CIR Systems Inc.

The *GAITRite* Electronic Walkway

Measurements & Definitions

Revision A.2

January 2006

1 INTRODUCTION

Encapsulated within the electronic walkway are sensor pads. Each sensor pad has an active area of 24 inches square (61cm square) and contains 2,304 sensors arranged in (48x48) grid pattern. The sensors are placed on .5 inch (1.27cm) centers. Multiple sensor pads are connected to form the desired length of the walkway.

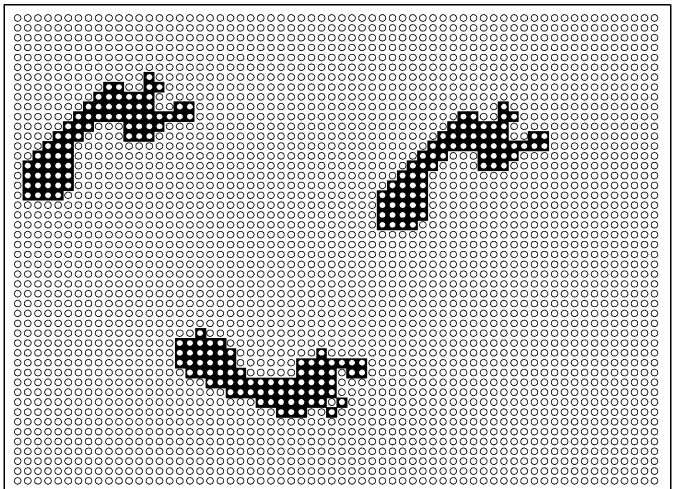

Figure 1

As the subject ambulates across the walkway, the pressure exerted by the feet onto the walkway activates the sensors. The walkway does not only sense the geometry of the activating objects but also the relative arrangement between them in a two dimensional space. In addition, the walkway senses the vertical component of the relative pressure exerted by the objects.

What makes the walkway valuable for gait analysis are the special algorithms build into the system. The algorithms isolate the objects and identify them as footprints.

2 FOOTPRINT ANALYSIS

The software utilizes special algorithms to automatically group sensors and form footprints. Once a footprint has been formed it will be divided and the following areas will be identified:

1. Identify a quadrilateral that encloses the footprint;
2. Identify the heel, mid and toe areas of the footprint;
3. Identify the centroid, the point that could balance the quadrilateral on a pin, of each area; and
4. Divide each quadrilateral into four equal quadrilaterals.

Each area will be examined separately.

2.1 Identify the quadrilateral

The method for defining the quadrilateral of a footprint was first developed by Shores[1] and later improved upon by Lisa Selby-Silverstein[2], while an automated improved version of the algorithm has been implemented by the GAITRite system. The following steps refer to Figure 2.

Identify the two most outer sensors on the medial side of the footprint, sensor 1 and sensor 3. Draw the medial line; the line that connects sensor 1 to sensor 3.

1. Identify the two most outer sensors on the lateral side of the footprint, sensor 5 and sensor 6. Draw the lateral line; the line that connects sensor 5 to sensor 6.

2. Identify the rear most outer sensor(s), sensor 2. From sensor 2 draw a line perpendicular to the medial line. The two lines intercept at point A. Extend the line to intercept the lateral side at point L.

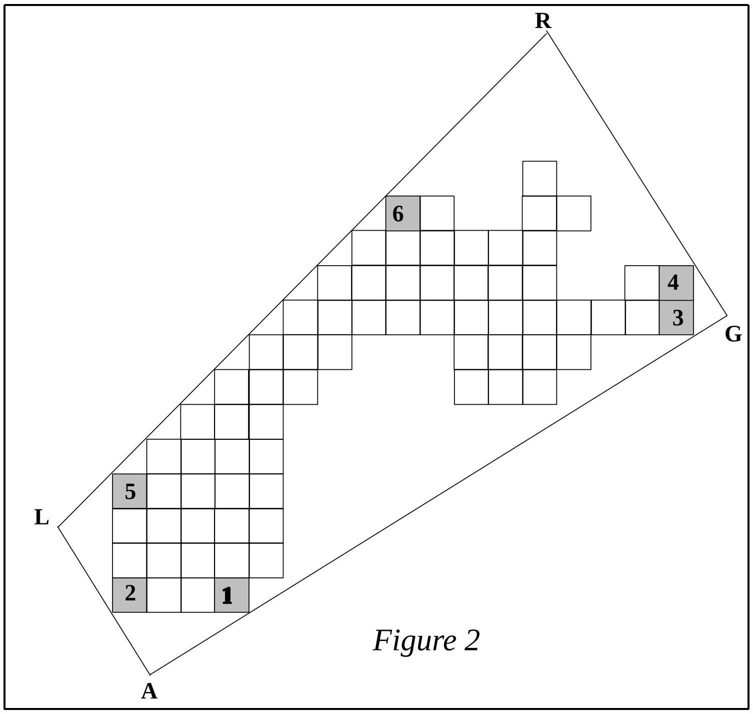

Figure 2

3. Identify the front most outer sensor(s), sensor 4. From sensor 4 draw a line perpendicular to the medial line. The two lines intercept at point G. Extend the line to intercept the lateral side at point R.

4. The formed quadrilateral (ALRG), in this case a trapezoid, encloses the footprint efficiently.

1. Shores M. Footprint analysis in gait documentation: an instructional sheet format, Phys Ther 60:1163, 1980.

2. Silverstein LS: the effect of neutral position foot orthoses on gait of children with down syndrome. Doctoral Thesis. PA, 1993, Hahnemann University.

2.2 Identify Heel, Mid and Toe areas

Refer to Figure 3 and identify points (C) and (E); these two points divide the medial line (AG) into three equal spaces.

From point (C), draw a line perpendicular to the medial line and extended it in order to intercept the lateral line at point (N). Similarly, from point (E), draw a line perpendicular to the medial line and extended it in order to intercept the lateral line at point (P).

Quadrilateral (ALNC) contains the Heel area sensors, (CNPE) contains the mid foot area sensors and (EPRG) contains the toe area sensors.

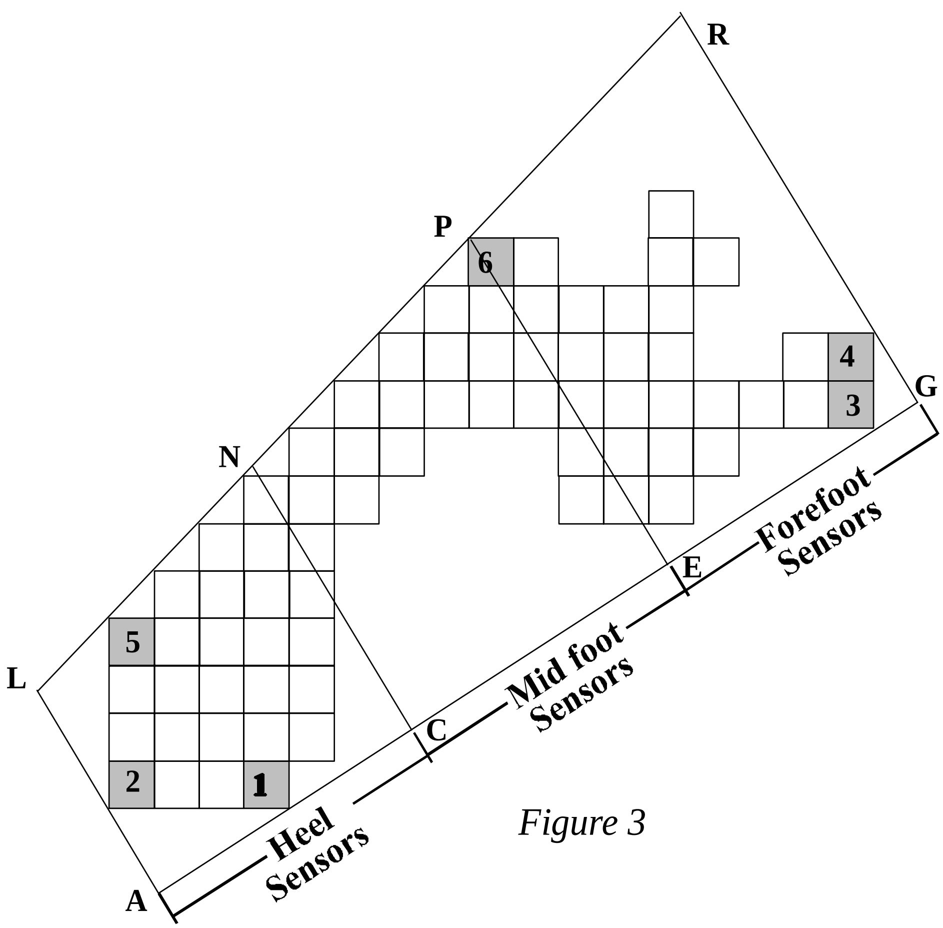

Figure 3

2.3 Identify the centroid

So far, the footprint was divided into three quadrilaterals with the intention of identifying the sensors for the heel, mid foot and toe areas.

Figure 4, illustrates the heel area quadrilateral (ALNC), in this case a trapezoid, and the sensors included in the heel area of the footprint.

Point (C1), the centroid, represents the center of the heel area. The centroid is the pivot point of the two dimensional sensor structure shown in gray.

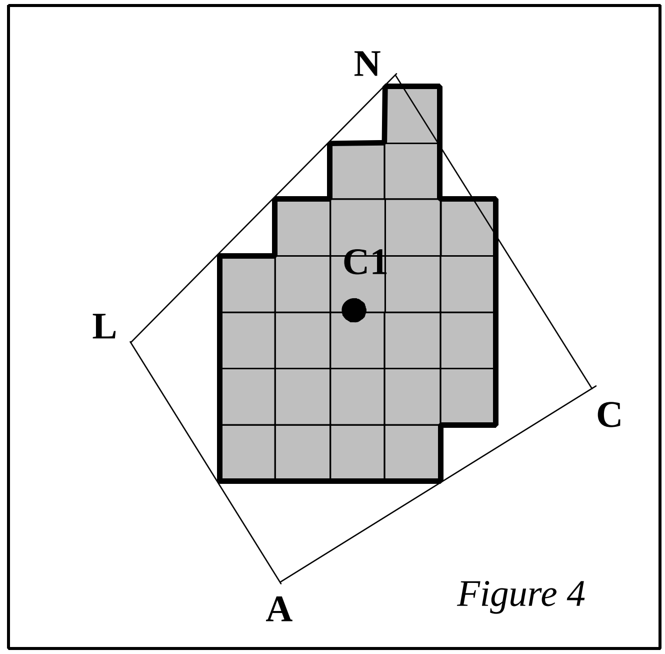

Figure 4

Figure 5, illustrates the toe area quadrilateral (EPRG), in this case a trapezoid, and the sensors included in the toe area of the footprint.

Point (C2), the centroid, represents the center of the toe area. The centroid is the pivot point of the two dimensional sensor structure shown in gray.

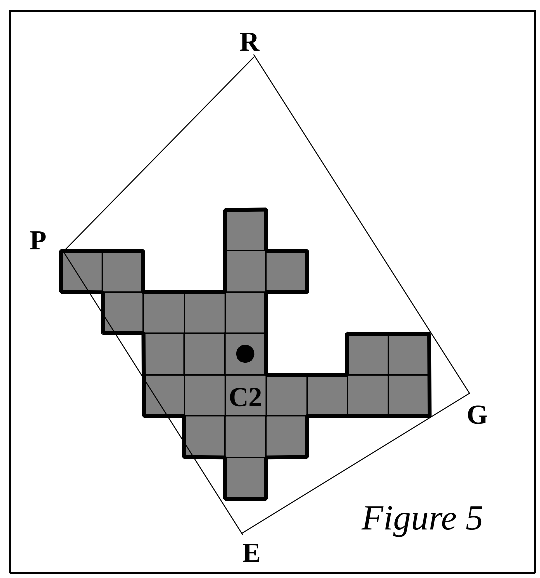

Figure 5

2.4 Identify the twelve quadrilaterals

As illustrated in Figure 6, in this specific footprint the quadrilaterals form trapezoids, but in other cases the quadrilaterals could form rectangles. Point (C1), the centroid of trapezoid (ALNC) represents the heel center of the footprint. Point (C2), the centroid of trapezoid (EPRG) represents the toe/metatarsal center point. This footprint is geometrically represented by twelve trapezoids; six medial and six lateral. Quadrilaterals are formed in the two dimensional representation of the footprint in order to isolate the sensors and later perform calculations based on the isolated sensors of each quadrilateral.

The line that connects point C1 to point C2 is the midline of the footprint.

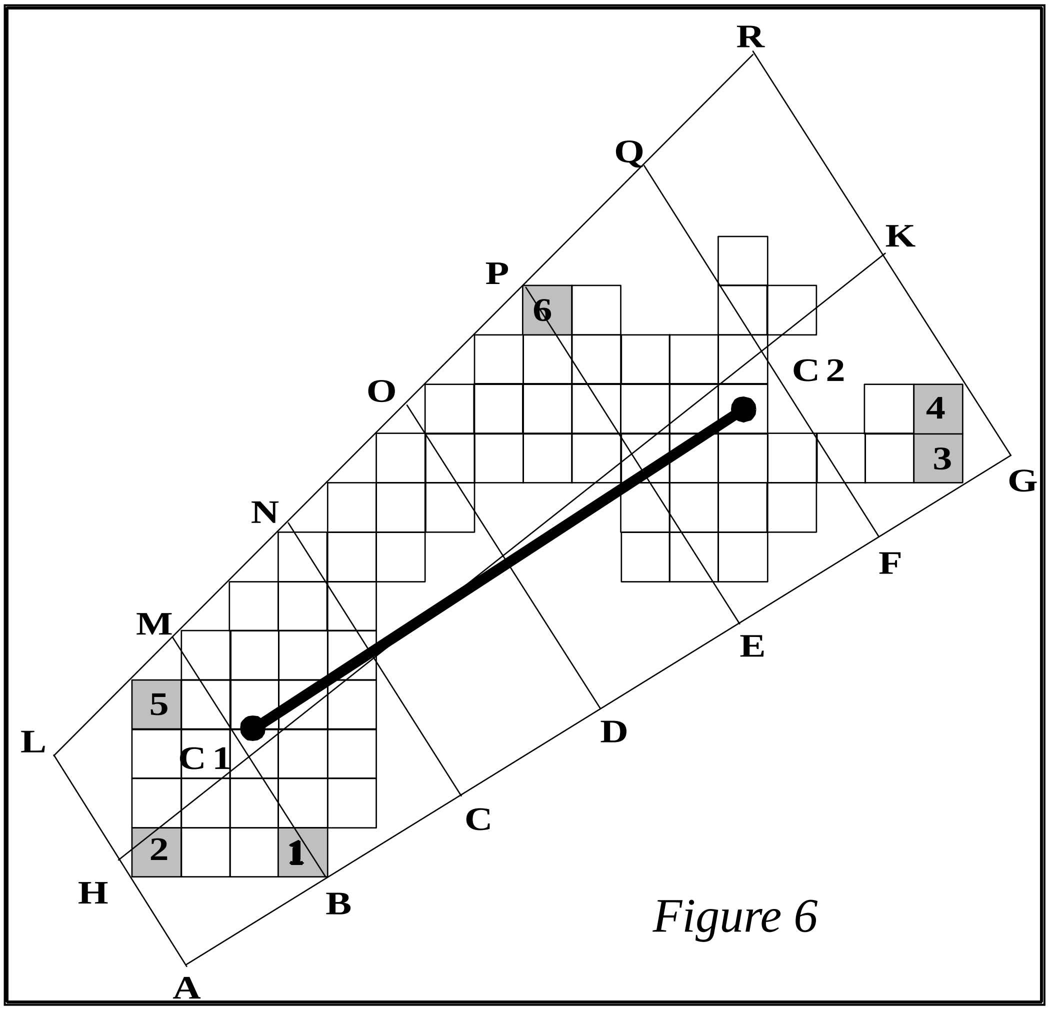

Figure 6

3 SPATIAL PARAMETERS & DEFINITIONS

The walkway does not only sense the geometry of the activating footprints but also the relative arrangement between them in a two dimensional space. Figure 7, illustrates three footprints.

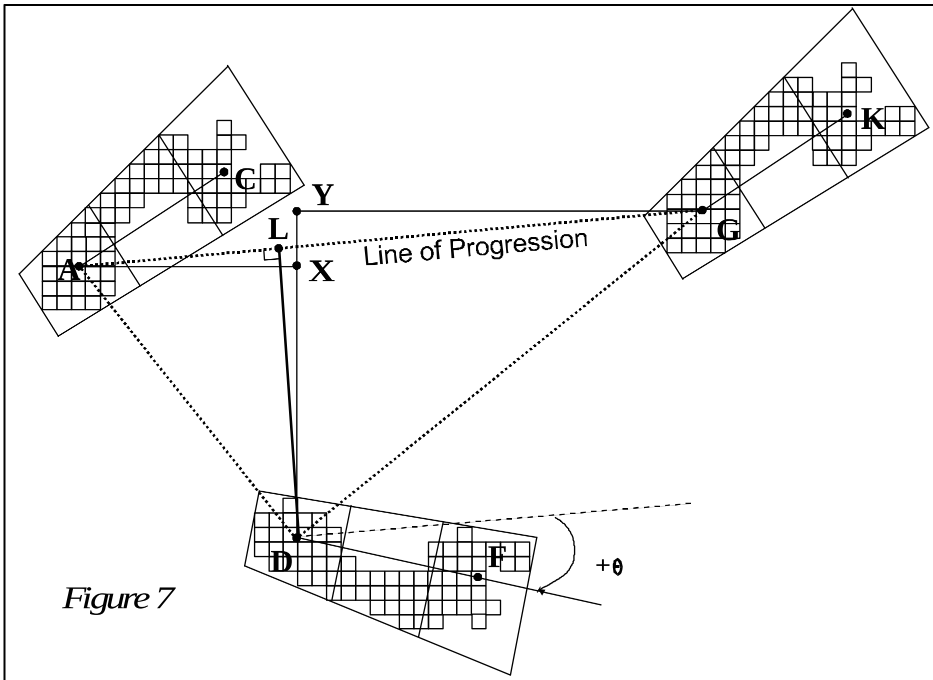

Figure 7

3.1 Heel Center

Points (A), (D) and (G) are the ***heel centers*** of each footprint.

3.2 Line of Progression

It is defined as the line connecting the heel centers of two consecutive footfalls of the same foot. Illustrated in Figure 7, the line of progression is formed by connecting point (A) to point (G).

3.3 Stride Length

It is measured on the line of progression between the heel points of two consecutive footprints of the same foot (left to left, right to right). In Figure 7, (AG) is the stride length of the left foot. The unit of measure is centimeters.

3.4 Step Length

It is measured along the line of progression, from the heel center of the current footprint to the heel center of the previous footprint on the opposite foot. In Figure 7, line (DL) is perpendicular to the line of progression (AG). The length of line (AL) is the ***step length*** of the right foot, while the length of line (LG) is the step length of the second left foot. The step length can be a negative value if the subject fails to bring the landing foot heel point forward of the stationary foot heel point. The unit of measure is centimeters.

3.5 H-H Base of Support or Base Width

It is the vertical distance from heel center of one footprint to the line of progression formed by two footprints of the opposite foot. In Figure 7, the height of the triangle (ADG) is (DL) which is the base width of the right foot. The unit of measure is centimeters.

3.6 Toe In / Toe Out

It is the angle between the line of progression and the midline of the footprint. In Figure 7, theta is the angle between the mid-line of the right footprint and the line of progression. Angle theta is zero if the geometric mid-line of the footprint is parallel to the line of progression; positive, toe-out, when the midline of the footprint is outside the line of progression and negative, toe-in, when inside the line of progression. The unit of measure is degrees.

3.7 Distance Traveled
It is measured on the horizontal axis from the heel center of the first footprint to the heel center of the last footprint. The unit of measure is centimeters.

3.8 Leg Length (LL)
It is measured in centimeters from the greater trocanter to the floor, bisecting the lateral Malleolus. Each leg should be measured separately. The unit of measure is centimeters.

3.9 Step/Extremity Ratio
It is defined as the Step Length divided by the Leg Length of the same leg. The result is an absolute number.

3.10 Step Width
It is measured from the midline midpoint of the current footprint to the midline midpoint of the previous footprint on the opposite foot. In Figure 8, distance (XY) is the right step width, while distance (YZ) is the left step width. The unit of measure is centimeters.

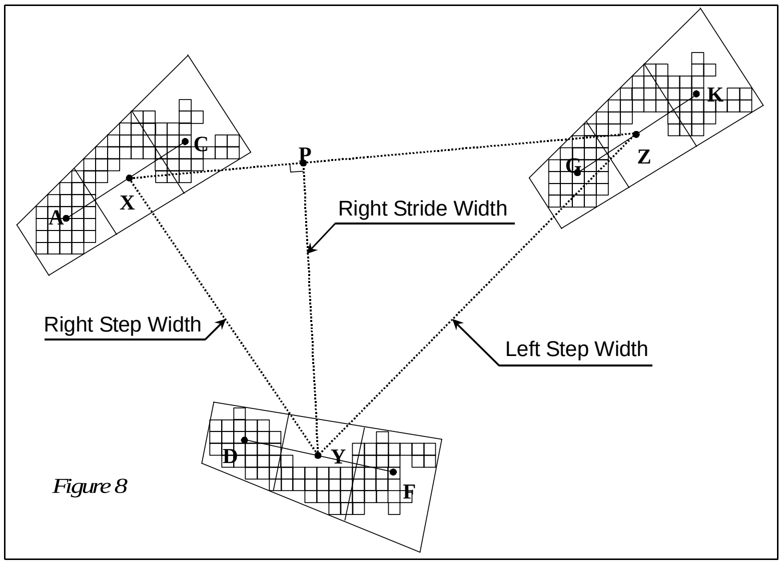

Figure 8

3.11 Stride width
It is the vertical distance from midline midpoint of one footprint to the line formed by midline midpoints of two footprints of the opposite foot. In Figure 8, the height of the triangle (XYZ) is (YP) which is the stride width of the right foot. The unit of measure is centimeters

4 TEMPORAL DEFINITIONS

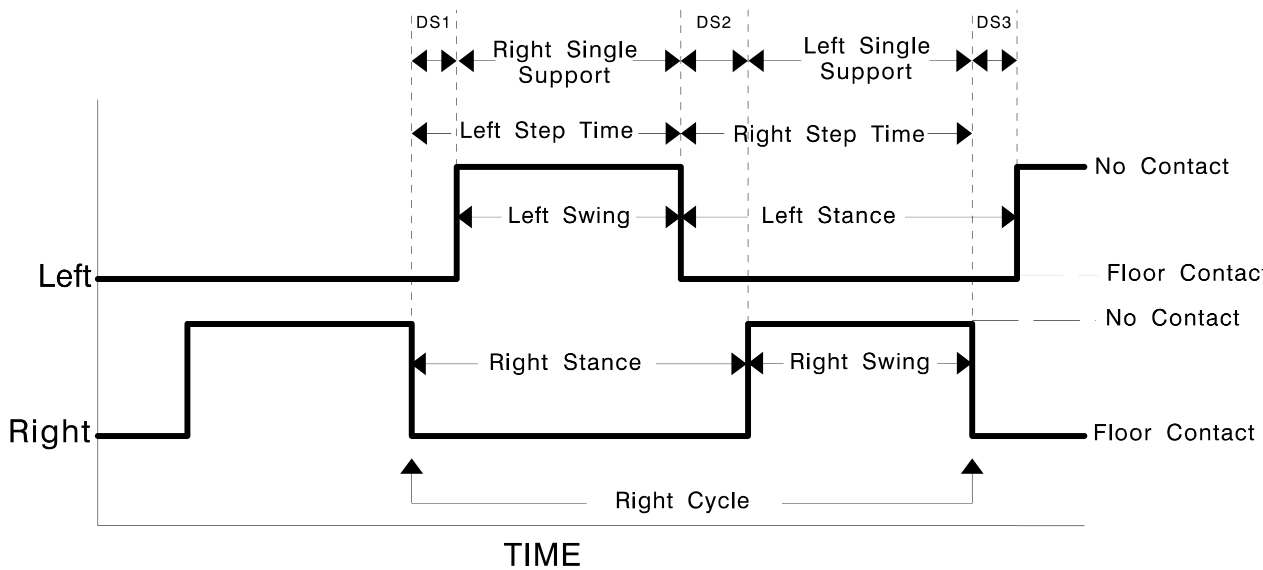

Figure 9

4.1 First Contact
It is the time that the first sensor appears in any quadrilateral. It is expressed in seconds (sec).

4.2 Heel Contact
It is the time that the first sensor appears in the heel quadrilateral of the foot. It is expressed in seconds (sec).

4.3 Last Contact
It is the time that the last sensor goes off in any quadrilateral. It is expressed in seconds (sec).

4.4 Toe Off
It is the time that the last sensor turns off in the forefoot quadrilateral of the foot. It is expressed in seconds (sec).

4.5 Step Time
It is the time elapsed from first contact of one foot to first contact of the opposite foot. It is measured in seconds (sec).

4.6 Stride Time
It is the time elapsed between the first contacts of two consecutive footfalls of the same foot. It is measured in seconds (sec).

4.7 Gait Cycle Time

It is the elapsed time between the first contacts of two consecutive footfalls of the same foot. It is measured in seconds (sec).

4.8 Ambulation Time

It is the time elapsed between first contact of the first and the last footfalls. It is measured in seconds (sec).

4.9 Velocity

It is obtained after dividing the Distance Traveled by the Ambulation time. It is expressed in centimeters per second (cm/sec).

4.10 Mean Normalized Velocity

It is obtained after dividing the Velocity by the Average Leg Length and it is expressed in leg length per second (LL/sec). The average Leg Length is computed (left leg length + right leg length)/2.

4.11 Stride Velocity

It is obtained after dividing the Stride Length by the Stride Time. It is expressed in centimeters per second (cm/sec).

4.12 Single Support and % Single Support

It is the time elapsed between the Last Contact of the current footfall to the First Contact of the next footfall of the same foot. Refer to Figure 9, Single Support time is equal to the **Swing Time** of the opposite foot. It is measured in seconds (sec) and expressed as a percent of the Gait Cycle time of the same foot.

4.13 Initial Double Support and %Initial Double Support

The two periods when both feet are on the floor, are called **initial double support** and **terminal double support**. Initial double support occurs from heel contact of one footfall to toe-off of the opposite footfall. It is measured in seconds (sec) and also expressed as a percent of the Gait Cycle time for the same foot. Refer to Figure 9, DS1 is the Initial Double Support for the right foot, while the DS3 is the Initial Double Support for the left foot.

4.14 Terminal Double Support and %Terminal Double Support

The two periods when both feet are on the floor, are called **initial double support** and **terminal double support**. Terminal double support occurs from opposite footfall heel strike to support footfall toe-off. It is measured in seconds (sec) and also expressed as a percent of the Gait Cycle time for the same foot. Refer to Figure 9, DS2 is the Terminal Double Support for the right foot.

4.15 Total Double Support and %Total Double Support

The two periods when both feet are on the floor, are called **initial double support** and **terminal double support**. Initial double support occurs from heel contact of one footfall to toe-off of the opposite footfall. Terminal double support occurs from opposite footfall heel strike to support footfall toe-off. Total double support is the sum of the initial double support added to the terminal double support. It is measured in seconds (sec) and also expressed as a percent of the Gait Cycle time for the same foot. Refer to Figure 9, the sum (DS1+DS2) is the Total Double Support for the right foot, while the sum (DS2+DS3) is the Total Double Support for the left foot.

4.16 Stance Time and % Stance

The **stance phase** is the weight bearing portion of each gait cycle. It is initiated by heel contact and ends with toe off of the same foot. It is the time elapsed between the First Contact and the Last Contact of two consecutive footfalls on the same foot. It is also presented as a percentage of the Gait Cycle time.

4.17 Contact phase

It begins with heel strike and continues until about 22% of the stance phase. Forefoot loading terminates contact phase.

4.18 Midstance phase or Foot Flat

It begins with the first sign of forefoot loading. The end of midstance is heel-lift of the support limb. This occurs at about 50% of the stance.

4.19 Propulsive phase

This is the final 50% of the stance phase. It begins heel lift until toe off.

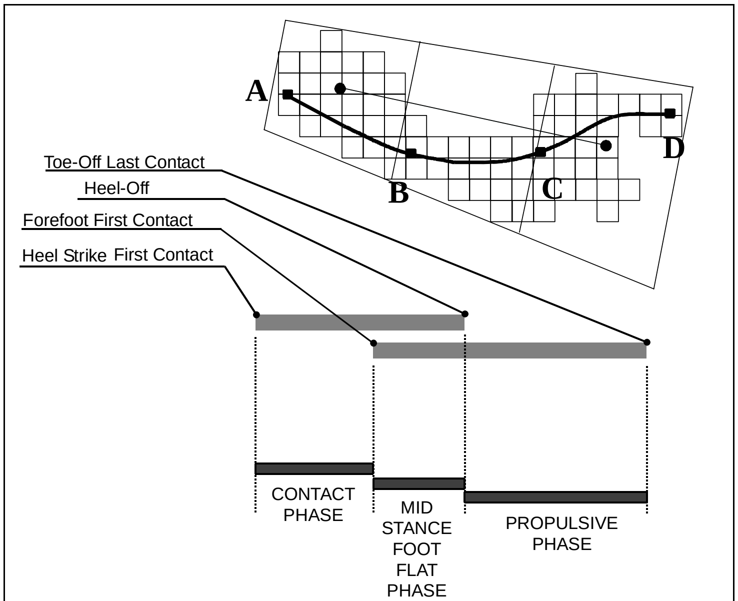

Figure 10

4.20 Swing Time and %Swing

It is initiated with toe off and ends with heel strike. It is the time elapsed between the Last Contact of the current footfall to the First Contact of the next footfall on the same foot. It is expressed in seconds (sec) and it is also presented as a percent of the Gait Cycle of the same foot. The Swing Time is equal to the Single Support time of the opposite foot.

5 SWITHING LEVELS

The GAITRite walkway's unique and patented sensor avoids false peripheral activation. Each sensor has been constructed with two flexible elements riding on a pivot point. When pressure is applied to the sensor both elements must flex around the pivot point to initiate activation, otherwise the pivot point will toggle the sensor in either side without activation. After activation, the sensor begins to change its value linearly with the vertical component of pressure exerted upon it.

The walkway contains thousands of sensors, therefore calibration of each and every sensor is not impossible but cost prohibitive. Pressure values are normalized and expressed as a percent of the maximum pressure and then divided into levels. Currently there are seven switching levels, illustrated in Table 1.

Color	Switching level
Dark Gray	1=lowest
Light Gray	2
Cyan	3
Yellow	4
Magenta	5
Red	6
Blue	7=highest

Table 1. ***Switching Levels, Color Assignment.***

The walkway does not only sense the geometry of the activating footprints but also the relative arrangement between them in a two dimensional plane and the relative vertical component of pressure exerted by each footprint.

The pressure is represented by a switching level. As discussed earlier, the division of the footprint produces us with twelve sections; six sections are located in the medial side of the footprint and six in the lateral. Each section contains a number of activated sensors enclosed within a trapezoid. The GAITRite algorithms utilize the sectional division to identify the activated sensors included within each quadrilateral and then perform calculations to objectively describe the behavior of the section.

As illustrated in Figure 11, medial trapezoid (AHIB) includes the following sensors: 1,2,3,4,6 and 7. Lateral trapezoid (HLMI) includes the sensors: 5,10,11,15 and 16. A sensor can be claimed by only one trapezoid and not shared by others. Sensor 4, has most of its surface area within trapezoid (AHIB) and will be claimed only by this trapezoid. If the surface area of a sensor is equally divided among two or more quadrilaterals, i.e. sensor 12, then the sensor will be claimed by the first trapezoid in the algorithm. The results of the switching parameters are presented in the format illustrated in Table 2.

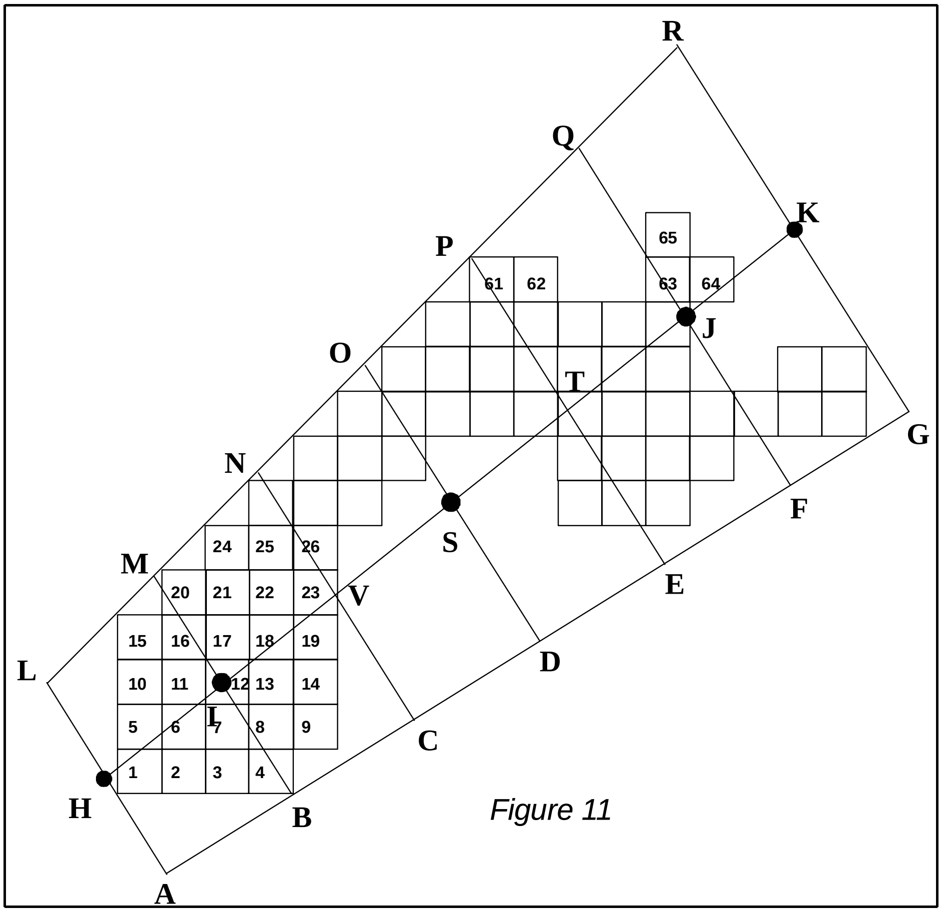

Figure 11

5.1 Switching Level Parameters

1) **P*t** for a section, is the sectional integrated pressure over time expressed as a percent of the overall integrated pressure over time. The overall P*t can be found by summing the P*t of each sensor, sectional P*t can be found by summing the P*t of the sensors included in the particular section also expressed as a percent of the overall P*t. As illustrated in Figure 12, P*t for sensor 1 is the total area under the curve calculated by:

   (P*t)s1=(.020-.010)*1+(.030-.020)*2+ ......+(.070-.060)*6+.........+(.140-.130)*1

2) **Peak Time** for a section is the first time point that one or more sensors within a section was at the maximum switching level. Assume that a section included only the two sensors, illustrated in Figure 12; the peak time is at .060 seconds. Time count begins from first contact of the footprint.

3) **Area** of a section is expressed in centimeters squared (cm^2) and represents the sum of the active sensor areas within a section. Each sensor has an area of .5 in x .5 in or (1.27 cm x 1.27 cm).

4) **Peak P**(ressure**)** for a section, is the maximum sectional switching level expressed as a percent of the overall maximum switching level. Sectional switching level occurs at the peak time of the section. Assume that a section included only the two sensors illustrated in Figure 12, then peak time is at .060 seconds and a peak switching level of 6, then expressed as a percent of the overall maximum switching level.

	<(HLMI)>	**<(IMNV)>**	**<(VNOS)>**	**<(SOPT)>**	**<(TPQJ)>**	**<(JQRK)>**
P*t						
Peak Time						
Area						
Peak P						
	<(AHIB)>	**<(BIVC)>**	**<(CVSD)>**	**<(DSTE)>**	**<(ETJF)>**	**<(FJKG)>**
<P*t>						
<Peak Time>						
<Area>						
<Peak P>						

Table 2. ***Switching Levels by Section.***

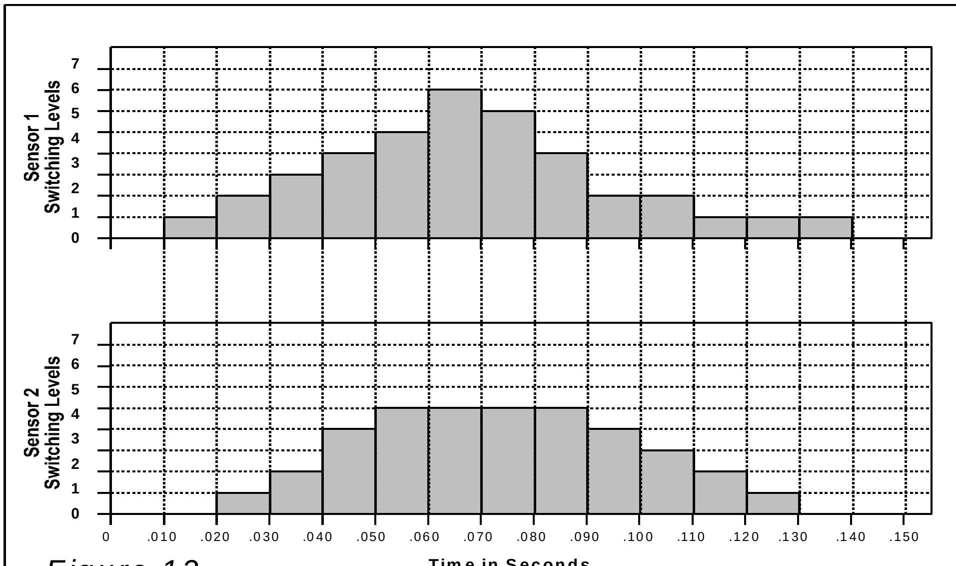

Figure 12