# HUMAN LOCOMOTION STUDY USING FOOT-PRINTS IN STATIONARY AND TRANSIENT STATES

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*Summary*

*The foot-print made by Barograph provide a rather simple method for studing the pressure distribution between the plantar surface of the foot and the ground, but there are many difficulties in quantifying the data.*

*In the paper, some newly developed apparatuses for quantifying the data and for recording the pressure distribution more effectively by using the foot-print, and thus study human locomotion are described. They are:*

*(1) An automatic calculator which can inexpensively denote numerically the position of a center of weight distribution by employing a photograph of the foot-print.*

*(2) A cathode-ray-tube display which can convert the foot-print to a colored contour of the pressure distribution.*

*Some results of human locomotion studies in stationary gait and transient phenomena between standing and stepping forth are given. They are discussed as a locus of the center of pressure distribution. An interesting result was obtained from the trasient phenomena. When the subject makes a step forward, the locus of the center of pressure distribution differs from active start to passive start. The change of locus is smooth in active starts, but it shows a zig-zag motion with hesitation between forward and backward movements.*

## 1. Introduction

Our Prosthetics Center was established in 1969. We have endeavoured to constitute a bioengineering laboratory which will make possible a systematic analysis of human locomotion to develop more useful prostheses and orthoses.

We have three kinesiological or kinematic measuring systems of human locomotion, i.e., force-plate system, foot-print system with glass walk-way, and stick-picture photography system. The foot-print system is the simpliest one for determining the pressure distribution between the plantar surface of the foot and the ground. But, it is not enough to quantify the data.

During the past three years, we developed two apparatuses. One makes possible the quantification of the position of center of the pressure distribution on the plantar surface. The other makes the pressure distribution more meaningful by the aid of a coloured cathode-ray-tube (C.R.T.) display for clinical examination. It can be used either on-line or off-line.

It is very difficult to measure the position of the center of gravity of the human body during locomotion, because the human body or its segment is not rigid enough for application of the dynamics of the rigid body. Therefore, we substituted the center of pressure distribution (C.P.D.) on the plantar surface for the horizontal projection of the center of gravity (H.P.C.G.) of the human body. The C.P.D. agrees with the H.P.C.G. of the subject when the body is still holding. But, it shows some error during locomotion. The maximum error appears at heel-contact and at toe-off, because at these time intervals large braking or driving forces result shear in the horizontal plane.

The foot-print system has a high sensitivity for vertical force, but it is not sensitive for horizontal forces.

The foot-prints were recorded by 16 mm cine-camera, and the locus of the center of pressure distribution on the planar surface in each frame was calculated by the calculator.

## 2. Automatic Calculator of the Center of Pressure Distribution on the Planar Surface

*Response of foot-print system*

The foot-print system consists of a glass walk-way (180 cm x 90 cm) and a silicone rubber mat with many matrices of uniform pyramidal projections which measure 5 mm x 5 mm x 4 mm.

The vertex of each pyramidal projection is pressed on the glass when it is loaded by the subject. The pressed area of a vertex is approximately proportional to the load as shown as in Figure 1. This characteristic curve was calibrated by the static load. The flattened area of the vertex has a time constant of 5 ms when the load is changed suddenly.

*Center of pressure distribution*

The flattened area of the vertex of a pyramid is regarded as a set of small optical data which tells us the total pressure loaded on the base of each pyramid. So, we can get information on the pressure on the base of each pyramid by counting the numbers of quantized light-spots. The photograph of the foot-print corresponds to the distribution of material at various points in the plane. Consequently, we can get the position of the C.P.D. by calculating the H.P.C.G. from the distribution of material at the various points.

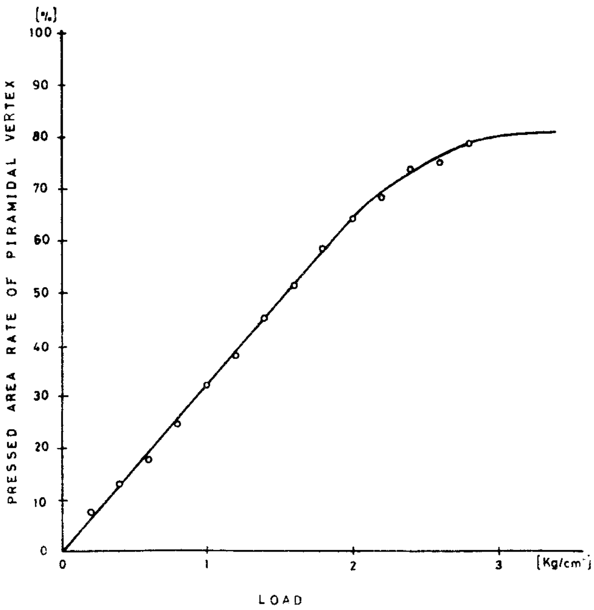


Fig. 1. Load response of Mat.

Put the coordination of a vertex of any pyramid in the glass walk-way ($X_i$, $Y_j$), and put the size of the pressed area of the vertex $A_{ij}$, then the center of the pressure distribution ($\overline{X}$, $\overline{Y}$) can be calculated by following equations,

$$\overline{X} = \frac{\sum_{i=1}^{n} \sum_{j=1}^{m} A_{ij} X_i}{\sum_{i=1}^{n} \sum_{j=1}^{m} A_{ij}} \tag{1}$$

$$\overline{Y} = \frac{\sum_{j=1}^{m} \sum_{i=1}^{n} A_{ij} X_i}{\sum_{j=1}^{m} \sum_{i=1}^{n} A_{ij}} \tag{2}$$

where, n and m are the number of pyramids in X-axis and Y-axis, respectively.

*Calculating system*

The calculating system of the C.P.D. (Fig.2.) consists of

3 sub-systems as follows.

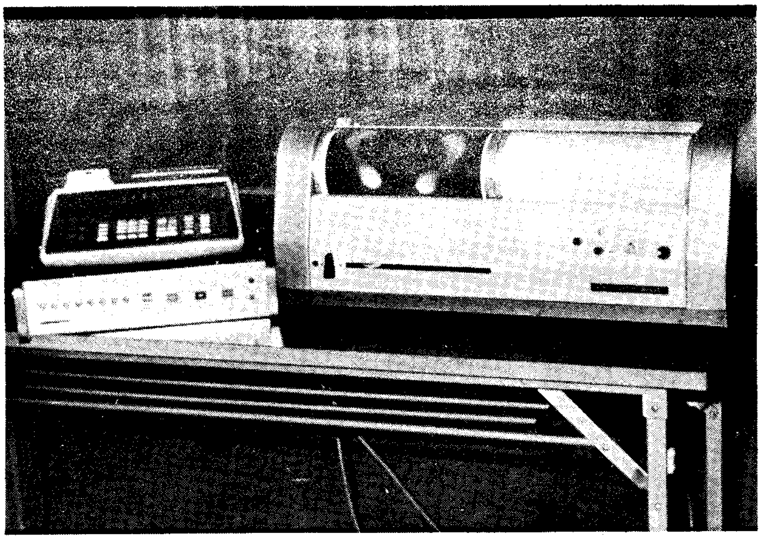

Fig. 2. Automatic calculator of the C.P.D.

(1) Data converting system

An electronic facsimile for mimeograph is used to convert the information of either white or black signals in the photograph of the foot-print into electric impulses.

Its resolving power is 3 - 30 lines per millimeter; the size of the scanning light-spot does not exceed 1/10 $mm^2$; and the size of photograph is 380 mm x 260 mm. The output signal is obtained as the sequences of electric impulse whose width is adjusted to within $10^5$ sec.

(2) Interface system

A stored program matrix is built into this system. When the sequence of impulse signals from the data converting system is received this system generates the control signal to the electronic calculator according to the stored program. The signal flow diagram of this program is shown in Figure 3.

(3) Electronic calculator

A programmable electronic calculator with 7 memories (Sharp Compet 363p) is used for calculation.

A photograph enlarged 20 power magnification (1/2 size of actual foot-print) was supplied to the data converting system for the test.

To calibrate the error of this system, the flattened area of the vertex of each pyramid was measured manually using the photograph enlarged by three times and the position of the C.P.D. was calculated. This position was compared with the output data of the calculator. As a result, it was recognized that the total error of this system does not exceed ±1.2mm in actual size. Figure 4 shows an example of the photograph of a typical foot-print.

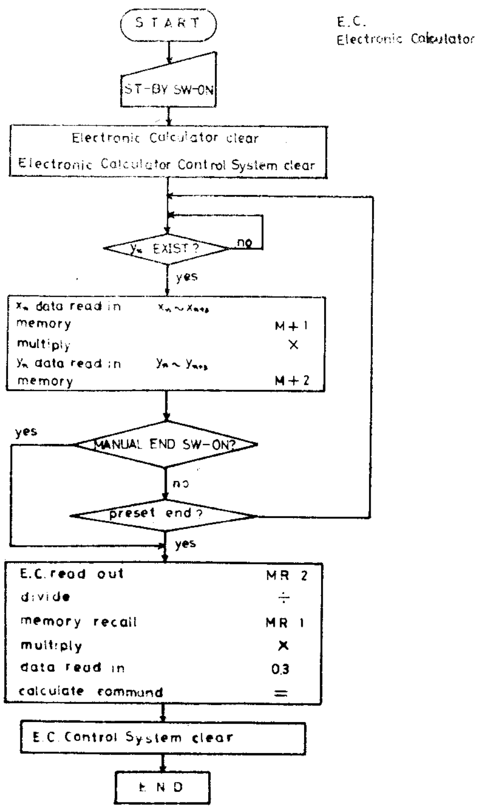


**Fig. 3.** Signal-Flow diagram in the automatic calculator

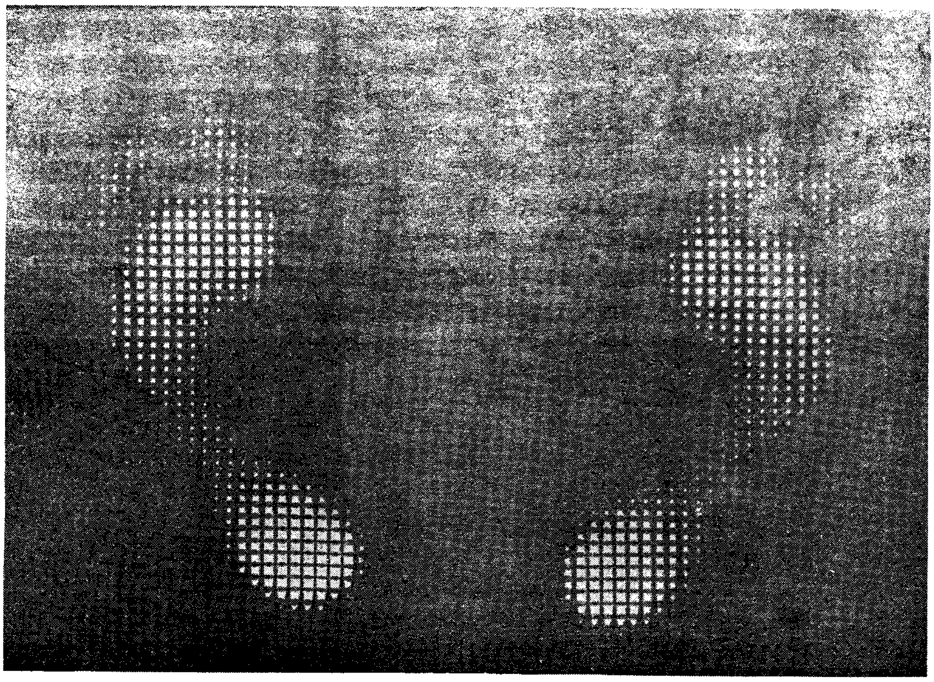

**Fig. 4** An example of the foot-print

## 3. Locomotion Studies

*Movement of C.P.D. in the Stationary Gait Cycle*

The C.P.D. obtained from each frame of 16 mm cine-film was plotted on a paper in sequence.

As stated above a locus of the C.P.D. is approximately equal to the H.P.C.G. of the subject. So, we can study the locomotion of the subject in the horizontal plane.

In the stationary gait cycle, the locus moves almost sinusoidally as shown in Figure 5. Two typical patterns were observed for many normal subjects. One pattern is a smooth sinusoid and the other is a stiff sinusoid with rollong and rocking at foot-flat.

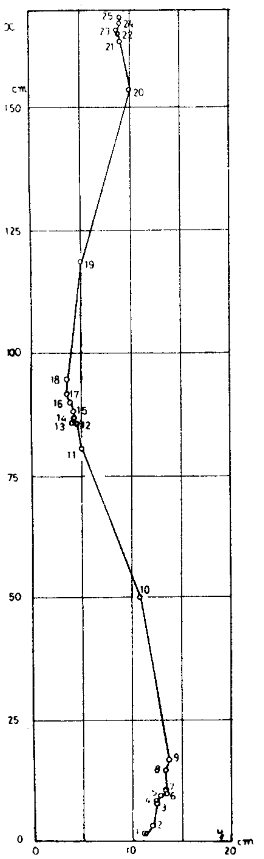


Fig. 5. Locus of the C.P.D. in stationary gait.

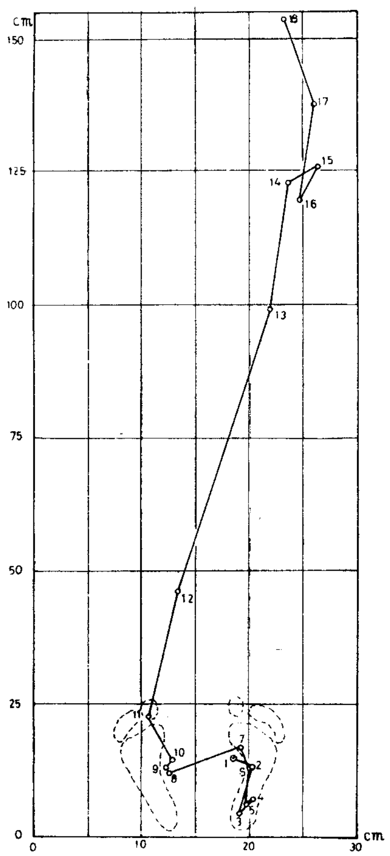


Fig. 7. Locus of the C.P.D. in transient gait.

These patterns do not always mean the personal speciality, but it seems to mean the existance of control on the balance of the body. Therefore, rollong or rocking appears when the ground is not flat or the subject who has a smooth pattern slightly loses ballance.

To analize the movement of the C.P.D. in more detail, phase-plane trajectory in y-axis is convenient (Fig.6). It can be seen that the existence of bang-bang control of the center of gravity of body is present, and it seems to be taking place when the velocity or position of the center of gravity exceeds each limited value.

The analysis of control mechanism will be undertaken soon. by us.

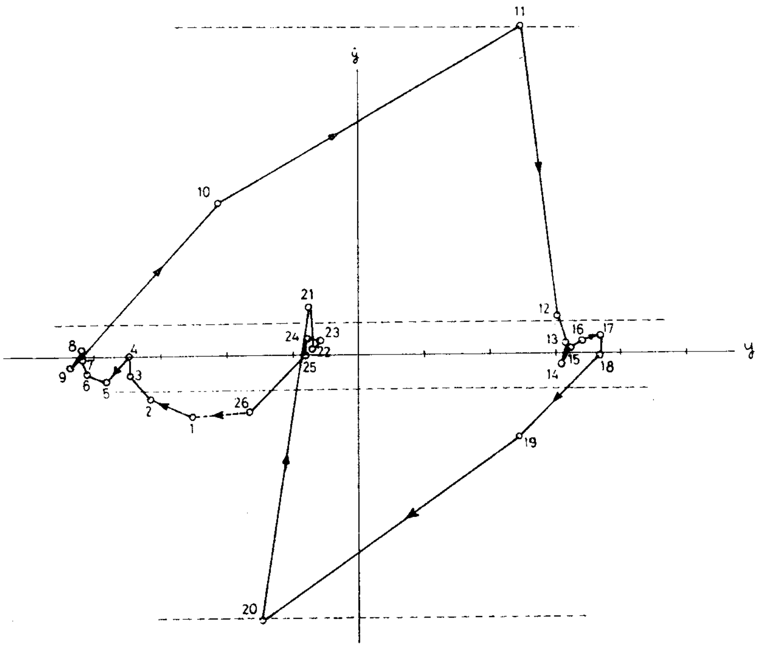

Fig. 6. Phase-plane trajectory of stationary gait in Y-axis.

*Movement of C.P.D. in Transient Gait*

The transient locus of C.P.D. between standing and advance is shown in Figure 7. This locus was obtained when the subject was given an order by the experimentor to begin advancing.

While the subject stands ready for the order, his weight was put on the plantar surface which was to step forward. As soon as he received the order to start with the right leg, his C.P.D. began rocking on his right plantar surface. His C.P.D. was transferred onto the left plantar surface after rocking twice, and then his right leg was put forward.

But, when the subject was ordered to advance freely, these rocking motions vanished and the locus of the C.P.D. drew a smooth curve with slight rolling while he was in stance phase.

This is a very interesting problem, but it is not clear why it is so.

4. Colored Display

The foot-print is a quantized display of the pressure between the plantar surface of the subject and the glass walk-way. But when the eyes of the experimenter received this quantized information, that information is converted again into analogue information of pressure distribution.

We tried to convert that information into a colored contour. Figure 8 shows the pressure contour calculated from the foot-print. Figure 8-a shows the pressure contour on the plantar surface when the subject stands normally on both legs and Figure 8-b shows the pressure contour when the subject stands on tiptoe. We developed a new method obtaining such contour maps directly from the foot-print.

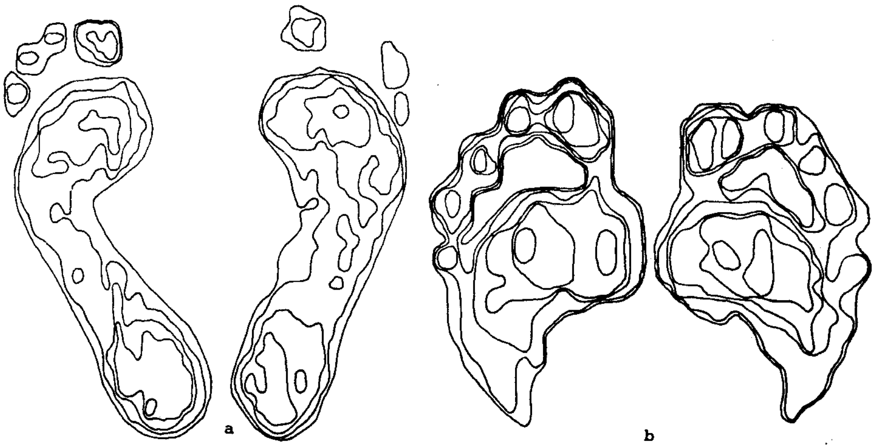


**Fig. 8**

(a) - Contour of pressure distribution plantar surface (standing with both legs)

(b) - Same above (stand of toetips)

An external appearance of the apparatus which used for this purpose is shown in Figure 9. Figure 10, shows a block diagram of this apparatus. It is one of the apparatuses used to convert the video signal of monochrom TV-camera into color signal for the colored cathode-ray-tube. The signal level between white and black is sliced off into 12 levels, and the signal level is converted into color signal corresponding to each signal level. The signal level obtained from foot-print has a hard contrast because of the quantized information. If we bring the lens of a TV-camera to our focus to be able to distribute the level of light signal, the signal level of the foot-print will be distributed so as to be proportional to the flattened area of the pyramidal vertex.

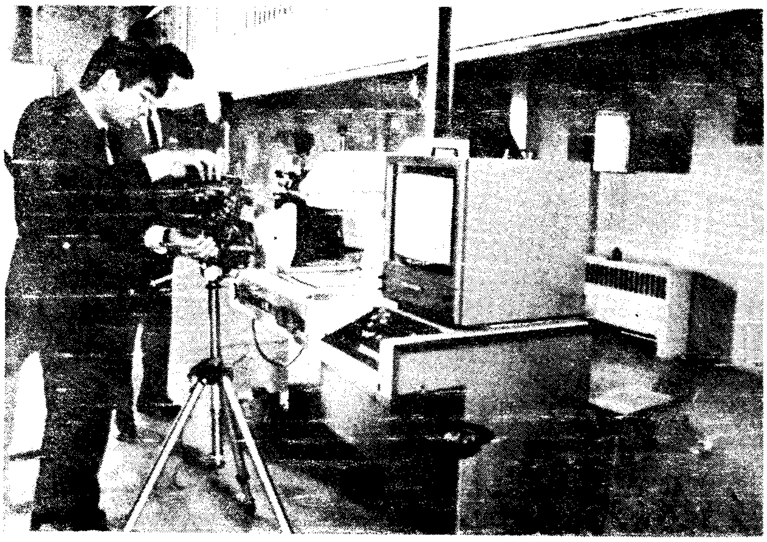

Fig. 9 Color conventer
(Color data system; Made by NAC Co.Ltd.)

Thus, we can obtain directly colored contours of the pressure distribution from the foot-print. An example of the contour is shown in Figure 11. Because this publication does not use color, the contour is photographed by monochrome film. This expression is very useful for the clinical examination, sport etc. To quantize this contour more precisely, more effort will be need.

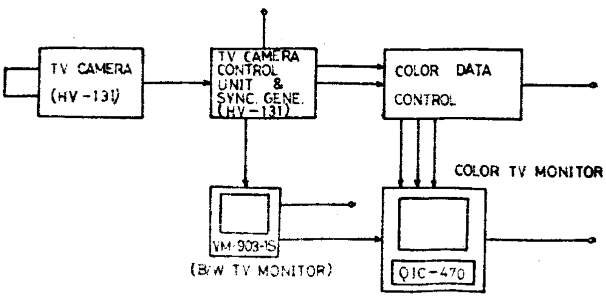


Fig. 10. Block diagram of color converting system

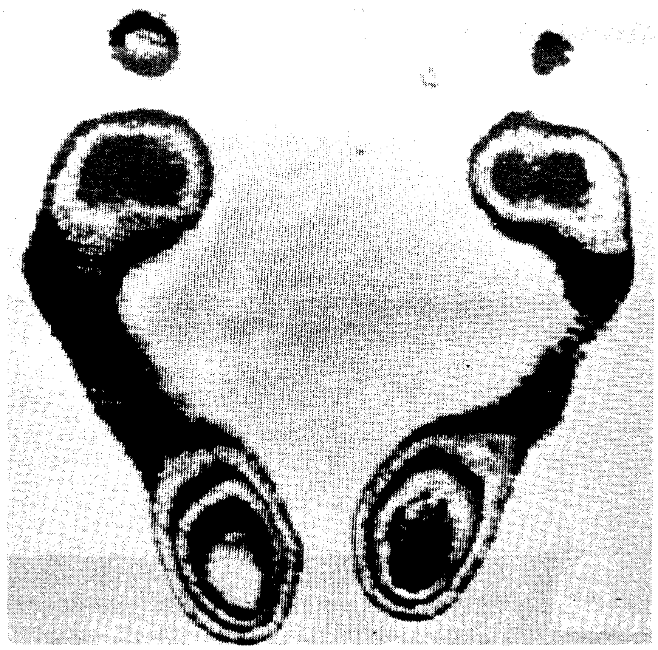

Fig. 11. Contour of the pressure distribution (obtained directly from the foot-print).

## 5. Conclusion

The functions of our apparatus were rather compatible. However, an analysis of the human locomotion requires all systems to be synchronized.

For example, the stick-picture and foot-print is rather easy to synchronize as shown in Figure 12. But, to synchronize three systems effectively is very difficult.

*Acknowledgment*

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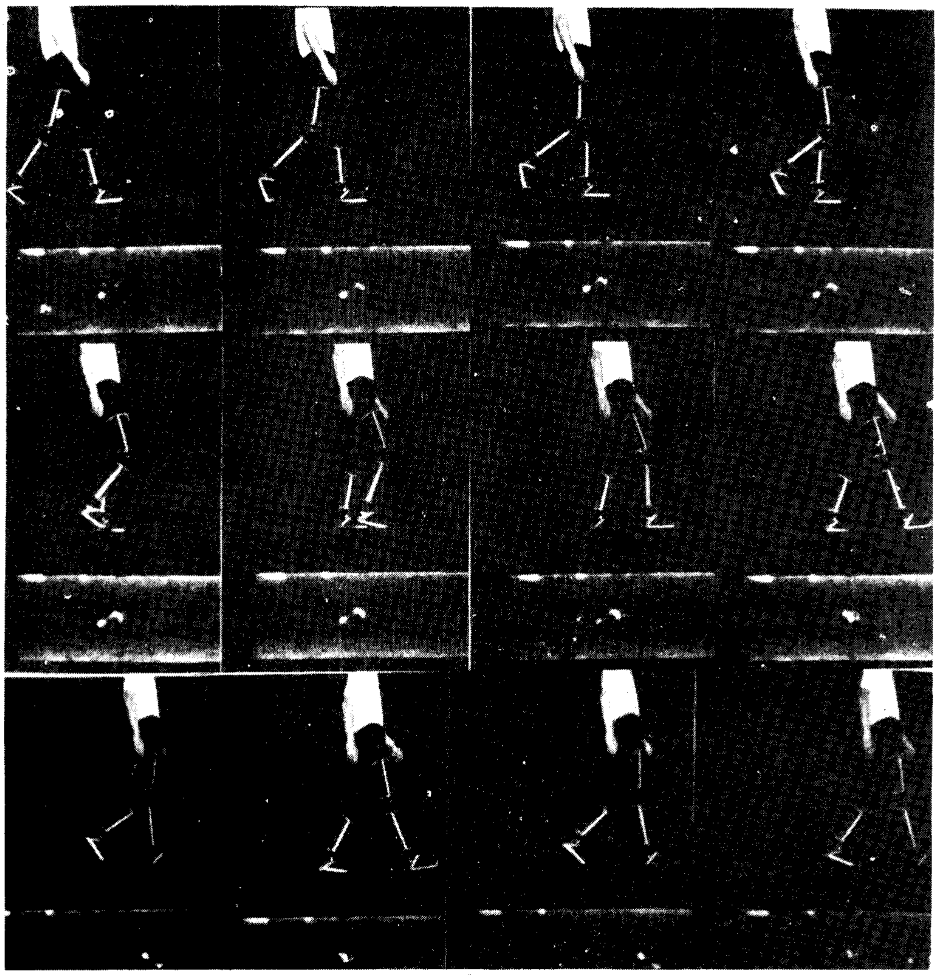

Fig. 12. Synchronized records between the stick-pictures and the foot-prints.