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The real time video vector display of ground reaction forces during ambulation

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Introduction

The Orthotic Research and Locomotor Assessment Unit (ORLAU) is engaged in research into particular ambulation problems and in the clinical evaluation of individual patient gait disorders. One of the most important areas of the work undertaken is the evaluation of forces generated during walking. Perhaps the simplest way of deriving this data is to monitor the ground reaction forces during the stance phase of the cycle.

The study of ground reaction forces during ambulation has been undertaken over a considerable period, and Elftman [3] reported the now classic pattern of forces during stance phase. Post war research exemplified by Bresler and Frankel [1] and Murray *et al* [5] led to more sophisticated designs of force platform and such devices are now available from at least one instrument manufacturer (Kistler), this being the type installed at ORLAU.

The vast majority of work carried out on force platforms is of a research nature, and although these devices have led to a much better understanding of the gait cycle, they have made little impact on clinical evaluation of individual patient problems. This is in no small part due to the manner in which results are presented in single component form for the three directions of interest, that is in vertical, horizontal, fore-aft and horizontal lateral directions. These force components can be used to derive joint forces and moments acting at the ankle, knee and hip as demonstrated by Bresler and Frankel [1] and Hughes [4], but the laborious nature of that process is intimidating to most clinicians.

What is required is an immediate visual presentation of the forces acting in a particular plane combined with a visual image of the patient's ambulation. Thus a vector of the forces acting in any visual plane, deriving from centre of force would enable a clinician to see immediately the implication of those forces to the joints in question.

A system in which the outputs from a force plate are used to produce a force vector has been developed at Moss Rehabilitation hospital by Cook *et al* [2]. It is also known that the Valley Instrument Company* is preparing a prototype of a production model that is believed will be suitable and feasible for both research and clinical use. In this system, the force plate outputs are used, in conjunction with analogue circuits, to produce Lissajous figures by deflecting a laser beam with galvanometer mirrors. The resulting 'line' is optically combined with a view of the patient and recorded on film, thus superimposing a force vector on the limb to be studied.

This system has a clear potential for use as a clinical tool, however an increasing amount of video recording as opposed to cine film is being used in the analysis of gait. The main disadvantage of film as a recording medium is the inherent delay involved in processing the film, preventing an 'on the spot' analysis of a patient disorder. Furthermore, it often happens that on the eventual return of a film from processing, insufficient data has been collected, the patient has stepped incorrectly on the plate, or some error has been made.

*Valley Instruments Company, 491 Clover Mill Road, Exton, Pennsylvania 19341, U.S.A.

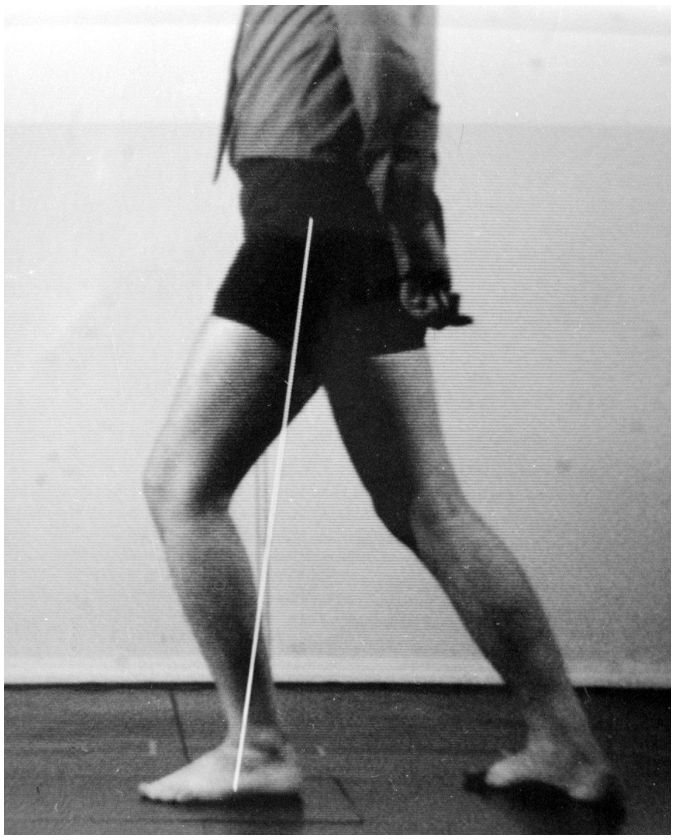

Figure 1. Example of video displayed vector.

While Cook *et al* have tried incorporating their force vector into a television system by viewing a Lissajous figure on the face of a cathode ray tube with an auxiliary TV camera and mixing the output of this camera with the output of another camera viewing the patient, the system is cumbersome, difficult to set up and lacking in accuracy.

A system has been designed at this Unit which produces an accurate force vector superimposed instantaneously on a television picture of the patient by electronically processing the video signal. The resulting composite signal can be recorded and played back immediately. A frame of a typical application is shown in Figure 1.

Video vector visualisation

The Kistler 9621A force plate and 9803 electronic unit produces analogue voltage outputs representing vertical and horizontal forces and the coordinates of the centre of pressure. Which of the two horizontal forces are used to synthesise a vector depends on the direction in which the platform is viewed, and the horizontal fore and aft (Fy) is selected for this description. The vertical force will be Fz and the coordinates of the centre of pressure in the fore-aft direction ay and in the lateral direction ax.

The video vector generator produces a 'line' on a television screen corresponding to the force vector by generating dots on each successive TV line. The position of the dots in the raster is computed by analogue means, analogue arithmetic sequences are controlled digitally. A purely digital system was rejected on the grounds of cost, complexity and potential lack of horizontal resolution.

The analogue system offers great flexibility (since it is processing analogue signals), high resolution, high computational speed and low cost; at the time of

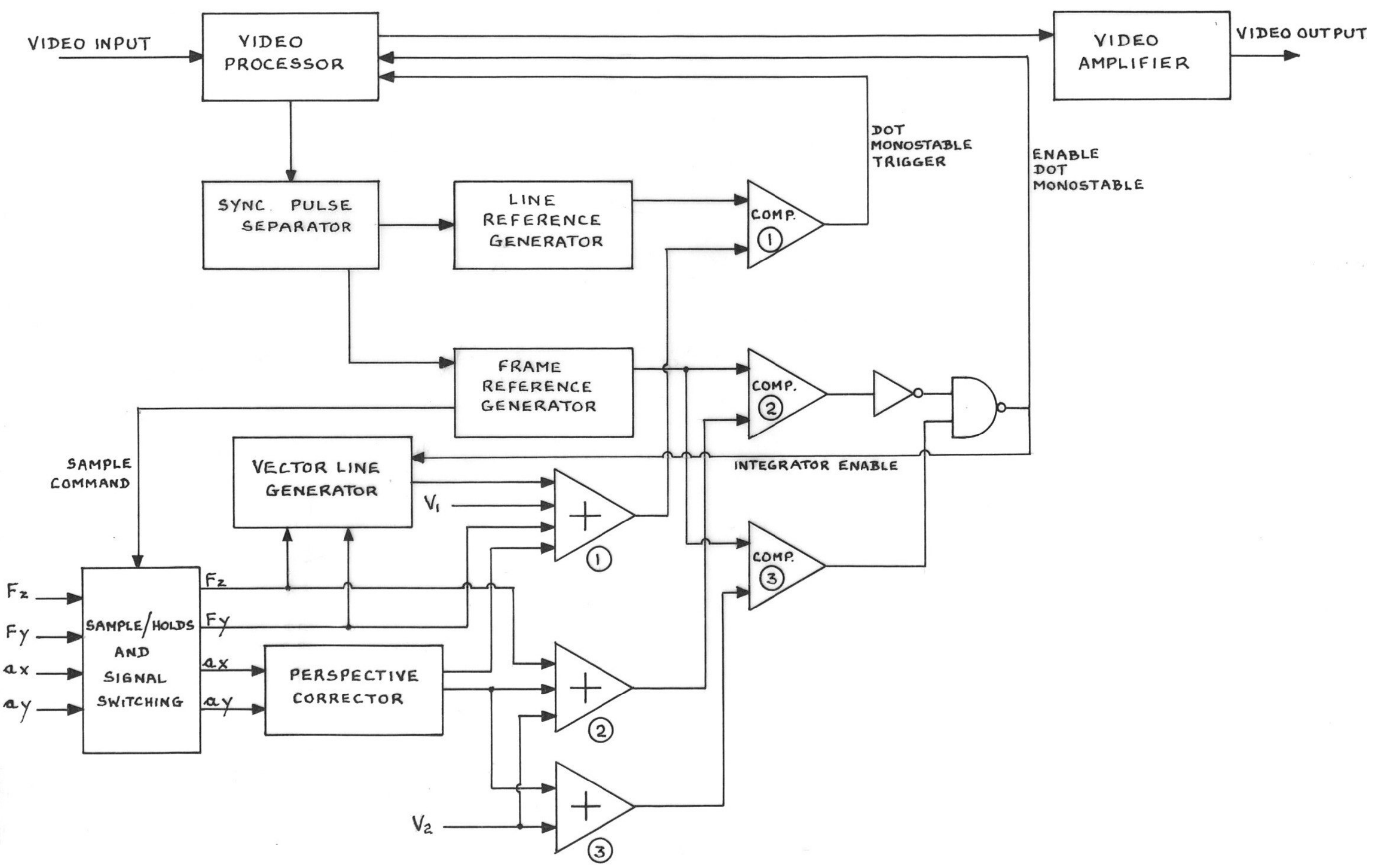

Figure 2. Video vector generator block diagram.

writing the total component cost of the instrument was less than £265. Accuracy is better than ± 0.5%, which exceeds that of most good quality TV monitors.

Description

As the output voltages of the force plate change during a gait cycle, the vector generator samples each input during the field reference voltage flyback period and stores each voltage for the duration of the field scan, i.e. 20 ms in the 625 line twin interlaced system. By the time the field fly-back is complete (100 µs in this instrument) all input signals have been operated on mathematically. Several control voltages become available to steer and position the dots making up the vector line in the ensuing 20 ms.

All control voltages are referenced (with fast analogue comparators) to two high linearity sawtooth voltages, the line and field (='half' interlaced frame) reference generators (Figure 2). These generators are triggered by the line and field synchronising pulses of the incoming video signal. Two signals exist therefore which can be used to define accurately any location within the raster, in terms of voltage.

Consider the production on a TV display of a typical vector (Figure 3) superimposed on a picture of patient and force plate.

The vertical force represented by a voltage Fz is applied to one of a pair of adders together with other voltages defining vertical position (to be dealt with later). The output of this adder is fed, together with the field reference voltage, to comparator (2) (Figure 2). When the field reference voltage is equal to the adder (2) output voltage, comparator (2) changes state, enabling the dot injector within the video processor. When the field reference voltage has swept through a voltage equal to Fz, comparator (3) operates and disables the dot injector. Simultaneous with the enabling of the dot injector by comparator (2) a digitally controlled operational integrator is set to run. This integrator produces a ramp voltage, the dv/dt of which is scaled to equal tan θ (i.e. Fy/Fz) when displayed on the screen. The result is that the dot on each successive line is displaced. Horizontal dot position is controlled by feeding, together with other positioning voltages, the above ramp voltage to adder (1). Output voltage from adder (1) is compared with the line reference voltage in comparator (1). When both are equal, comparator (1) switches and triggers a monostable (controlled as described above by comparators (1) and (2) within the video processor. This monostable operates an analogue switch which removes the input video signal and substitutes another d.c. voltage, adjustable by the operator. A dot thus appears on the screen for the duration of the monostable operating time. Dot brightness is infinitely adjustable between peak white and black, enabling the vector to be easily visible against the background in use.

By the time the field reference voltage has swept through Fz, the vector line ramp voltage has swept through a voltage equal to Fy, thus the dots on each line are displaced and the line terminates at the origin of the vector, 'O'. Provided θ does not exceed ±45°, (in practice θ can never exceed 45°) no matter what the values of Fz (Fz is always positive) and ±Fy, the unit will generate a vector on the screen with origin at O.

Position of the origin

It will be realised that a rectangle (the shape of the plate) when viewed from an angle other than the perpendicular appears as a trapezium to the viewer and any object, were it to move across the plate at a constant velocity away from the viewer, would appear to slow down as it receded from the observer. This implies that for accurate placement of the vector origin, the rectangular coordinates (ax, ay) of the centre of pressure must be conditioned for the display to be correct.

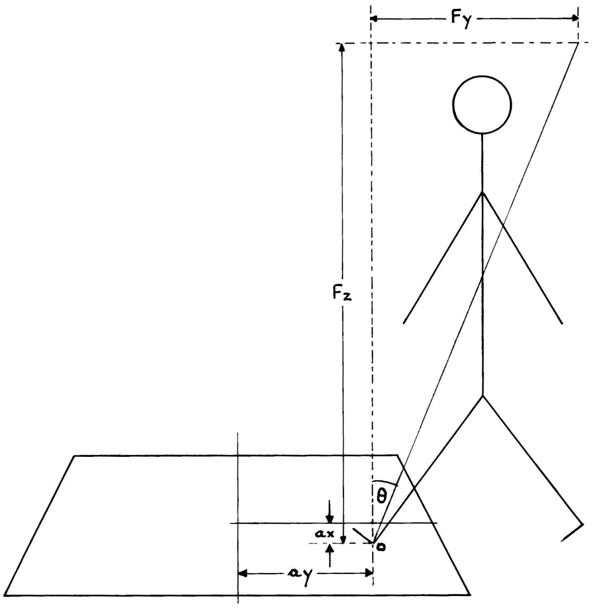

Figure3. Representation of the force system.

This is especially important in cases where the force plate fills an appreciable fraction of a frame.

The coordinates (ax, ay) are processed in a perspective corrector which, once set by the operator for a particular view, will automatically compute the correct visual position of the vector origin on the screen

While the operation of the perspective corrector is not mathematically exact, it is sufficiently accurate to make it impossible to detect any discrepancy between actual centre of pressure and that presented visually. This part of the system is an important contribution to accuracy and a further advantage over that used at Moss Rehabilitation Hospital.

The modified versions of ax and ay are presented to their respective adders during the field flyback period, presetting the origin before the generation of a vector in the ensuing field scan.

The two reference voltages V1 and V2 shown in Figure 2 are derived from potentiometers controlled by the operator and serve to shift the origin in horizontal and vertical directions when first setting up at the commencement of an assessment.

Setting up of the perspective corrector is a simple procedure irrespective of camera position and is aided by internally generated simulation voltages.

Calibration

In addition to the simulation voltages used to set the perspective corrector further signals are available within the instrument to facilitate calibration and also serve to verify correct operation. The vector generator is ready for use after a period of two minutes from switch-on; calibration and set-up take a further three minutes.

Playback

Patient assessments at ORLAU are recorded on a Sony 3620 video tape recorder. It was mentioned earlier that the vector display is up-dated every 20 ms, i.e. every half frame, giving a sample rate of 50 per second. When the Sony recorder is used to play back pictures frame by frame it actually displays a stationary half frame (field), but inserts the 'missing' lines on the monitor by pairing. This effectively reduces vertical resolution; however the loss is of little consequence since it is difficult to measure from a tube face with high accuracy in practice.

Clinical application

The value of such a tool is immediately obvious to those engaged in the day to day work of a gait laboratory, and indeed the calculation of such vectors has long been used in the study of the stresses applied to normal joints during walking and other activities. To the clinician treating knee and foot pathology by surgical, physical or orthotic means, the opportunity to inspect the visual vector before and after any form of treatment can be of very considerable value in the decision regarding the treatment to be given and in the assessment of the results of such treatment. We have a particular interest in the treatment of rheumatoid conditions of the knee and in foot-ankle deformities in rheumatoid conditions and a variety of neurogenic disorders such as spina bifida, cerebral palsy and muscular dystrophy. Abnormal mechanical stress in these joints is a product of muscle balance or imbalance inter-relating with the dynamic body weight loading. This latter is demonstrated in degree and position during all phases of gait by the vector which will then give an indication of the type of support required; for example, muscle strengthened by appropriate physiotherapy, orthosis, re-alignment osteotomy (division) of the bone or replacement joint prosthesis. In the last event, the placement of the axes of the prosthesis in relationship to the potential load line is critical and the present efforts to determine this have been largely static by means of weight bearing x-rays. Such information is very limited because of the demonstrated considerable change which can occur in the vector during different phases of gait. Account must be taken particularly of the position of maximum abnormal stress. Similarly, following the insertion, the case can be re-assessed, the degree of potential abnormal stress estimated and consideration be given to appropriate further treatment or advice to the patient.

In the foot-ankle complex we are evaluating present standing x-ray techniques in relationship to the vector particularly in conditions which require osteotomy of the *os calcis* where the degree of displacement of the support area of the heel bone required for stabilisation must be estimated pre-operatively and achieved precisely at operation.

The present use of this device in a clinical field is exploratory and limited, but it is abundantly clear that the routine use pre- and post-treatment must result in a considerable improvement in predicted efficiency of that treatment.

Conclusion

The instrument has not yet been extensively used for clinical work, since its construction has only recently been completed. We are negotiating with a manufacturer for the commercial production of this instrument.

REFERENCES

[1] Bresler, B. and Frankel. J.P. (1950). The forces and moment in the leg during level walking. *Trans. ASME* (Paper No, 48-A-62)

[2] Cook, T.M., Cozzens, B.A. and Kenosian, H. (1977). Real time force line visualisation *Bioengineering Applications. Trans. ASME* (Paper No. 77-WA/Bio-6).

[3] Elftman, H. (1939). Forces and energy changes in the leg during walking. *American Journal of Physiology.* 125 : 339-356.

[4] Hughes, J. (1976). Human locomotion, the advance in orthotics, 57-73. Edward Arnold, London.

[5] Murray, M.P., Seireg, A. and Scholz, R.C. (1967). Centre of gravity, centre of pressure and supportive forces during human activities. *Journal of Applied Physiology.* 23 : 831-838.