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Design of a Laboratory Independent Posture and Gait Analysis System (POGASYS)

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Abstract: In the first part of our study, a posture and gait analysis system, shortly called POGASYS, is developed to be used in quantifying the gait of the individuals, and tested with healthy individuals to obtain their gait parameters. POGASYS has two main components: The first component is the shoe module having four different types of installed sensors and mounted on the shoes of the individuals, and the second component is the computer module with a user friendly software that is used to obtain the data from the sensors wirelessly and to analyze it. More than fifty gait parameters can be determined by POGASYS to utilize for the quantification of the diseases affecting the individuals' gait patterns. In the second part of our study, the gait parameters will be examined to decide what parameters among all of the parameters can be used to differentiate the hemiplegic patients from the healthy individuals using POGASYS software. In this paper, which is the first part of our study, the designs of POGASYS hardware and software, the processes to determine the principal gait parameters and the results of the tests performed by POGASYS are discussed.

Laboratuardan Bağımsız Bir Duruş ve Yürüyüş Analiz Sisteminin Tasarımı (POGASYS)

Anahtar Kelimeler
Yürüyüş analizi
Giyilebilir algılayıcı sistemi
Denge ve duruş bozuklukları
Kuvvet ve eylemsizlik ölçümleri

Özet: Çalışmamızın ilk kısmında, , yürüyüş parametrelerinin nicelleştirilmesi için kısaca POGASYS adı verilen bir duruş ve yürüyüş analiz sistemi geliştirilmiş ve yürüyüş parametrelerini elde etmek için sağlıklı bireylerle test edilmiştir. POGASYS iki ana bileşenden oluşmaktadır: Birinci bileşen üzerinde dört farklı algılayıcısı olan ve bireylerin ayakkabısında monte edilen ayakkabı modülü, ikinci bileşen ise dört farklı algılayıcıdan alınan verilerin kablosuz bir şekilde aktarıldığı ve analiz edildiği bilgisayarda kurulu kullanıcı dostu arayüz yazılımıdır. Bireylerin yürüyüş örüntüsünü etkileyen hastalıkların nicelleştirilmesinde kullanılmak üzere elliden fazla yürüyüş parametresi POGASYS tarafından elde edilebilmekte ve analiz edilebilmektedir. Çalışmamızın ikinci kısmında, POGASYS yazılımı ile elde edilen bu yürüyüş parametrelerinden hangilerinin hemipleji hastalarının sağlıklı bireylerden ayırd edilmesinde kullanılabileceği araştırılacaktır. Çalışmamızın ilk kısmını veren bu makalede, POGASYS donanımının ve yazılımının tasarımı, esas yürüyüş parametrelerinin belirlenmesi için yapılan işlemler ve POGASYS ile gerçekleştirilen testler tartışılmıştır.

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1. Introduction

Automation has now become the one of the targets in many areas of services in the technologically developing world. Especially, in medical services, many medical devices have been developed not only for the treatment but also for the diagnosis of the diseases. The more practical and cost effective these devices are, the more their widespread use are in clinical environments. Although the human motion test is performed extensively in clinics to assess the neurological diseases, there isn't any widespread use of a practical motion analysis system to assist the clinicians by means of quantitative data for both the diagnosis and prognosis of the diseases.

Gait analysis quantifies the movement of the individuals by means of measurement systems such as video camera based image processing systems, force plates, inertial measurement systems, EEG and the other systems. The parameters that are analyzed in these systems vary depending on the type of the system used. There are commercial video camera systems, treadmills and force plates or mat systems that have been recently used in clinics. By means of these systems, the step or stride length, step speed, gait pattern timing in 2D or 3D, pressure distribution underneath the feet can be measured and utilized to quantify the gait as well as to follow up the improvement in the gait quality as a result of the therapy or rehabilitation of a patient. Most diseases that affect the motor system of individuals result in changes in their gait patterns. Many of the studies in the literature show that use of the correct gait parameters provides information for clinicians to distinguish healthy individuals from the individuals with neurological disorders. Parkinson disease [Mariani (2010, 2013), Klucken (2013), Moore (2007), Bamberg (2008), Tien (2010)] and Vestibular lesions and disorders [Angusri (2011), Labini (2012)] are the most popular diseases studied using gait analysis.

Morris (2004), Sabatini (2005), Moore (2007) Stefanovic ve Caltenco (2009), Huang vd. (2009), Mariani vd. (2010, 2013), Atallah (2012), Liu (2009) and Chelius (2011) are some of the gait analysis system studies accomplished in the past. In these studies, body-worn sensor equipped devices including combination of varying numbers of accelerometers, gyroscopes, force sensors, magnetometers, flexible sensors at different parts of the body are designed and tested.

There are also gait analysis systems that are commercially available, like MINISUN (2000), PHYSILOG (Gait Up, 2012), GAIT-O-GRAM (University of Nebraska), TEKSCEN (2014), E-SHOE and VITALISHOE (CEIT, 2008). However, similar to the systems designed in the abovementioned studies; these commercial systems are not in widespread use in the clinics due to lack of their practicality to the clinicians.

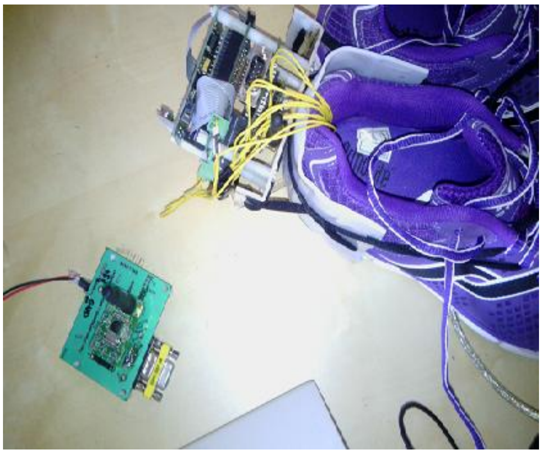
In the conventional diagnosis system of the clinicians, after performing some physical tests to the patients, they comment on the diseases, if exist, according to the patients' physical responses. These comments depend on the clinicians' experience in which subjective grading is more likely to occur compared to a computer assisted gait analysis system. Besides, in order to track the improvement in the patient's situation who is under treatmeant, a gait analysis system including a user-friendly analysis software will be more reliable by comparing the quantitative data obtained before and after the treatment,

In this study, a practical, cost-effective and laboratory independent gait analysis system, shortly called POGASYS, is designed and its test results with healthy individuals are reported.

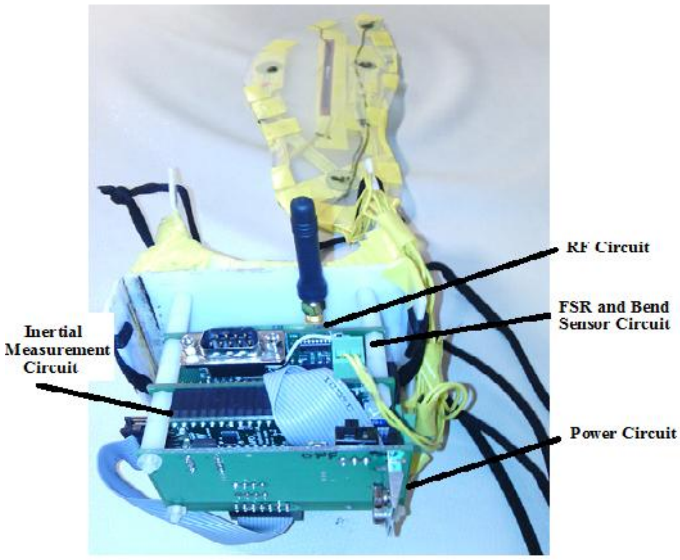
2. Materials and Methods

The posture and gait analysis system, POGASYS, consists of a hardware to gain the gait data, and a software that collects and analyzes the gait parameters and make the classification for the diseases automatically. POGASYS hardware also consists of two main components. The first main component is the shoe module that includes the accelerometer, gyroscope, microcontroller, RF transmitter, voltage supplier at the back of the shoe and with the force and bend sensor placed in the shoe insole underneath the foot. The second main component of the POGASYS hardware, is the RF receiver connected to the computer to get the data and its voltage supplier circuit. POGASYS shoe module is designed to be easily mounted on the users' shoes. In order to be able to measure the bending of the foot as accurate as possible, flexible sole sport shoes are preferred in the tests of our study (Figure 1a).

Adjustment of the orientation of the shoe module is not necessary since its orientation with respect to the shoe is determined by the POGASYS software automatically during the gait analysis. The POGASYS shoe module consists of four PCBs (printed circuit board) connected to 2 mm Plexiglas by plastic connection elements. The module is mounted at the back of the shoe with a plexiglas adapter formed in a semicircular form in order to be seated at the back of shoe by means of filling material to avoid the relative motion of the shoe module with respect to the foot.



(a)



(b)

Figure 1. (a) Shoe module and receiver of POGASYS (b) Parts of the shoe module, and location points of FSR (force sensitive resistor) and bending sensor

The insole is designed as a sandwich model, outer layer of which is made up of PVC (polyvinyl chloride), in between four force sensitive resistors (FSRs) and bending sensor are placed by insulated tapes avoiding slipping (Figure 1b). Although in the FSR catalog (Interlink Electronics, 2014), it is recommended to use these sensors with double sided tape, in the tests, during mounting and demounting processes, it is observed that the double sided tape deforms the sensors, so insulated tape is used for mounting. The sensors equipped insole is placed under the shoes' own insole, in such a way that any elevation difference or any deformation in the shoe is avoided. Due to the thinness of the PVC, it is aimed to prevent the individual from feeling a discrepancy within the shoe and change her/his usual gait pattern. The points of the foot to place the FSRs' are marked on the PVC for every individual that participate in the tests. During the gait tests, all the FSRs are used at the same places for all of the individuals, by adjusting their locations according to their marked points under toe, heel, first and fifth metatarsals.

Table 1. Sensors used in POGASYS, their location points, and gait parameters calculated

Sensors	Location points	Gait parameters calculated
3-d accelerometer (1pc) *(STM LIS3L02AS4, Analog, ±2g/±6g)*	Back of the shoe, on the main circuit	- 3-d acceleration and velocity of the foot - Step velocity and step length - Lateral and superior displacement of the foot
3-d gyroscope (1 pc) *(STM L3G4200D, Digital, ±250dps, ±500dps ve ±2000dps)*	Back of the shoe, on the main circuit	- Roll, yaw and pitch angles - Gait timing, stance and swing interval
Force sensitive resistors (4 pcs) *(Interlink Electronics, FSR 402, Diameter 18,28 mm.)*	Under the insole of the shoe 1. Under the toe 2. Under I. metatarsal 3. Under V. metatarsal 4. Under the heel	- The force distribution underneath the foot - Balance and lateral deviation of foot analysis
Bend Sensor (1pc) *(Spectra Symbol Flex Sensor – 4.5")*	Under the insole of the shoe on the medial plane of the foot	- The dorsal-flexion angle of the foot

The sensor features, their placement points and the principal gait parameters that can be calculated from the data obtained from the sensors are given in Table 1.

The forces under the first metatarsal and the fifth metatarsal is divided by the individuals' weight are analyzed and the ratio of the individuals loading on the inside and outside the foot is automatically interpreted by the POGASYS software.

The data obtained by the shoe module is transferred to the computer through the RF transceiver via RS232 serial port. The data transmitted to the computer is first checked for integrity and then identified and disaggregated to select the data of each sensor for every measurement. These processes are achieved by a user-interface software designed in Labview (National Instruments, 2009). During the gait tests, start of the POGASYS hardware and the communication between the shoe module and the computer is provided by means of this user-interface software. The raw data is saved to a text file during the gait tests in a predetermined sensor order by Labview interface (Figure 2).

No. Test Tarih/Zaman
10.07.2014 14:50

Rec No.	ACC_X	ACC_Y	ACC_Z	FSR1	FSR2	FSR3	FSR4	BEND1	BEND2	GYRO_X	GYRO_Y	GYRO_Z	ZAMAN
50	1344	2499	2045	9	9	9	62	41	3087	4020	805	1374	1,05
51	1456	2625	2027	9	9	9	63	41	3084	2612	4530	1321	1,071
52	1594	2640	1967	9	9	10	63	40	3071	1279	7641	953	1,092
53	1704	2584	1947	9	9	9	62	39	3080	1027	10077	2050	1,113
54	1782	2534	1950	8	10	7	63	39	3097	1413	10824	2526	1,134
55	1895	2629	1943	9	7	9	63	39	3081	510	10454	1510	1,155
56	1973	2547	1928	10	9	10	61	36	3071	207	9199	64651	1,176
57	2066	2463	1956	9	9	9	62	39	3089	160	7780	65196	1,197
58	1977	2581	2003	9	10	9	62	41	3096	63157	5561	65260	1,218
59	1987	2711	2027	9	9	9	62	41	3081	61269	4487	32	1,239
60	2027	2688	2037	9	7	9	62	41	3086	61724	4165	1593	1,26
61	2083	2630	2062	9	9	9	62	42	3083	63984	3370	2036	1,281
62	2115	2709	2058	9	9	9	62	41	3096	64427	2110	1526	1,302
63	2483	2970	1648	10	9	9	60	31	3055	156	158	2072	1,323
64	2727	1535	2110	200	11	9	62	43	3083	4970	63273	3539	1,344
65	1776	3294	2073	506	15	9	62	42	3078	57433	383	879	1,365
66	1628	2436	2118	585	15	9	62	43	3072	58915	62251	1919	1,386
67	1712	2608	2086	617	17	9	62	42	3106	63269	62586	521	1,407

Figure 2. The raw data text file obtained using POGASYS

In order to analyze the raw data and to determine the gait parameters, POGASYS software is developed in Visual Basic 2010 Express (2010) platform. The POGASYS software does not only allow determining the gait parameters step by step with the graphical representations, but also provide the facility to be used by a clinician to gain the direct classification results and the gait parameters.

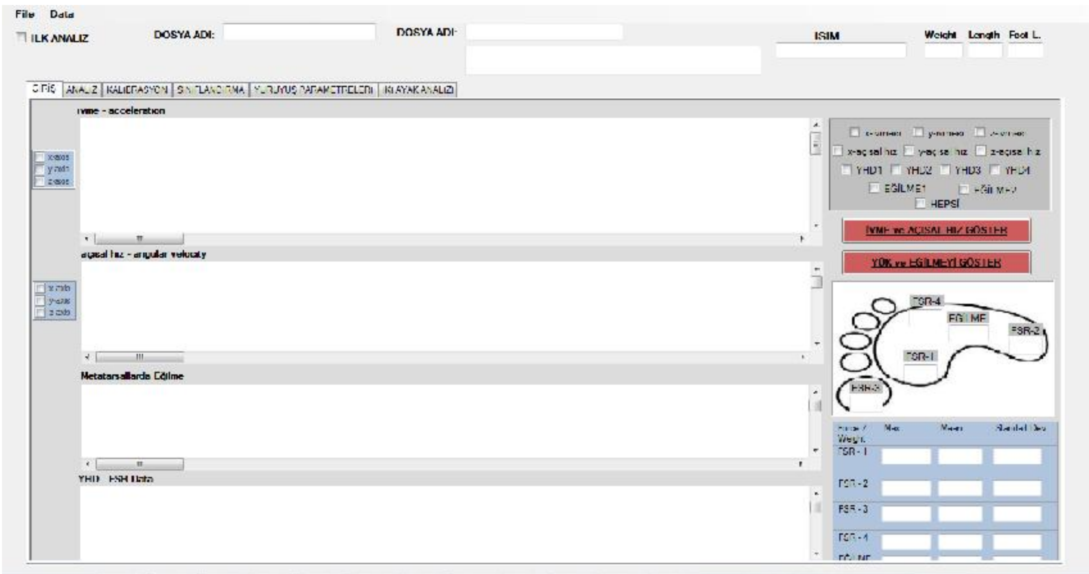


Figure 3. The “Introduction” page of the POGASYS software

The POGASYS software’s “Introduction” page provides the user to open the raw data text file and visualize the raw sensor data in graphical form. Also, in this page, the maximum, minimum, mean values and standard deviations of force distribution at the four points under the foot divided by the weight of individual and the maximum bending angle of the foot is given by POGASYS (Figure 3).

The “Analysis” page of POGASYS allow the user to step-by-step calculate the angular velocity, pitch, yaw and roll angles with linear acceleration, velocity and displacement values with their minimum, maximum, mean and standard deviation values and visualize these parameters for whole gait test in graphical forms (Figure 4).

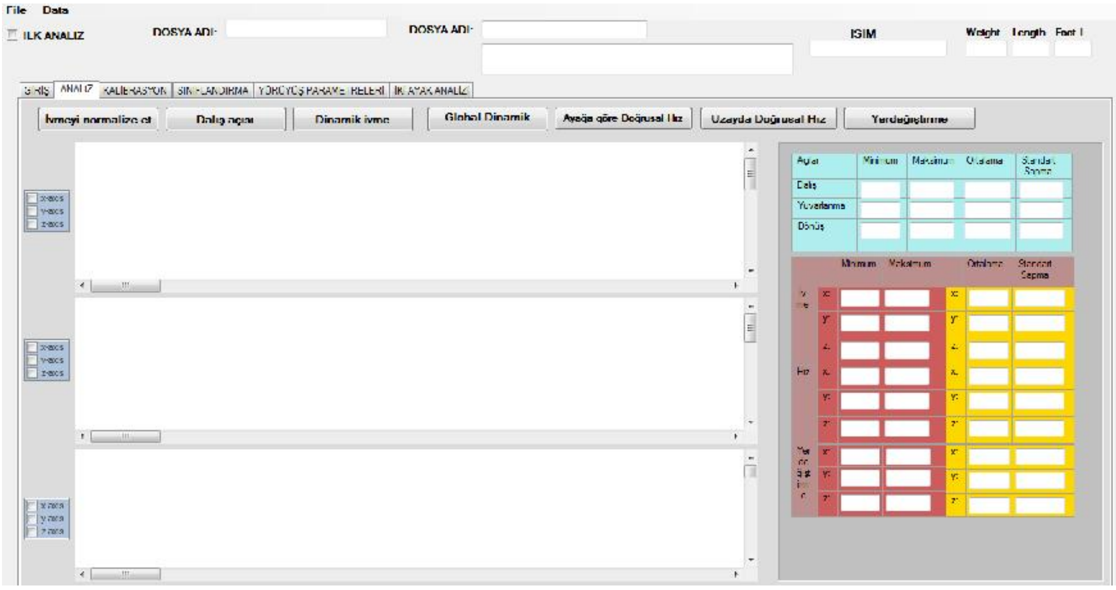


Figure 4. The “Analysis” page of POGASYS

In the “Double Foot Analysis” page, the above mentioned parameters are also calculated for both feet of the individual at the same time (Figure 5). In the “Gait Parameters” page of POGASYS, the minimum, maximum, mean and the standard deviation values of the step length, step velocity, stance and swing timing are calculated by the software automatically (Figure 6).

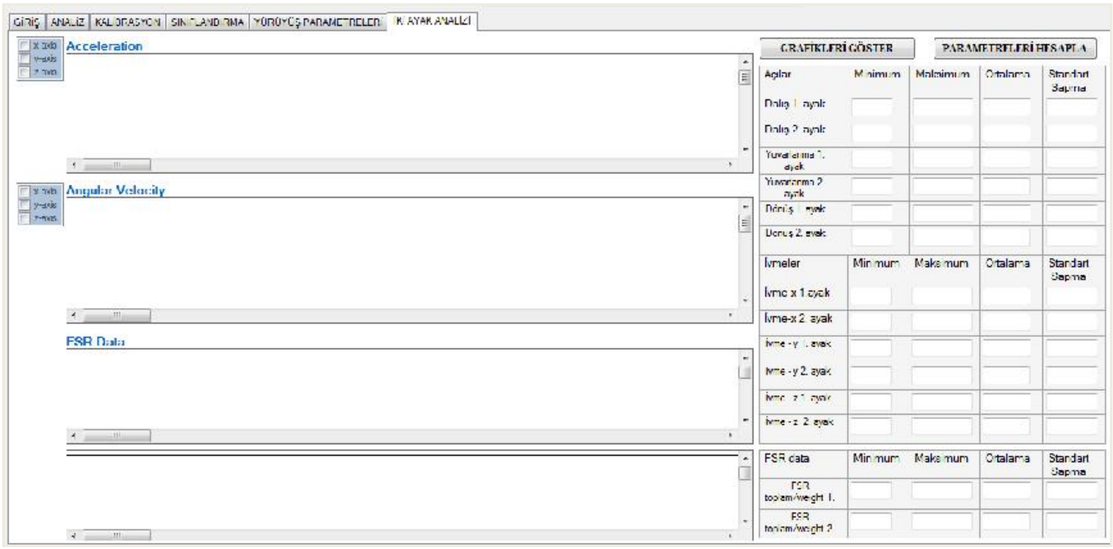


Figure 5. The “Double Foot Analysis” page of POGASYS

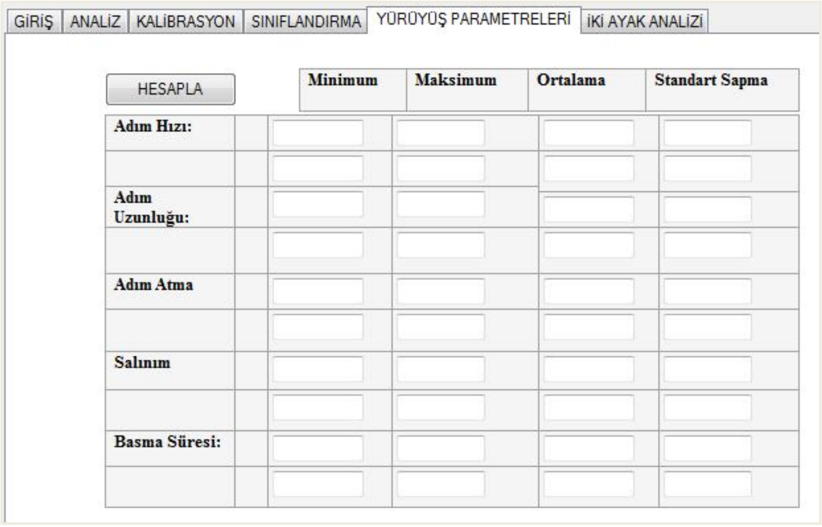


Figure 6. The "Gait Parameters" page of POGASYS

3. Results

By integrating the angular velocity data obtained from POGASYS, pitch, yaw and roll angles of the foot are calculated. The integration limits for the calculation of pitch angle are determined at each step as the instant at which the foot is fully touches the ground. The pitch angle is reset to zero at these points. There are several ways of determining the instant the foot fully touches the ground:

1. The point at which the values of FSR sensors are near to their maximum values.
2. The zero bending angle of the foot determined by the bending sensor underneath the foot.
3. The point at which the y-acceleration of the foot is zero.
4. The point where the derivative of the x-angular velocity and x-angular velocity itself are close to zero.

The first option cannot be utilized for the gait data that belongs to the individuals who walk by only pressing on their toe or by only pressing on their heel. Although, in this study, any individual with such a gait characteristic is not tested; in individuals with Parkinson's disease etc., these kinds of walking patterns are encountered. Since the bending sensor data has shown no significant change during the tests of the groups included in this study, the second option related to the bending of the foot is not used.

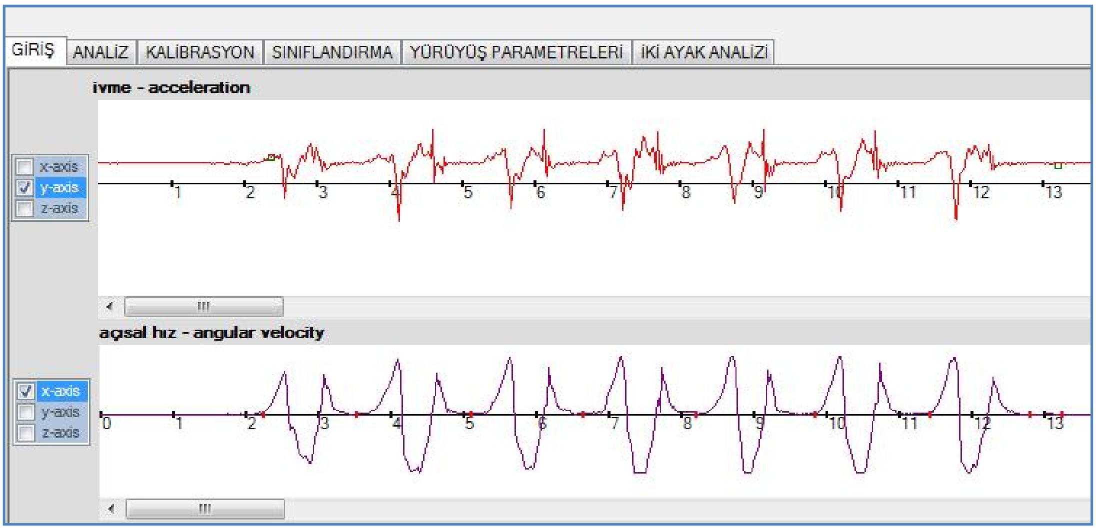


Figure 7. Instantaneous zero velocity points for each step (red points)

Although the y-acceleration data is used to determine the beginning and the end of walking activity, because of the noise in the data set observed at the instants when the heel touches ground, the third option is not used in determining the instantaneous zero velocity points. In order to meet the instantaneous zero velocity points, the fourth option related to the x-angular velocity and its derivative are employed. The algorithm is stated as: "In the gait data, the four points of x-angular velocity experiencing a value under 5% of its maximum value and fewer than 3% of its maximum increase value are the instantaneous zero velocity points. Within these points the instantaneous zero velocity point for that mere step is chosen as the one in the middle of these points." In Figure 7, the zero velocity points of a healthy volunteer found by POGASYS software is marked by the software itself with red points. By integrating the x-angular velocity between these zero velocity points, the pitch angle of the foot is obtained (Figure 8).

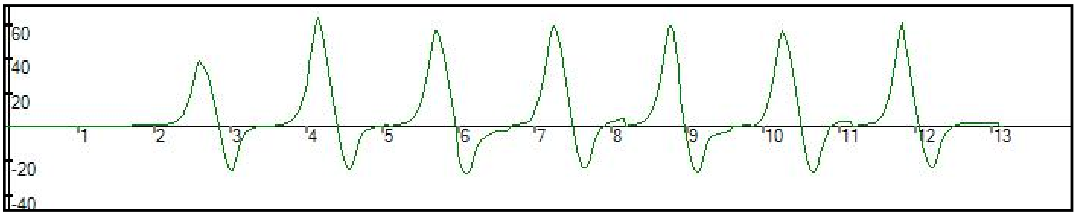


Figure 8. Pitch angle from the POGASYS software

The results of the four gait tests, performed for the same foot of the individual, are analyzed, and the minimum, maximum, mean and standard deviation values of the pitch angle data calculated with POGASYS are compared in Table 2. When the mean and standard deviation values of these minimum, maximum, mean and standard deviation values are calculated, it is found that standard deviations of the column values for the maximum, mean and standart deviation are less than 10% of their mean value correspondences. However the standard deviation of the column value for the minimum is 17 % of the mean value of that column.

Table 2. The pitch angle results of the gait tests performed for the same foot of the individual

Pitch angle	**Minimum**	**Maximum**	**Mean**	**Standard deviation**
Test 1	-26.37	56.68	4.55	16.99
Test 2	-34.87	61.83	4.89	18.42
Test 3	-38.10	57.04	5.45	18.40
Test 4	-27.94	63.96	5.49	18.98
Mean of column values	**-31.82**	**59.88**	**5.09**	**18.20**
Standard deviation (SS) of column values	**5.58**	**3.59**	**0.46**	**0.85**
(SS / Mean) *100	-17.54	6.00	8.96	4.66

3.1. Modelling

By means of accelerometer, the resultant vector of static (gravitational acceleration) and the dynamic acceleration is measured. Before transforming the acceleration values in the shoe coordinate system to the room coordinate system and integrating them to obtain the velocity and displacement values, the static component of acceleration should be left out. In order to perform this operation, the component of gravitational acceleration on the axis of interest is calculated while the inertial reference frame is stationary. The division of the acceleration components to the gravitational acceleration gives the sinus of the angle between the gravitational axis (vertical axis) and the axis of the shoe reference frame (Equation 1).

$$\sin\mu_{x,y,z} = \frac{a_{x,y,z}}{g} \quad (1)$$

$a_{x,y,z}$: The acceleration values on x-, y-, z- axes measured within the shoe reference frame;

g : The gravitational acceleration;

$\mu_{x,y,z}$: The angle between the vertical axis of the room and the axes of the acceleration (x-, y- and z-axis).

Since the orientation of the POGASYS shoe module with respect to the foot is assumed to be stationary, with the motion of the foot, the orientation of the shoe module within the vertical axis of the room changes continuously. The y- and z- axis of the foot reference frame changes by the pitch angle about the x-axis (the axis normal to the medial plane of the foot). Hence, the dynamic acceleration in y- and z-axes can be found by means of the Equation 2:

$$a^{dyn}_{y,z}(t_i) = a_{y,z}(t_i) - g * \sin(\beta_x(t_i) + \mu_{y,z}) \quad (2)$$

$a^{dyn}_{y,z}$: The y-axis and z-axis dynamic acceleration,

$a_{y,z}$: The total acceleration (dynamic and static acceleration) in y- and z-axes.

$_{x}$: The pitch angle of the foot (rotation of the foot about the x-axis),

«$_{y,z}$: The orientation of accelerometer with respect to the x-axis at the beginning of the motion.

Similarly, the x-axis component of the acceleration in the shoe reference frame also includes a static acceleration component due to the rotation of the foot about the z-axis. The x-axis dynamic acceleration in the shoe reference frame can be obtained by Equation 3.

$$a^{dyn}_{x}(t_i) = a_x(t_i) - g * \sin(\beta_z(t_i) + \mu_x) \qquad (3)$$

a^{dyn}_{x} : The x-axis dynamic acceleration in the shoe reference frame,

a_x : The total acceleration in the shoe reference frame,

β_z : The angular displacement of the foot about the z-axis of the shoe reference frame,

«$_{x}$: The orientation of the accelerometer with respect to the x-axis of the shoe frame at the beginning of the motion.

In Figure 9, graphics of the total acceleration components (the sum of the static and dynamic accelerations) measured by the accelerometer in three axes and the dynamic components of these 3-b acceleration values in shoe reference frame are shown. The data is obtained from a healthy individual during the free gait test, analyzed and graphically represented by POGASYS.

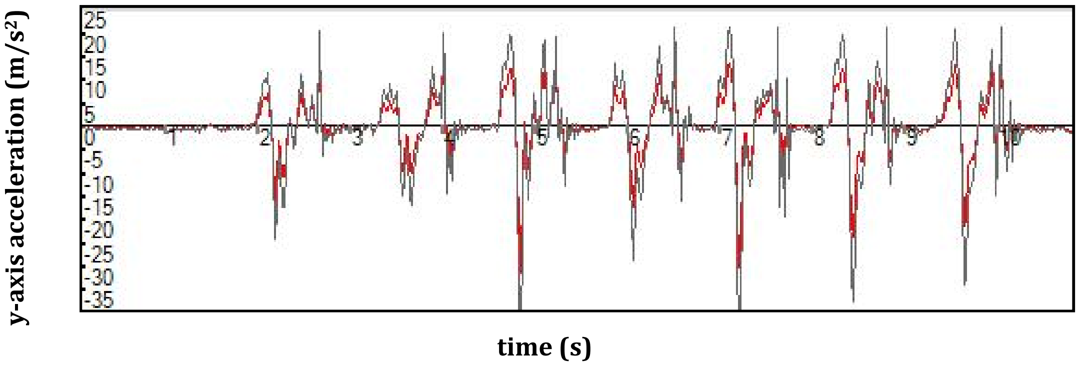


Figure 9. y-axis (vertical axis) total acceleration (gray), y-axis dynamic acceleration (red)

The minimum, maximum, mean and standard deviation values for the dynamic acceleration obtained of the same individual from the gait tests performed four times are given in Table 3.

Table 3. y- axis dynamic acceleration in the shoe reference frame for the same individual

y- axis dynamic acceleration(m/s^2)	Minimum	Maximum	Mean	St. Deviation
Test 1	-15.86	31.78	0.03	5.42
Test 2	-16.64	29.62	0.13	5.09
Test 3	-18.17	31.37	0.02	5.16
Test4	-15.76	31.40	-0.20	6.52
Mean of the values in the columns	**-16.61**	**31.04**	**-0.01**	**5.55**
Standard deviation of the values in the columns	**1.11**	**0.97**		**0.66**

The minimum and maximum values of the dynamic acceleration in the vertical axis are -16.61 m/s^2 and 31.04 m/s^2, respectively, while the mean value is near to zero and the standard deviation is about 5.55 m/s^2. The standard deviation of these test values is about 1 m/s^2. As it can be understood from the values, the dynamic acceleration values obtained from the different tests for the same individual do not show any significant difference.

The forward dynamic acceleration values for the same tests are given in Table 4. Means of the minimum and maximum values for these tests are -19.89 m/s^2 ve 22.59 m/s^2. The standard deviation value for the minimum acceleration draws attention while the change for the other values doesn't show much difference.

Table 4. z- axis dynamic acceleration in the shoe reference frame for the same individual

	Minimum	Maximum	Mean	St. Deviation
Test 1	-21.81	22.95	-5.72	3.32
Test 2	-15.96	24.34	-4.95	3.21
Test 3	-22.17	22.07	-5.15	3.11
Test4	-19.62	21.01	-5.28	3.88
Mean of the values in the columns	**-19.89**	**22.59**	**-5.28**	**3.38**
Standard deviation of the values in the columns	**2.85**	**1.41**	**0.33**	**0.34**

In order to determine the acceleration, velocity and displacement of the foot with respect to the room coordinate system, coordinate transformation from the shoe reference frame to the room coordinate system is needed. When the modelling used by Morris (2004) is applied, the dynamic acceleration components in the room coordinate system are calculated as a function of the dynamic acceleration components in the shoe coordinate system (Equations 4, 5, and 6).

$$a_x^{room} = \frac{a_y^{shoe}.\cos(\mu_x+\beta_z) - a_x^{shoe}.\cos(\mu_y+\beta_z)}{(\cos(\mu_x+\beta_z).\sin(\mu_y+\beta_z) - \cos(\mu_y+\beta_z).\sin(\mu_x+\beta_z))} \quad (4)$$

$$a_y^{room} = \frac{a_y^{shoe}.\cos(\mu_z+\beta_x) - a_z^{shoe}.\cos(\mu_y+\beta_x)}{(\cos(\mu_y+\beta_x).\sin(\mu_z+\beta_x) - \cos(\mu_z+\beta_x).\sin(\mu_y+\beta_x))} \quad (5)$$

$$a_z^{room} = \frac{a_y^{shoe}.\sin(\mu_z+\beta_x) - a_z^{shoe}.\sin(\mu_y+\beta_x)}{(\cos(\mu_z+\beta_x).\sin(\mu_y+\beta_x) - \cos(\mu_y+\beta_x).\sin(\mu_z+\beta_x))} \quad (6)$$

3.2 Velocity and Displacement of the Foot

The first integration of the dynamic acceleration gives the velocity of the foot while the second integration gives the displacement of the foot in the room coordinate system. At the instances which the foot base fully touches the ground, the velocity of the foot is accepted as zero. The POGASYS software determines these points as the ones at which the change in the pitch angle is fewer than %3 of the maximum change of pitch angle and at these points the velocity of the foot at three axes are estimated as zero. The forward acceleration, velocity and displacement graphs of POGASYS for a free gait test are shown In Figure 10.

By means of the forward velocity and displacement values, step speed and step length can be determined. Step length is estimated as the distance traveled by the same foot, between the instances of zero velocity points. During the tests, it is observed that, the first step and the last step for the gait tests show different gait patterns when compared to the intermediate steps. These differences occur at the first step due to the focusing of the individual to the POGASYS shoe module, and at the last step due to the hesitation of the individual due to his/her slowing down while approaching the destination point. Therefore, the first and last steps are not taken into consideration in the calculation of the step length, step speed and step timing parameters. Walking range is determined by utilizing the acceleration data in the y-axis by POGASYS software. The software determines the gait starting point as the instance at which the value of the y-axis acceleration exceeds %10 of the mean of the y-axis acceleration values within the second second (the data in the first second is not taken into account to allow the system to stabilize itself). Likewise, the end of the gait is regarded by the software as the first whole second in which the y-acceleration data is below the %10 more of the same mean value at the start. After the software sets the gait period, within this range, the zero velocity points are determined again by the software using the algorithm defined previously, and finally step length, step velocity and step timing are calculated.

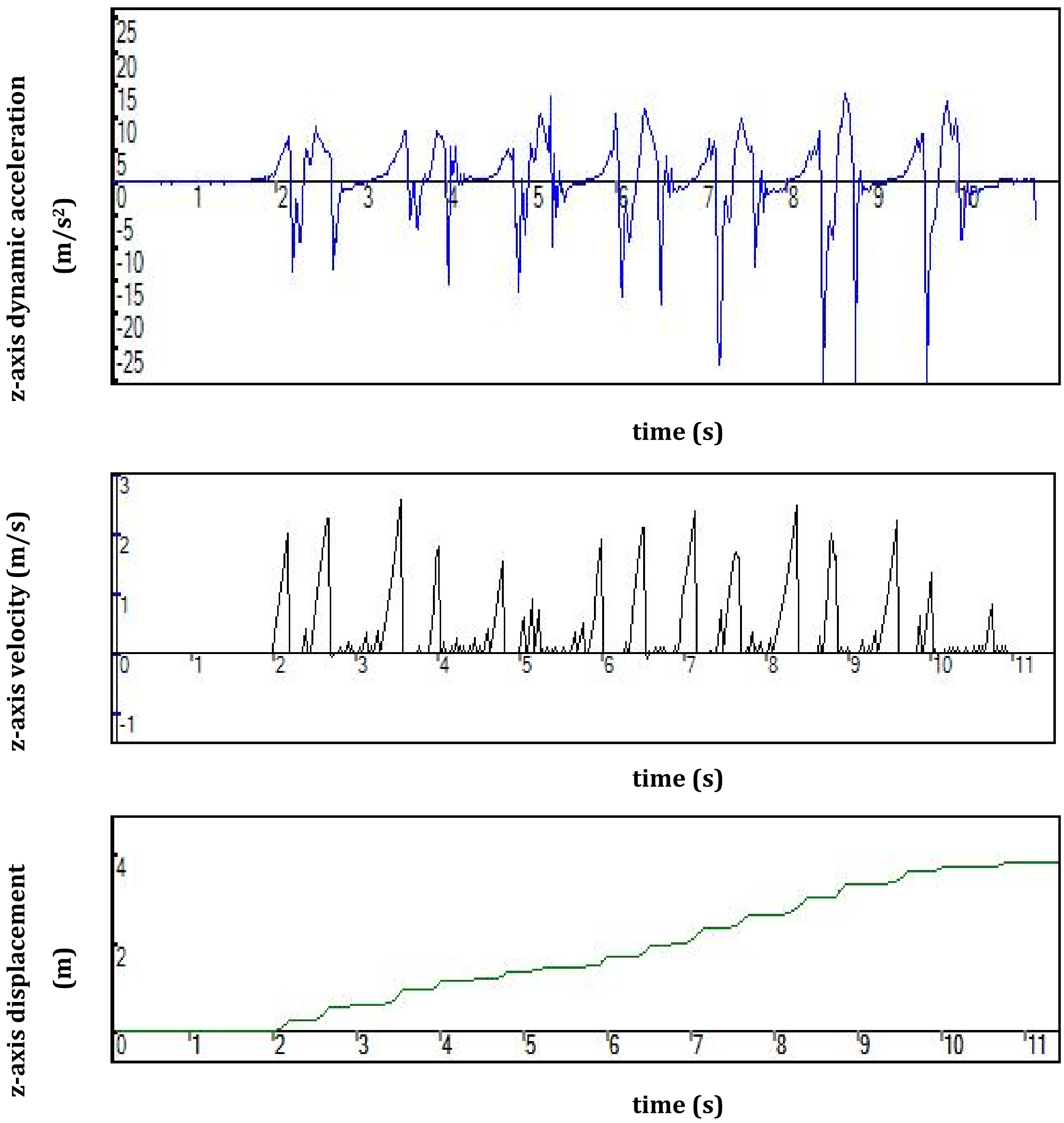


Figure 10. Forward acceleration, velocity and displacement graphs

Although step length, step velocity and step timing can change from one individual to the other, by age or gender, the ratios of these values of one foot to the other foot are calculated and used in the gait analysis system. The y-axis acceleration, velocity and displacement graphs obtained by the POGASYS software from the gait tests performed for a healthy individual are shown in Figure 11.

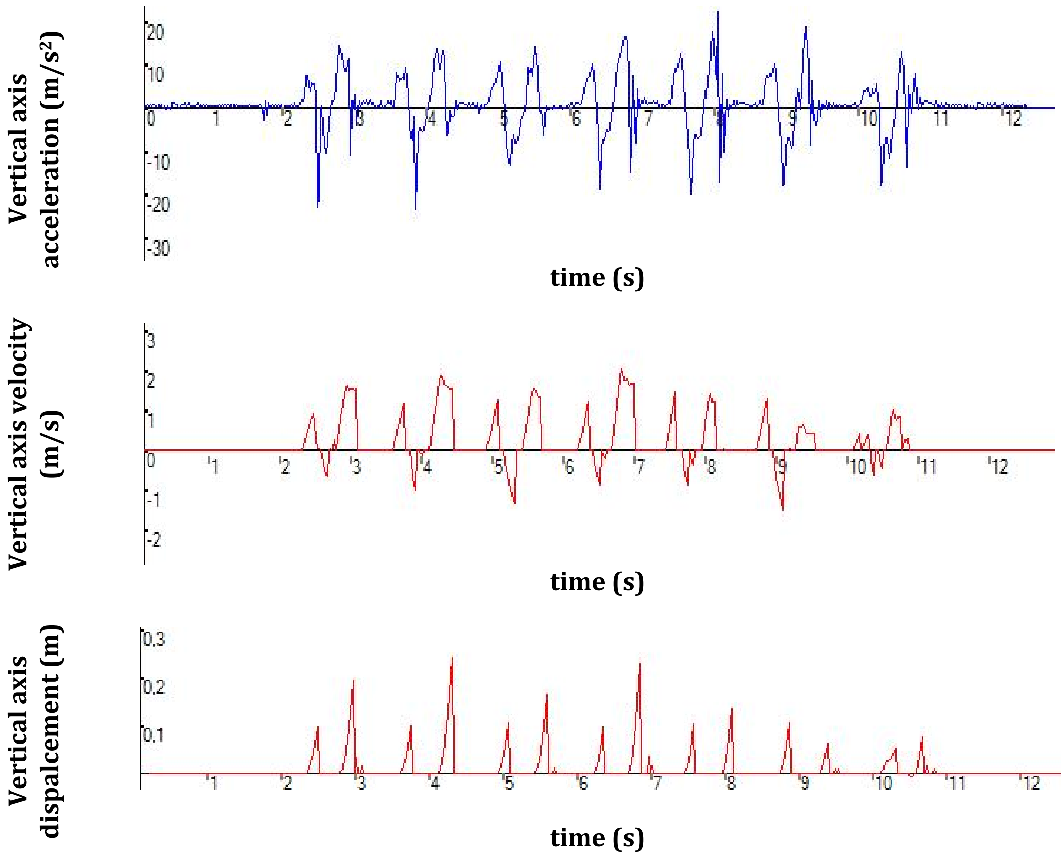


Figure 11. Vertical axis acceleration, velocity and displacement graphs

In Tables 5 and 6, the velocity and displacement values obtained from the repeated gait tests of the same individual are given. As it can be seen from the data given in these tables, the standard deviation of the minimum, maximum and mean values doesn't exceed 21 cm/s for the velocity and 5 cm for the displacement.

Table 5. y-axis velocity data for the same healthy individual

y-axis velocity (m/s)	**Minimum**	**Maximum**	**Mean**	**St. Deviation**
Test 1	-1.68	2.42	0.17	0.58
Test 2	-1.49	2.05	0.17	0.51
Test 3	-1.63	2.29	0.23	0.61
Test 4	-1.98	2.14	0.12	0.67
Mean of the data in the columns	**-1.69**	**2.22**	**0.17**	**0.59**
Standard deviation of the data in the columns	**0.21**	**0.16**	**0.05**	**0.06**

Table 6. y-axis displacement data for the same healthy individual

y-axis velocity (m)	**Minimum**	**Maximum**	**Mean**	**St. Deviation**
Test 1	0.00	0.22	0.01	0.03
Test 2	0.00	0.24	0.01	0.03
Test 3	0.03	0.19	0.01	0.02
Test 4	-0.02	0.30	0.02	0.05
Mean of the data in columns	**0.00**	**0.24**	**0.01**	**0.03**
Standard deviation of the data in columns	**0.02**	**0.05**	**0.00**	**0.01**

During the gait, the displacement of the foot in the axis normal to the medial plane of the foot (x-axis) is also equated to zero at the zero velocity instants. Thus, at each step, the distance from the center plane of the foot is measured. The minimum, maximum, mean and standard deviation values of the velocity and displacement in the lateral axis are shown in Tables 7 and 8, respectively.

Table 7. x-axis (lateral axis) velocity data for the same healthy individual

Lateral axis velocity (m/s)	**Minimum**	**Maximum**	**Mean**	**Standard Deviation**
Test 1	-1.58	1.73	0.06	0.63
Test 2	-1.57	2.26	0.06	0.52
Test 3	-1.84	2.70	0.18	0.68
Test 4	-1.55	1.63	0.14	0.44
Mean of the data in the columns	**-1.63**	**2.08**	**0.11**	**0.57**
Standard deviation of the data in the columns	**0.14**	**0.50**	**0.06**	**0.11**

Table 8. x-axis (lateral axis) displacement data for the same healthy individual

Lateral displacement (m)	**Minimum**	**Maximum**	**Mean**	**St. Deviation**
Test 1	-0.09	0.16	0.00	0.03
Test 2	-0.11	0.29	0.01	0.03
Test 3	-0.21	0.30	0.01	0.04
Test 4	-0.03	0.11	0.00	0.01
Mean of the data in the columns	**-0.11**	**0.21**	**0.00**	**0.03**
Standard deviation of the data in the columns	**0.07**	**0.10**	**0.00**	**0.01**

4. Conclusion

In the first part of our study, a gait analysis system, named POGASYS, is designed and tested with healthy individuals. The POGASYS includes a practical and cost effective shoe module which is used to obtain gait data using variou kinds of sensors, and a software which is used by researchers and clinicians to analyze gait data automatically. More than fifty gait parameters can be calculated using the POGASYS software, and some of them can also be visualized in graphical forms in the software. The test results are given to determine the gait parameters of the healthy individuals by the POGASYS. It is shown that the values obtained by the software are in the expected ranges for healthy individuals, and the results are verified by repeating the tests four times for the same individuals. In the second part of our study, the classification algorithm to distinguish the hemiplegic patients from the healthy individuals will be included in the POGASYS software.

The cost of the POGASYS hardware is about 500 $ for one shoe module, and when compared to the other force mats or video camera systems, it can be easily said that it is a very cost-effective system. The use of POGASYS by the researchers and clinicians can increase in the near future due to its laboratory independent features and its user-friendly software interface.

In the future studies, the POGASYS software can be improved for the classification of other "gait affecting diseases" such as Parkinson and Cerebral Palsy. Secondly, the POGASYS shoe module can be improved with a more compact circuit design, so that it can be used to quantify the gait pattern of the children for Cerebral Palsy or other diseases. Moreover, by editing the RF communication protocol of the shoe module, data from both feet can be obtained using two shoe modules simultaneously.

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