the place where the routine post-flight medical testing occurs.

As data are taken on shuttle crews against the background of normal subject tests, individuals from different age groups and with known pathologies will be tested as part of other programs. It is hoped that the testing of flight crews and the other groups will be mutually beneficial in the study of postural mechanisms.

B. Platform

Through our experiences with Model 1 of the moving platform, it has become obvious that it is not really portable. In addition, we feel that the noise and vibration levels of Model 1 during operation can be lowered. The following recommendations take these two problems into consideration.

1. Open base design:

The first model depended upon its outside covering, which consisted of 1/4 inch aluminum plate, for structural strength. The new model will utilize a stronger frame and only a light protection grid on the sides. The top will be covered only to the extent needed to protect the subject while the bottom will not be covered at all. The ends will retain their heavy aluminum plates which are needed to support the steel rods on which the moving platform rides. As far as possible, the device will be made from aircraft metal for light weight and ease of machining. The advantages of this construction technique are reduced weight, ventilation for electronics and reduced "sound box" effect.

2. Mounting of drive electronics in platform base:

The power amplifier and transformer will be mounted within the platform base. This design feature will result in a more compact total system, less cumbersome cabling and more efficient wiring for safety stops. Only data lines to and from the computer need be connected to the moving platform device. All power carrying lines and safety stops will be contained within the power base.

3. Outside motor mount:

The bulk of the drive motor will be outside the platform base with one of the aluminum end plates serving as the mount. The motor shaft will extend through the platform base end plate and couple with the lead screw just inside the platform base. The drive nut will be located under the edge of the platform closest to the motor, thus reducing the length of the lead screw to only the length needed to produce the total of 16 inches of travel plus the length of the nut (20 inches total). The advantage of this motor mounting system is the saving of the weight of an internal motor mount and an overall reduction of the base dimensions. The reduction of lead screw length reduces alignment problems which occur with long spans. Vibration from the eccentric motion of the lead screw at high angular velocity is also reduced.

4. Elimination of ball bearings and ball bushings:

The new platform will ride on the same type steel rods as the first model but will not make use of ball bushings for support. As in the current configuration Model 1, the lead screw will not ride in ball bearings. Although this new arrangement will result in an increased power consumption and possibly a slight dead zone at the end of the path, much of the noise and vibration which results from ball motion will no longer be generated.

5. Reduced overall size:

A reduction in the total platform motion coupled with the outside motor mount results in a much reduced platform size. The principle advantage of this reduction is reduced weight and more convenient handling. A secondary advantage is a smaller work area for the test both in terms of the platform length and the subject to camera distance. Since the field of the camera will now span a shorter distance, the absolute accuracy of measurement will be enhanced.

6. Safety Stops

The configuration of safety stops on Model 1 is such that three inches before the platform reaches a hard mechanical stop it triggers a microswitch which shuts down the torque motor, causing the platform to glide to a stop. However, if the velocity of the platform is high enough it is still possible to hit the hard mechanical limit, jamming the platform. We recommend that one inch beyond the first microswitch we install a second microswitch which will bring the platform to a power stop. The reason for this added precaution is that jamming the platform against its hard mechanical limit could damage the drive mechanism.

C. Computer and Electronics

Our experience to date and the projected use of the system give no indication that modification of a major nature will be needed in either the computer or the associated hardware.

V. RECOMMENDATIONS FOR A CLINICAL TEST BATTERY

Our use of the platform has yet to be extended into the clinical arena, but several constraints have surfaced as a result of system and software development.

A. Data Capacity

Since we can only record slightly more than five minutes worth of data on one diskette it seems logical to recommend that a subject only be required to stand on the platform for five minute intervals. With only 120 blocks of storage available for each of the 4 data channels, the stimulus period of 1024 pts., or 4 blocks, permits only 30 cycles of a 1024 pt. stimulus for each 5 minute session. Knowledge of these constraints will enable us to select and order the stimuli desired for each session the subject spends on the platform.

B. Platform Performance

An intensive study of the frequency response characteristics of the platform has not yet been concluded, but it is obvious that at any sinusoidal platform motion frequencies above 2Hz motion will be greatly attenuated. This limits our selection of stimuli considerably.

C. Test Battery Design

Each trial for a subject will last five minutes. During a trial four different types of stimuli will be presented: sinusoidal, impulsive, pseudorandom, and static. The sinusoidal frequencies must be within, and span, the range of frequencies in the pseudorandom sequences for comparison purposes. We suggest that two different amplitude impulses be used twice each in a trial, in other words accounting for four different cycles. Four cycles of pseudorandom inputs should also be included. This leaves 18 cycles available for the different amplitude and frequency sinusoids desired. All of these stimuli for one trial will be presented in a random order to remove the effects of stimulus ordering from our results.

These preliminary recommendations for a test battery will be subject to change as soon as we have more experience with subjects on the platform.

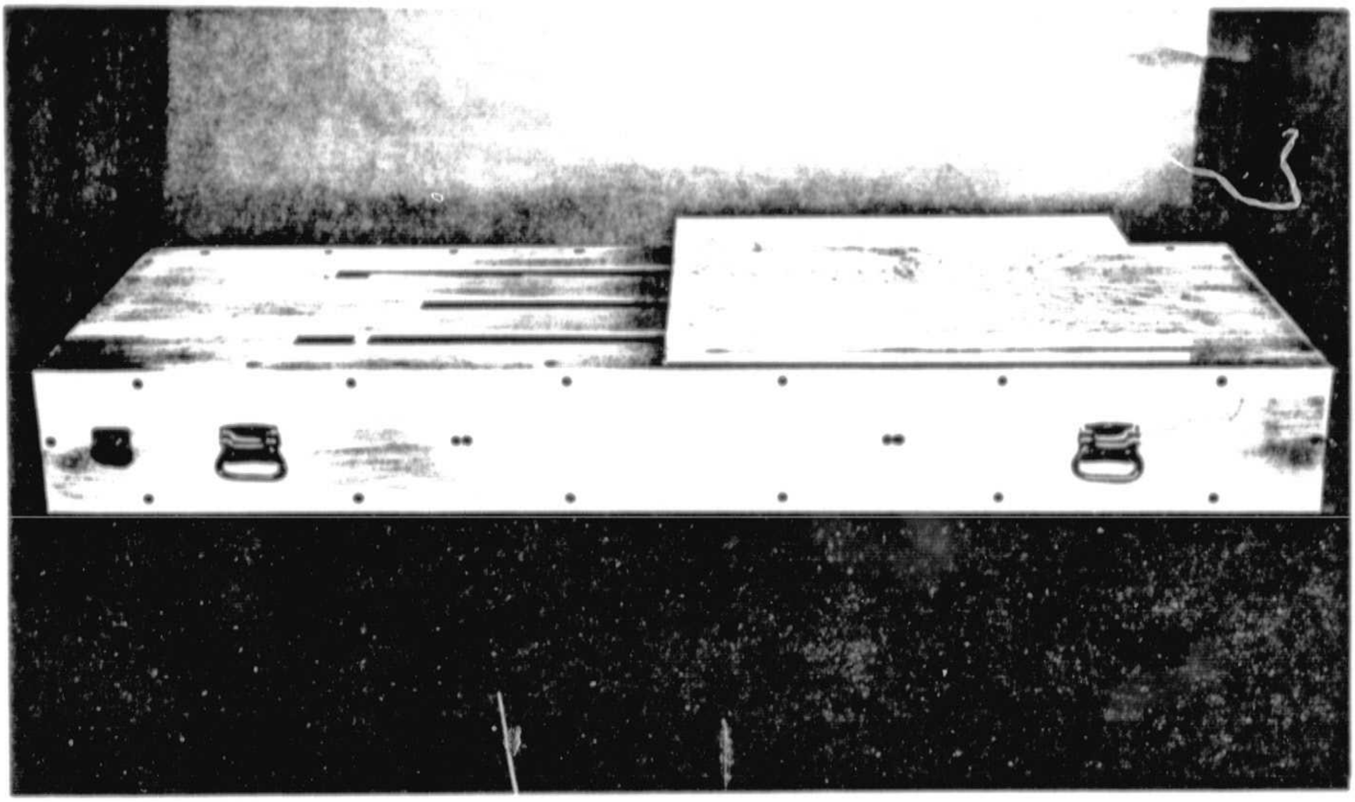

Figure 1- Complete platform enclosure is shown minus the slot covers and the guard rail.

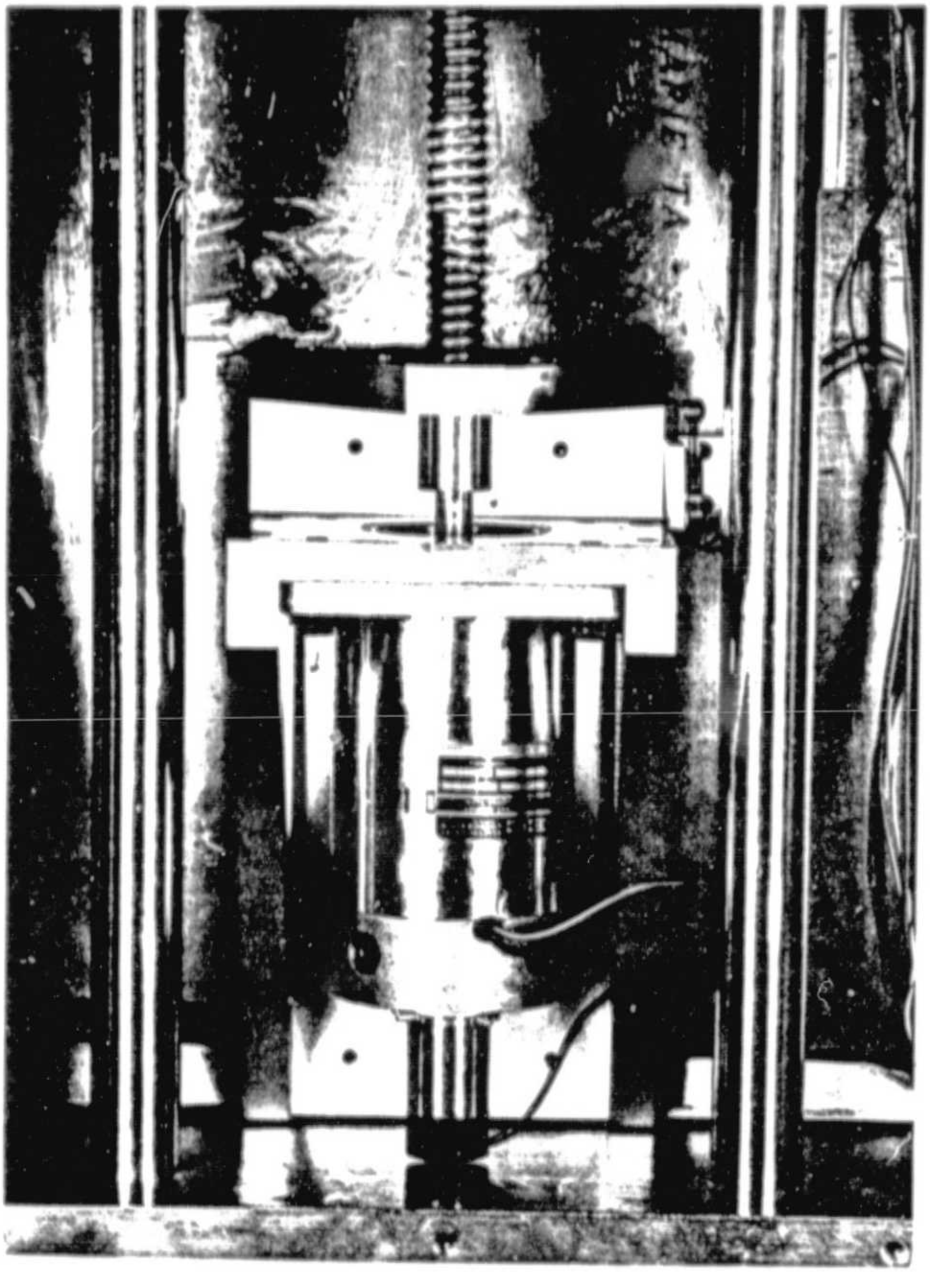

Figure 2- Motor and tachometer are shown fitted to the lead screw. On each side of the motor are the stainless steel rods which support the platform.

Figure 3- Complete clinical environment showing a subject in position, the cameras and the instrumentation racks.

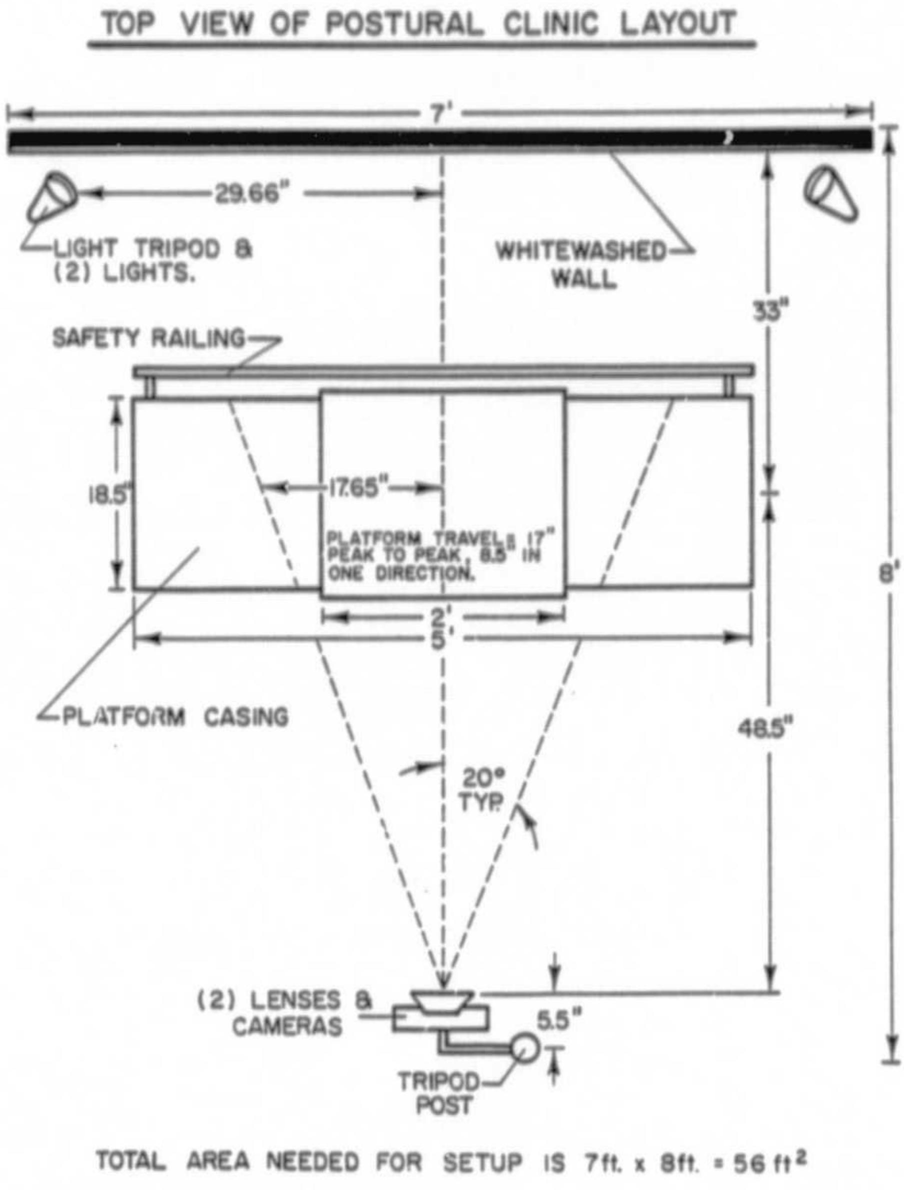

Figure 4- Two Reticon line scan cameras are shown mounted on the vertical post aligned and in position.

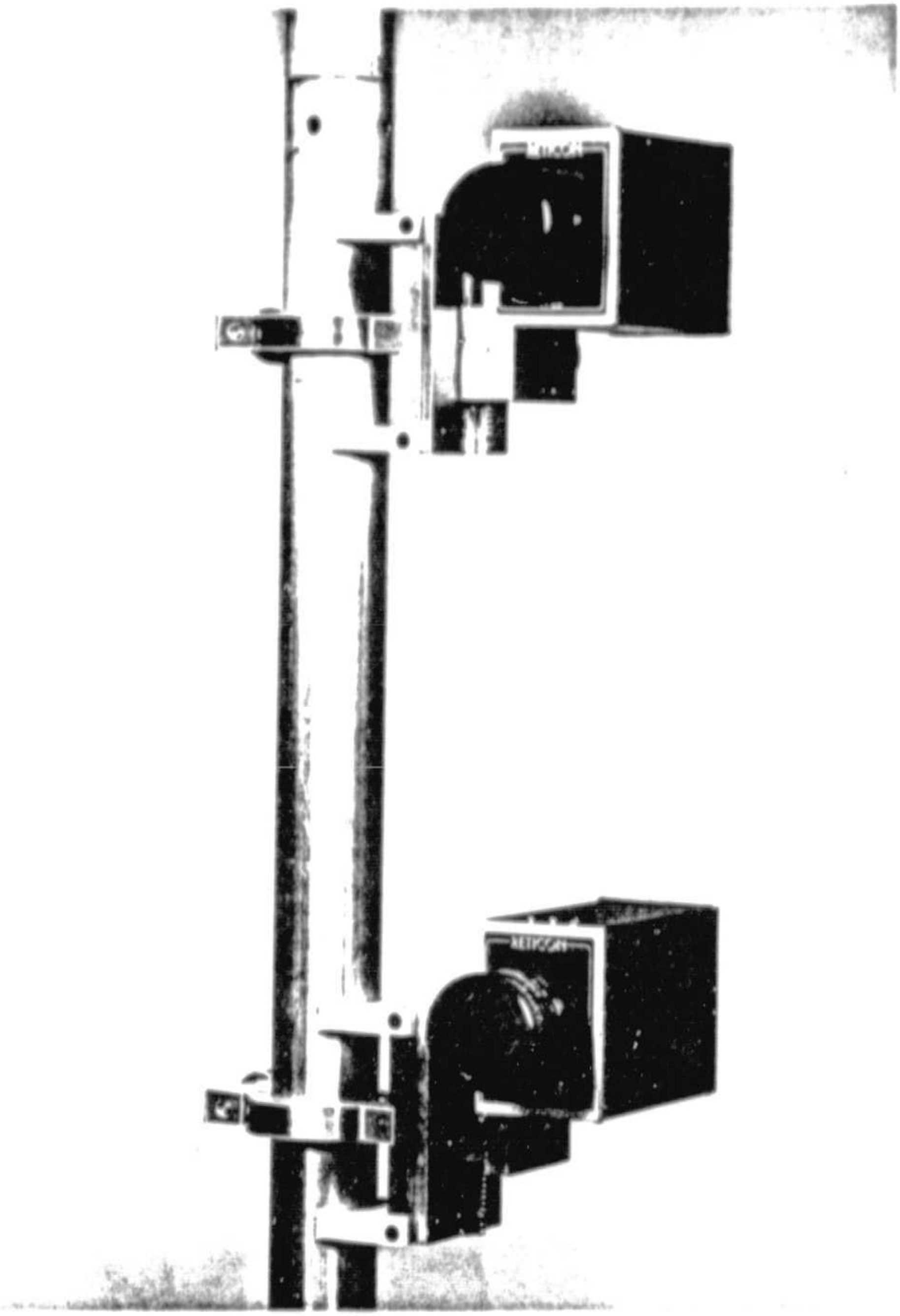

Figure 5- A top view of the required space for the backdrop, platform and camera tripod. The electronic equipment can be up to 15 ft. distant from the platform.