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Cox et al.

(10) **Patent No.: US 7,736,273 B2**
(45) **Date of Patent: Jun. 15, 2010**

(54) **ELECTRICAL SIGNAL ANALYSIS TO ASSESS THE PHYSICAL CONDITION OF A HUMAN OR ANIMAL**

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(73) Assignee: **UT-Battelle, LLC**, Oak Ridge, TN (US)

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(21) Appl. No.: **12/401,139**

(22) Filed: **Mar. 10, 2009**

(65) **Prior Publication Data**

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(51) **Int. Cl.**
A63B 71/00 (2006.01)
A61B 5/22 (2006.01)
A61B 5/103 (2006.01)

(52) **U.S. Cl.** **482/8**; 73/379.04; 73/865.4; 600/587; 600/592

(58) **Field of Classification Search** 482/1–9, 482/54; 72/862.68, 865.4; 73/865.4, 862.68, 73/116, 862.193, 379.04; 600/595, 587; 702/160; 324/71.1, 76.11, 76.13; 235/105
See application file for complete search history.

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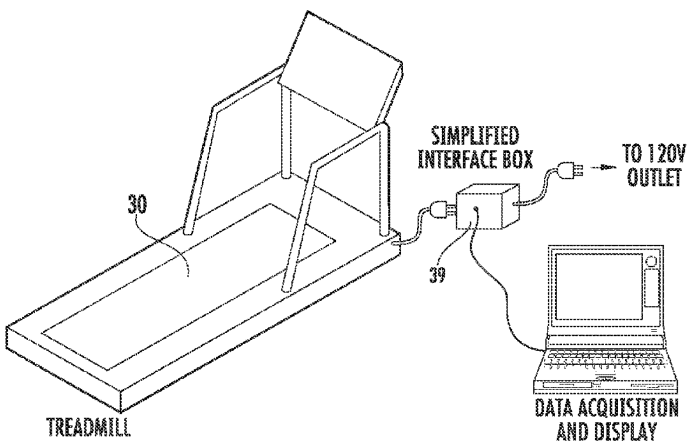
(57) **ABSTRACT**

The invention is a human and animal performance data acquisition, analysis, and diagnostic system for fitness and therapy devices having an interface box removably disposed on incoming power wiring to a fitness and therapy device, at least one current transducer removably disposed on said interface box for sensing current signals to said fitness and therapy device, and a means for analyzing, displaying, and reporting said current signals to determine human and animal performance on said device using measurable parameters.

25 Claims, 13 Drawing Sheets



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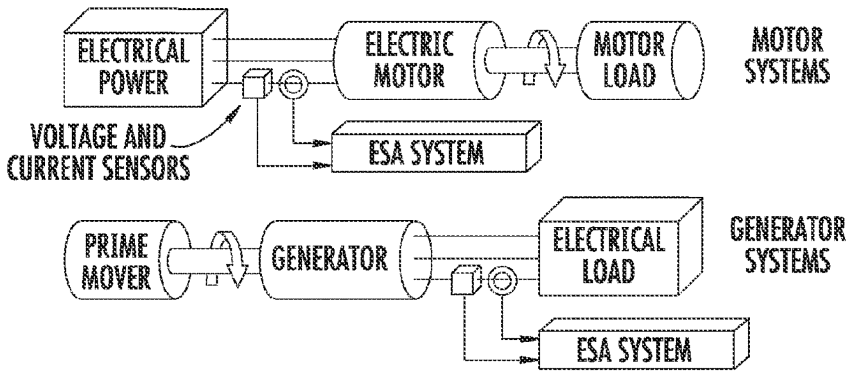
ELECTRICAL POWER
ELECTRIC MOTOR
MOTOR LOAD
MOTOR SYSTEMS
VOLTAGE AND CURRENT SENSORS
ESA SYSTEM
PRIME MOVER
GENERATOR
ELECTRICAL LOAD
GENERATOR SYSTEMS
ESA SYSTEM

FIG. 1

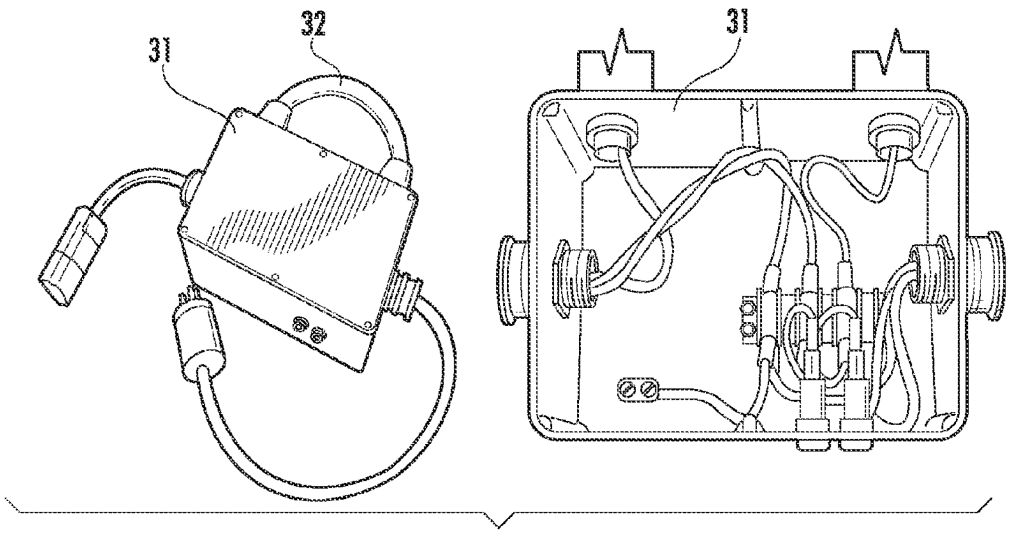
31
32
31

FIG. 2

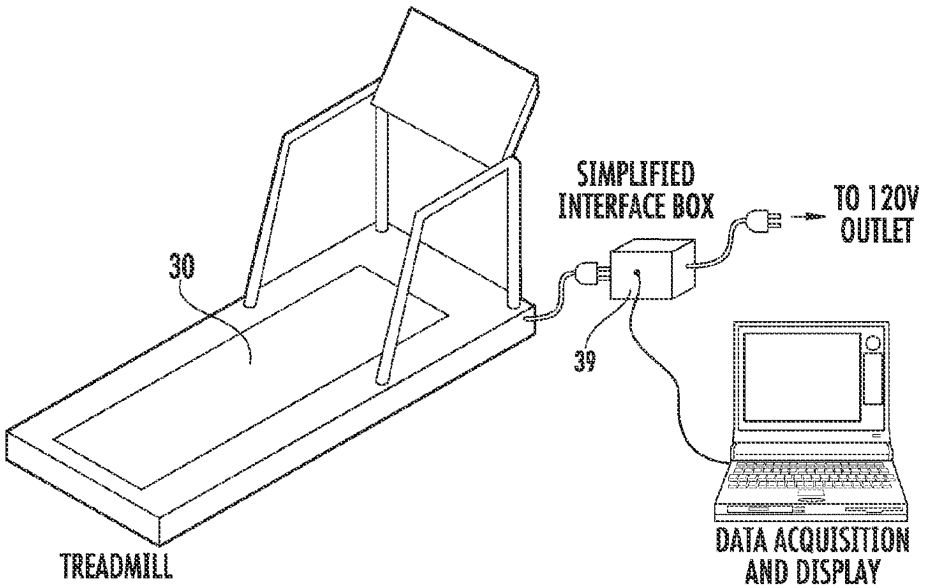
SIMPLIFIED
INTERFACE BOX
TO 120V
OUTLET
30
39
TREADMILL
DATA ACQUISITION
AND DISPLAY

FIG. 3

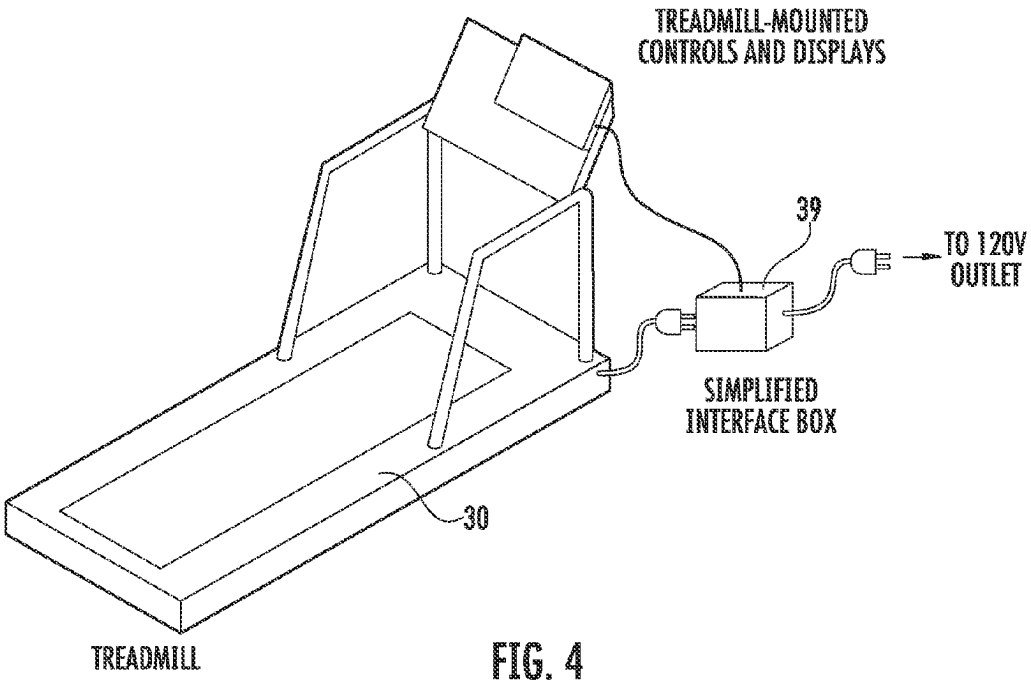
TREADMILL-MOUNTED
CONTROLS AND DISPLAYS
39
TO 120V
OUTLET
SIMPLIFIED
INTERFACE BOX
30
TREADMILL

FIG. 4

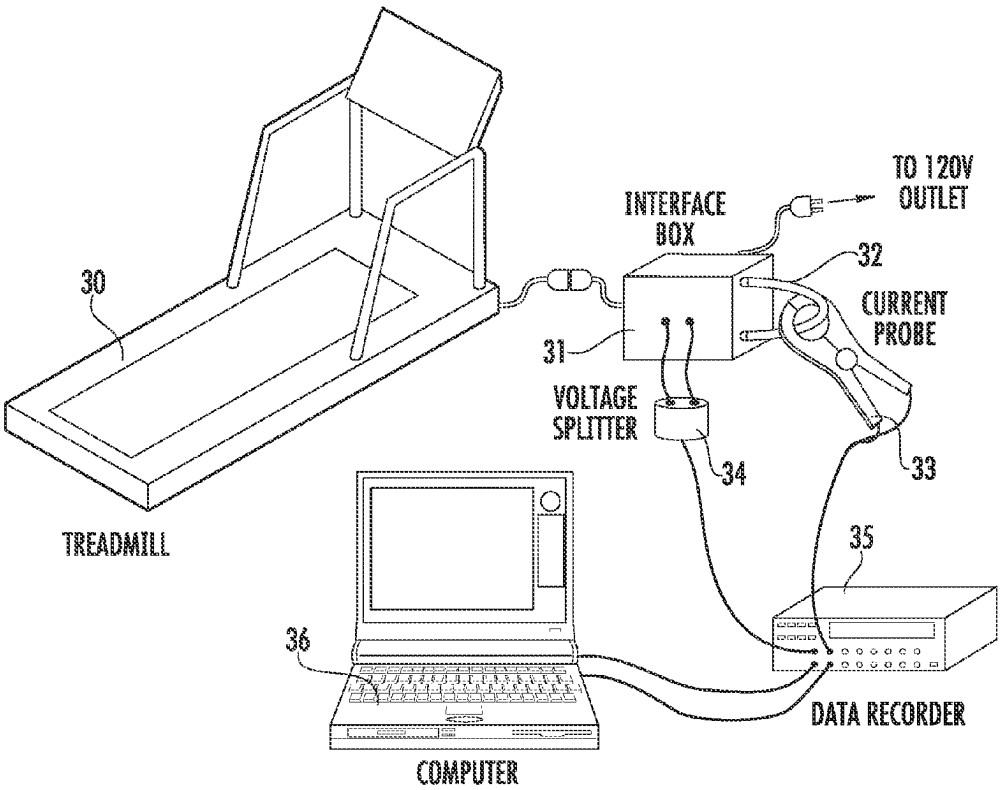
TO 120V
OUTLET
INTERFACE
BOX
32
30
CURRENT
PROBE
31
VOLTAGE
SPLITTER
34
33
35
TREADMILL
36
DATA RECORDER
COMPUTER

FIG. 5

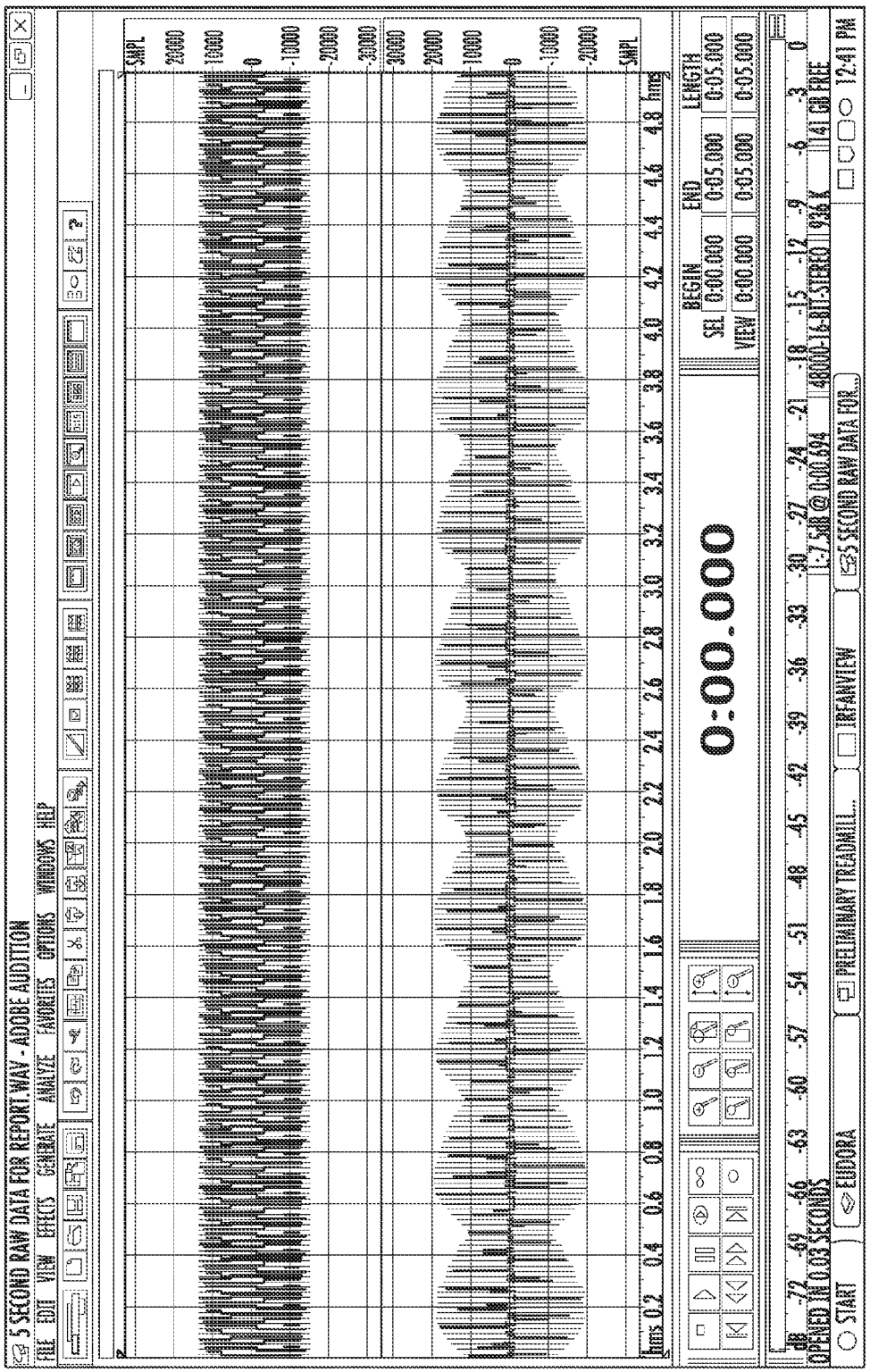
5 SECOND RAW DATA FOR REPORT.WAV - ADOBE AUDITION
FILE EDIT VIEW EFFECTS GENERATE ANALYZE FAVORITES OPTIONS WINDOWS HELP
SMPL
hms
0:00.000
BEGIN
END
LENGTH
SEL
VIEW
48000 16-BIT STEREO
OPENED IN 0.03 SECONDS
START
EUDORA
PRELIMINARY TREADMILL...
IRFANVIEW
5 SECOND RAW DATA FOR...
12:41 PM

FIG. 6

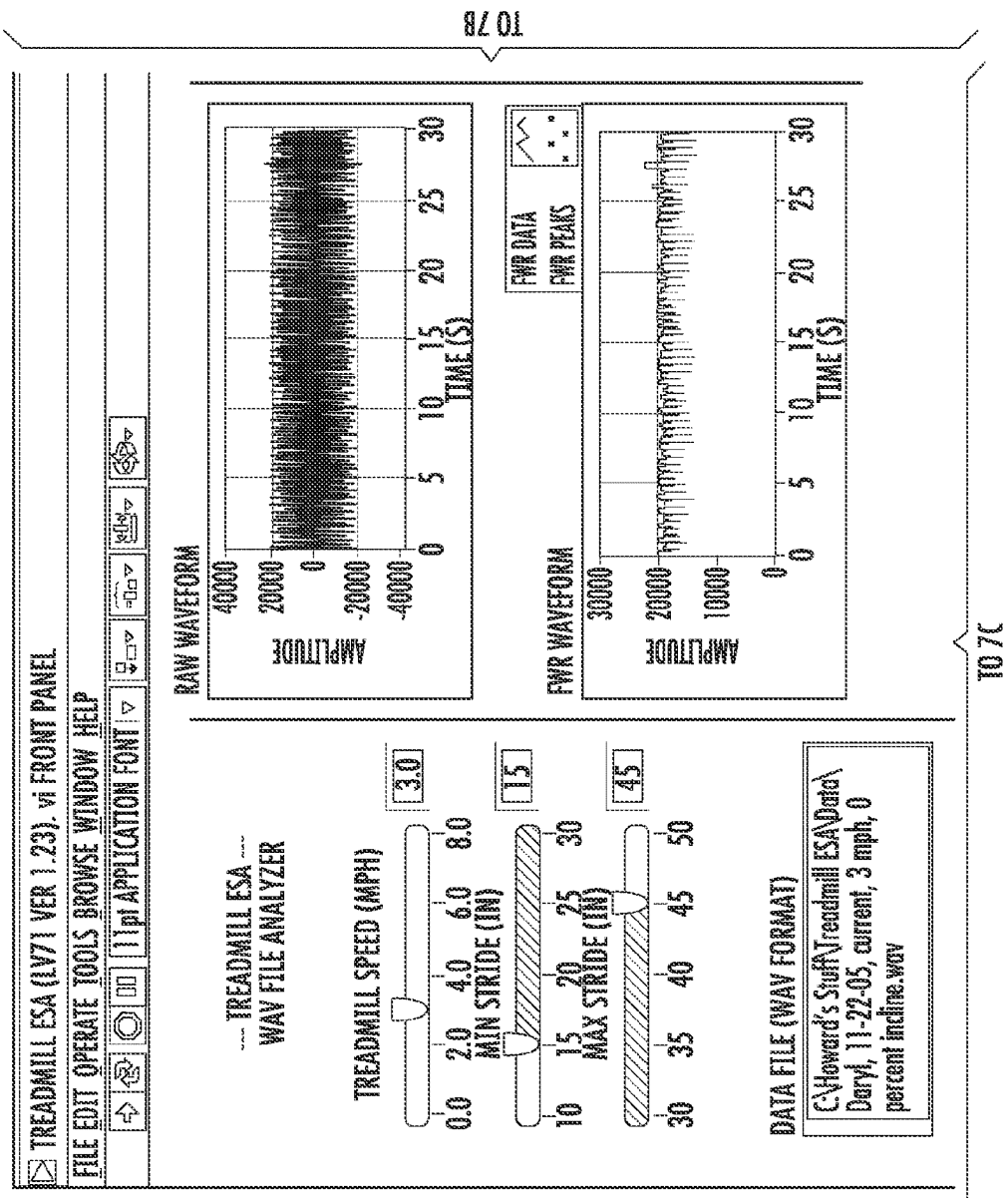
TO 7B
TREADMILL ESA (LV71 VER 1.23).vi FRONT PANEL
FILE EDIT OPERATE TOOLS BROWSE WINDOW HELP
11pt APPLICATION FONT
--- TREADMILL ESA ---
WAV FILE ANALYZER
TREADMILL SPEED (MPH)
3.0
0.0 2.0 4.0 6.0 8.0
MIN STRIDE (IN)
15
10 15 20 25 30
MAX STRIDE (IN)
45
30 35 40 45 50
DATA FILE (WAV FORMAT)
C:\Howard's Stuff\Treadmill ESA\Data\
Daryl, 11-22-05, current, 3 mph, 0
percent incline.wav
RAW WAVEFORM
AMPLITUDE
40000
20000
0
-20000
-40000
0 5 10 15 20 25 30
TIME (S)
PWR WAVEFORM
PWR DATA
PWR PEAKS
AMPLITUDE
30000
20000
10000
0
0 5 10 15 20 25 30
TIME (S)
TO 7C

FIG. 7A

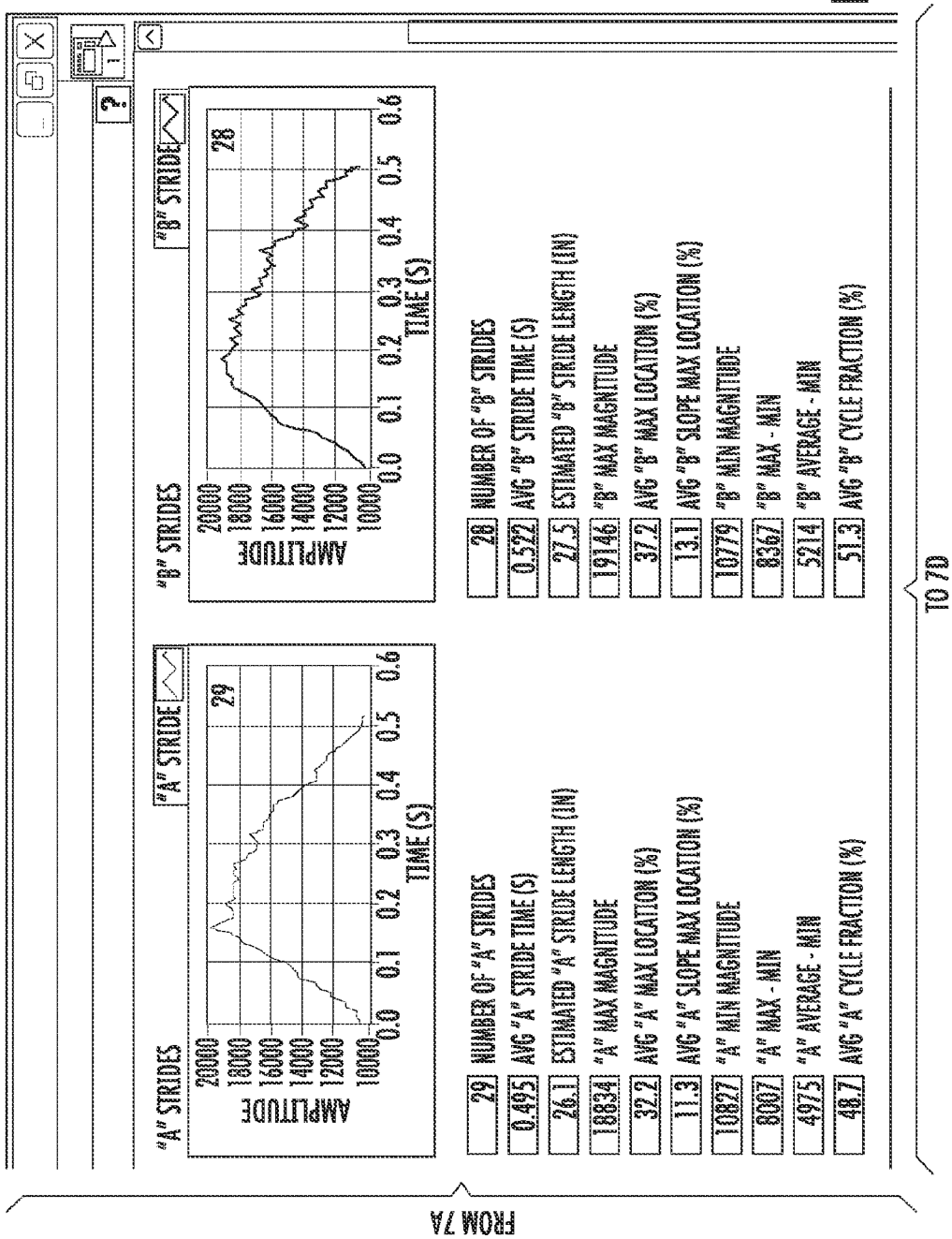
FROM 7A
"A" STRIDES
"A" STRIDE
AMPLITUDE
TIME (S)
29
"B" STRIDES
"B" STRIDE
28
29 NUMBER OF "A" STRIDES
0.495 AVG "A" STRIDE TIME (S)
26.1 ESTIMATED "A" STRIDE LENGTH (IN)
18834 "A" MAX MAGNITUDE
32.2 AVG "A" MAX LOCATION (%)
11.3 AVG "A" SLOPE MAX LOCATION (%)
10827 "A" MIN MAGNITUDE
8007 "A" MAX - MIN
4975 "A" AVERAGE - MIN
48.7 AVG "A" CYCLE FRACTION (%)
28 NUMBER OF "B" STRIDES
0.522 AVG "B" STRIDE TIME (S)
27.5 ESTIMATED "B" STRIDE LENGTH (IN)
19146 "B" MAX MAGNITUDE
37.2 AVG "B" MAX LOCATION (%)
13.1 AVG "B" SLOPE MAX LOCATION (%)
10779 "B" MIN MAGNITUDE
8367 "B" MAX - MIN
5214 "B" AVERAGE - MIN
51.3 AVG "B" CYCLE FRACTION (%)
TO 7D

FIG. 7B

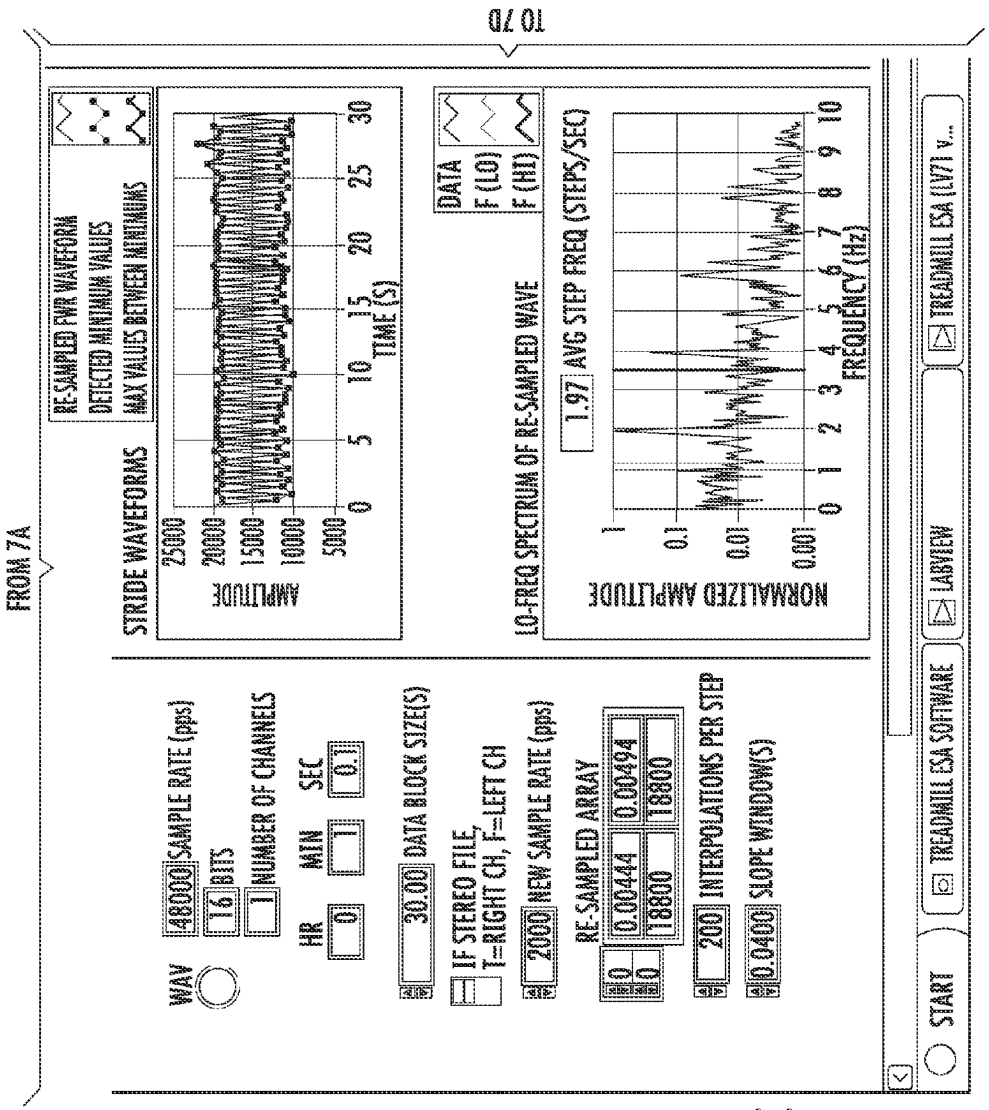
FROM 7A
TO 7B
RE-SAMPLED PWR WAVEFORM
DETECTED MINIMUM VALUES
MAX VALUES BETWEEN MINIMUMS
STRIDE WAVEFORMS
AMPLITUDE
TIME (S)
DATA
F (LO)
F (HI)
LO-FREQ SPECTRUM OF RE-SAMPLED WAVE
1.97 AVG STEP FREQ (STEPS/SEC)
NORMALIZED AMPLITUDE
FREQUENCY (Hz)
WAV
48000 SAMPLE RATE (pps)
16 BITS
1 NUMBER OF CHANNELS
HR MIN SEC
0 0 0.1
30.00 DATA BLOCK SIZE(S)
IF STEREO FILE,
T=RIGHT CH, F=LEFT CH
2000 NEW SAMPLE RATE (pps)
RE-SAMPLED ARRAY
0 0.00444 0.00494
0 18800 18800
200 INTERPOLATIONS PER STEP
0.0400 SLOPE WINDOW(S)
START
TREADMILL ESA SOFTWARE
LABVIEW
TREADMILL ESA (LV7) v...

FIG. 7C

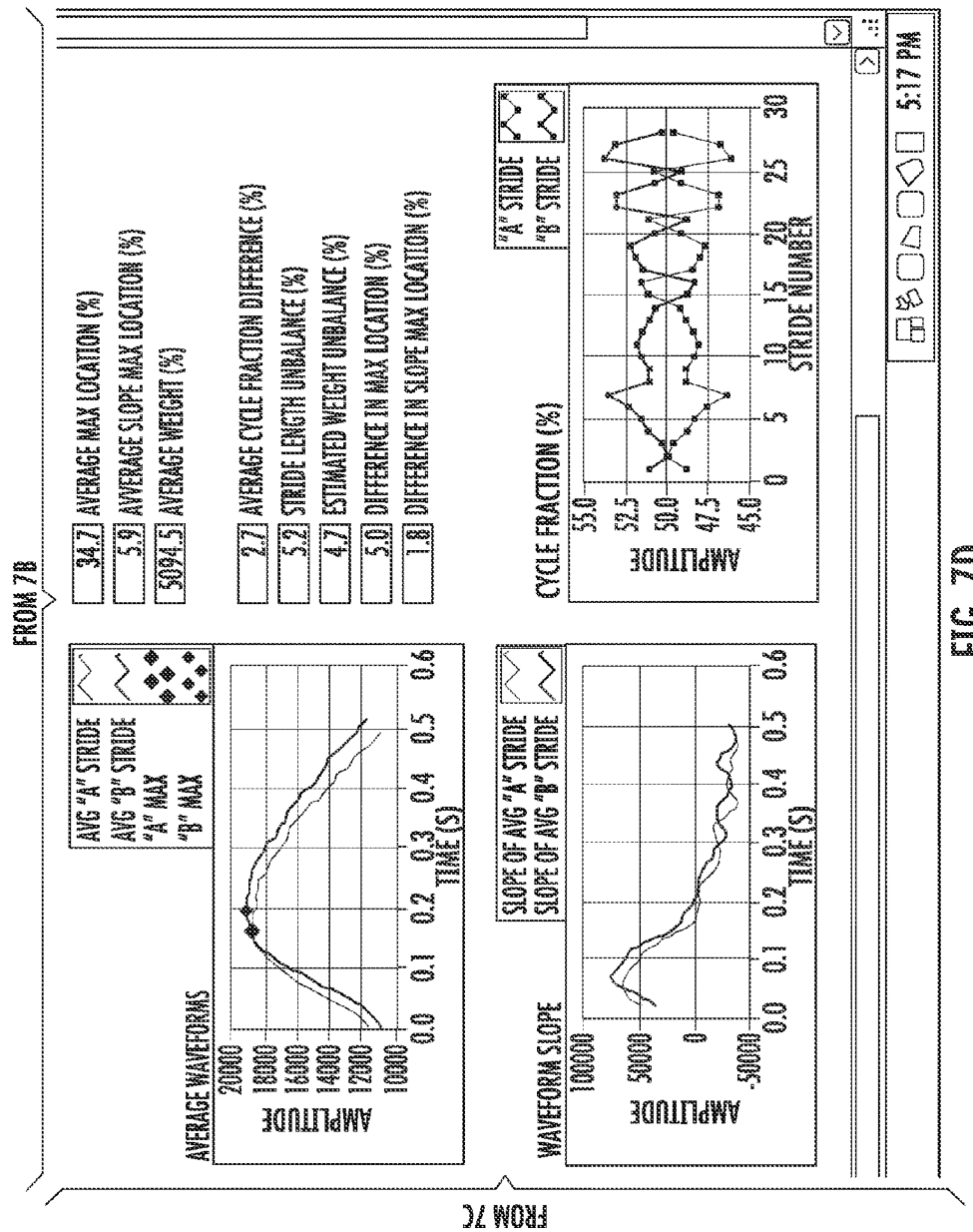
FROM 7B
FROM 7C
34.7 AVERAGE MAX LOCATION (%)
5.9 AVERAGE SLOPE MAX LOCATION (%)
5094.5 AVERAGE WEIGHT (%)
2.7 AVERAGE CYCLE FRACTION DIFFERENCE (%)
5.2 STRIDE LENGTH UNBALANCE (%)
4.7 ESTIMATED WEIGHT UNBALANCE (%)
5.0 DIFFERENCE IN MAX LOCATION (%)
1.8 DIFFERENCE IN SLOPE MAX LOCATION (%)
AVG "A" STRIDE
AVG "B" STRIDE
"A" MAX
"B" MAX
AVERAGE WAVEFORMS
AMPLITUDE
TIME (S)
SLOPE OF AVG "A" STRIDE
SLOPE OF AVG "B" STRIDE
WAVEFORM SLOPE
"A" STRIDE
"B" STRIDE
CYCLE FRACTION (%)
STRIDE NUMBER
5:17 PM

FIG. 7D

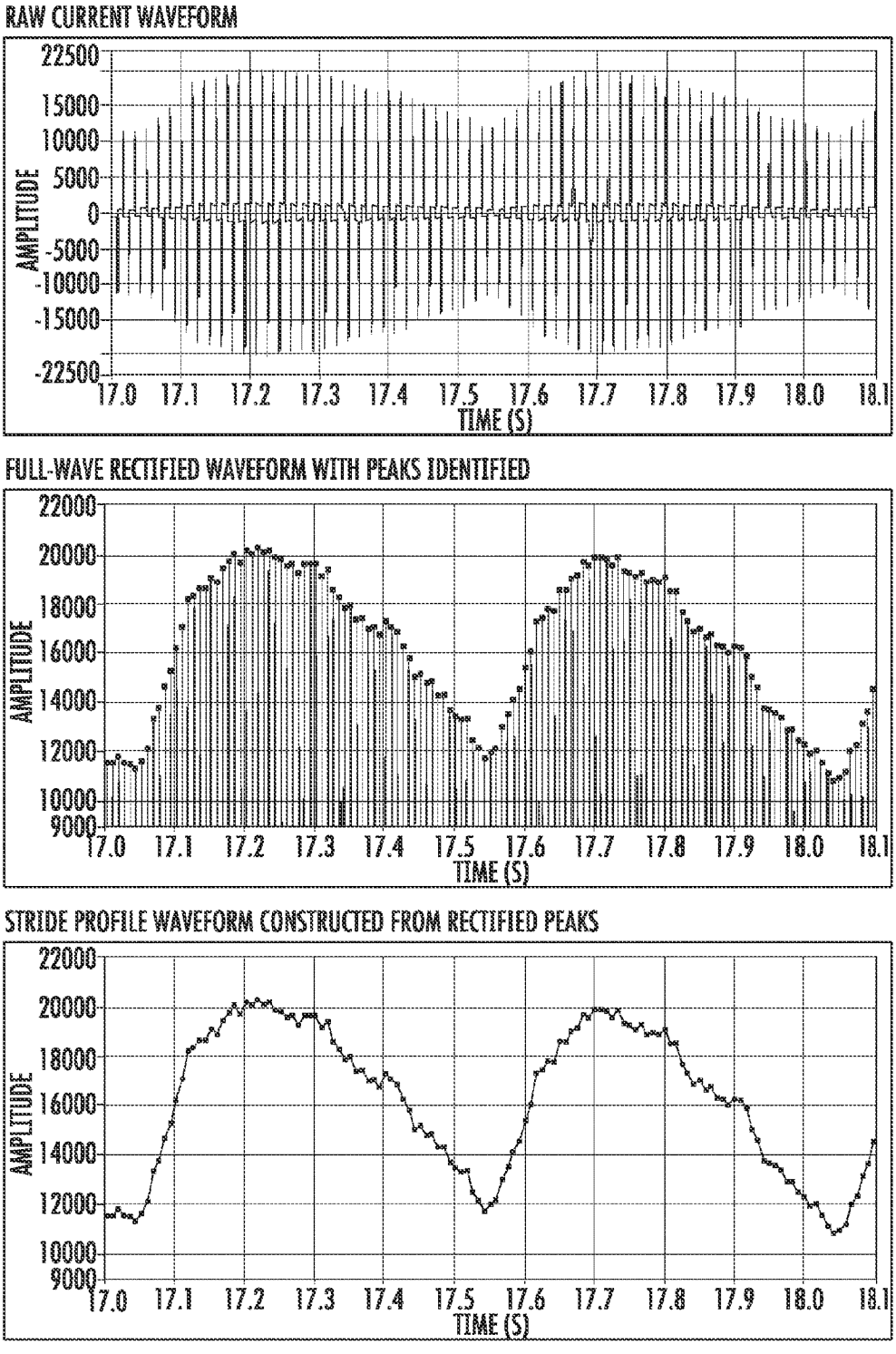
RAW CURRENT WAVEFORM
AMPLITUDE
22500
15000
10000
5000
0
-5000
-10000
-15000
-22500
17.0 17.1 17.2 17.3 17.4 17.5 17.6 17.7 17.8 17.9 18.0 18.1
TIME (S)
FULL-WAVE RECTIFIED WAVEFORM WITH PEAKS IDENTIFIED
AMPLITUDE
22000
20000
18000
16000
14000
12000
10000
9000
17.0 17.1 17.2 17.3 17.4 17.5 17.6 17.7 17.8 17.9 18.0 18.1
TIME (S)
STRIDE PROFILE WAVEFORM CONSTRUCTED FROM RECTIFIED PEAKS
AMPLITUDE
22000
20000
18000
16000
14000
12000
10000
9000
17.0 17.1 17.2 17.3 17.4 17.5 17.6 17.7 17.8 17.9 18.0 18.1
TIME (S)

FIG. 8

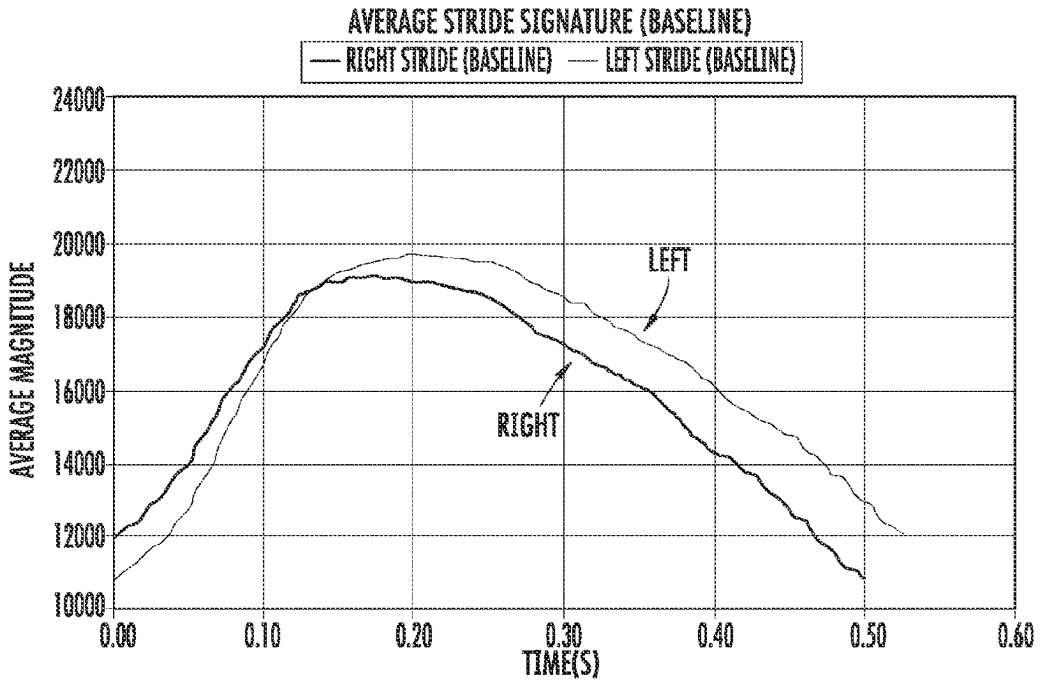

FIG. 9

29	NUMBER OF "A" STRIDES	28	NUMBER OF "B" STRIDES
0.495	AVG "A" STRIDE TIME (S)	0.522	AVG "B" STRIDE TIME (S)
26.1	ESTIMATED "A" STRIDE LENGTH (IN)	27.5	ESTIMATED "B" STRIDE LENGTH (IN)
18834	"A" MAX MAGNITUDE	19146	"B" MAX MAGNITUDE
32.2	AVG "A" MAX LOCATION (%)	37.2	AVG "B" MAX LOCATION (%)
11.3	AVG "A" SLOPE MAX LOCATION (%)	13.1	AVG "B" SLOPE MAX LOCATION (%)
10827	"A" MIN MAGNITUDE	10779	"B" MIN MAGNITUDE
8007	"A" MAX - MIN	8367	"B" MAX - MIN
4975	"A" AVERAGE - MIN	5214	"B" AVERAGE - MIN
48.7	AVG "A" CYCLE FRACTION (%)	51.3	AVG "B" CYCLE FRACTION (%)

34.7	AVERAGE MAX LOCATION (%)
5.9	AVVERAGE SLOPE MAX LOCATION (%)
5094.5	AVERAGE WEIGHT
2.7	AVERAGE CYCLE FRACTION DIFFERENCE (%)
5.2	STRIDE LENGTH UNBALANCE (%)
4.7	ESTIMATED WEIGHT UNBALANCE (%)
5.0	DIFFERENCE IN MAX LOCATION (%)
1.8	DIFFERENCE IN SLOPE MAX LOCATION (%)

FIG. 10

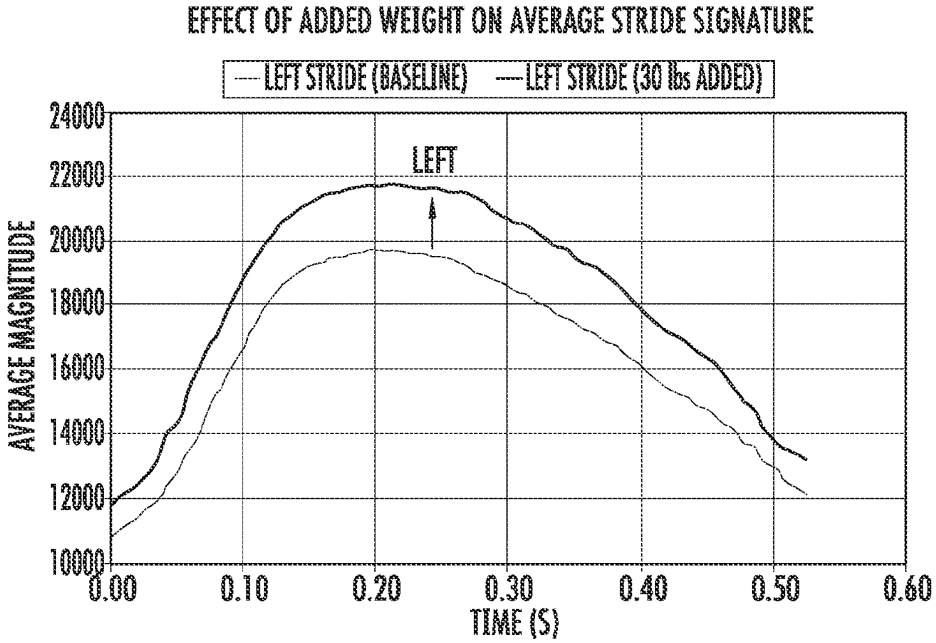
EFFECT OF ADDED WEIGHT ON AVERAGE STRIDE SIGNATURE
LEFT STRIDE (BASELINE)
LEFT STRIDE (30 lbs ADDED)
LEFT
AVERAGE MAGNITUDE
24000
22000
20000
18000
16000
14000
12000
10000
0.00
0.10
0.20
0.30
0.40
0.50
0.60
TIME (S)

FIG. 11

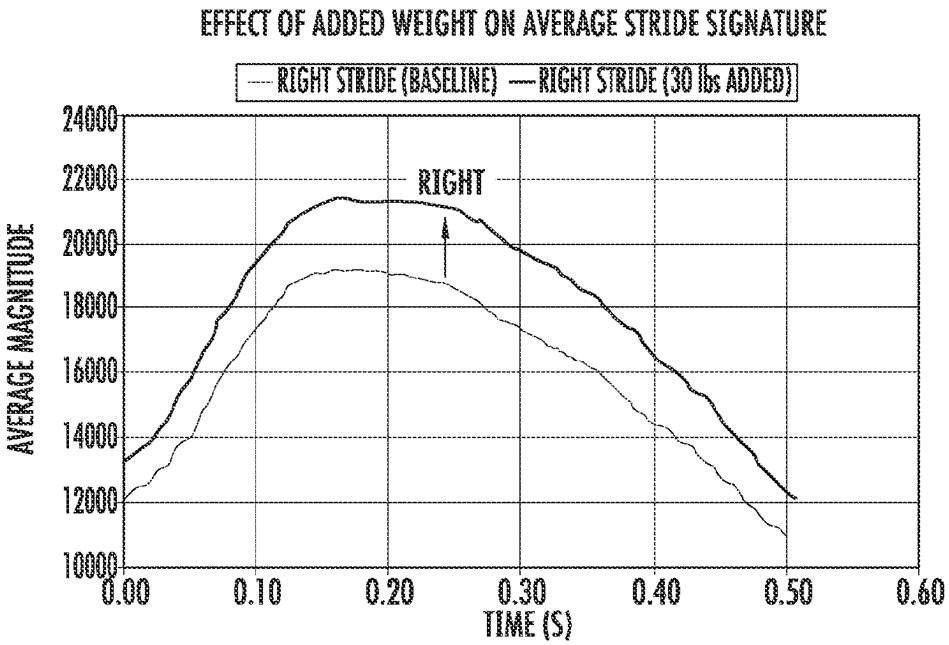
EFFECT OF ADDED WEIGHT ON AVERAGE STRIDE SIGNATURE
RIGHT STRIDE (BASELINE)
RIGHT STRIDE (30 lbs ADDED)
RIGHT
AVERAGE MAGNITUDE
24000
22000
20000
18000
16000
14000
12000
10000
0.00
0.10
0.20
0.30
0.40
0.50
0.60
TIME (S)

FIG. 12

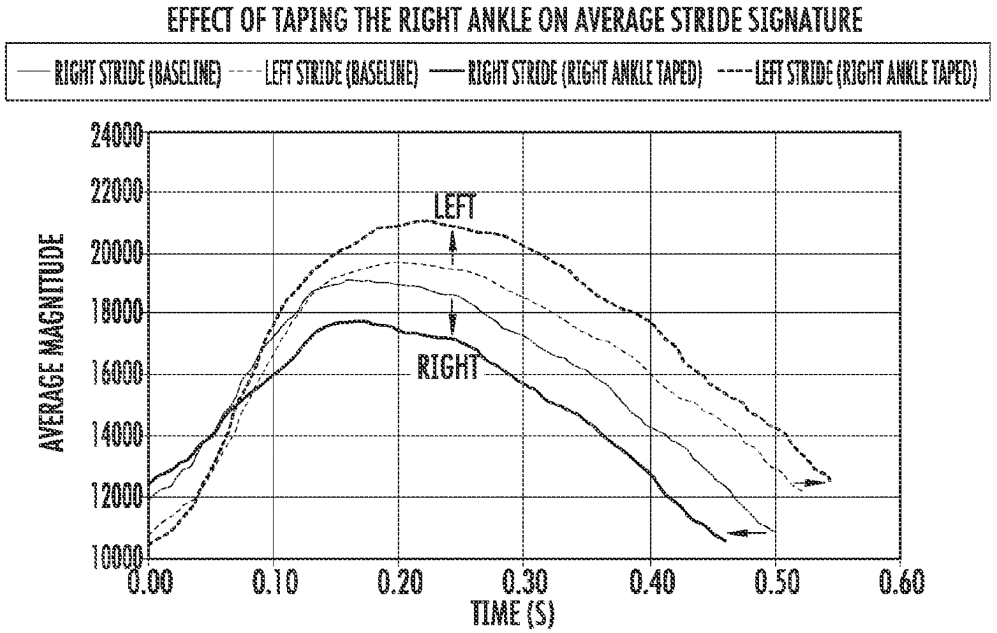
EFFECT OF TAPING THE RIGHT ANKLE ON AVERAGE STRIDE SIGNATURE
RIGHT STRIDE (BASELINE)
LEFT STRIDE (BASELINE)
RIGHT STRIDE (RIGHT ANKLE TAPED)
LEFT STRIDE (RIGHT ANKLE TAPED)
AVERAGE MAGNITUDE
24000
22000
20000
18000
16000
14000
12000
10000
LEFT
RIGHT
0.00
0.10
0.20
0.30
0.40
0.50
0.60
TIME (S)

FIG. 13

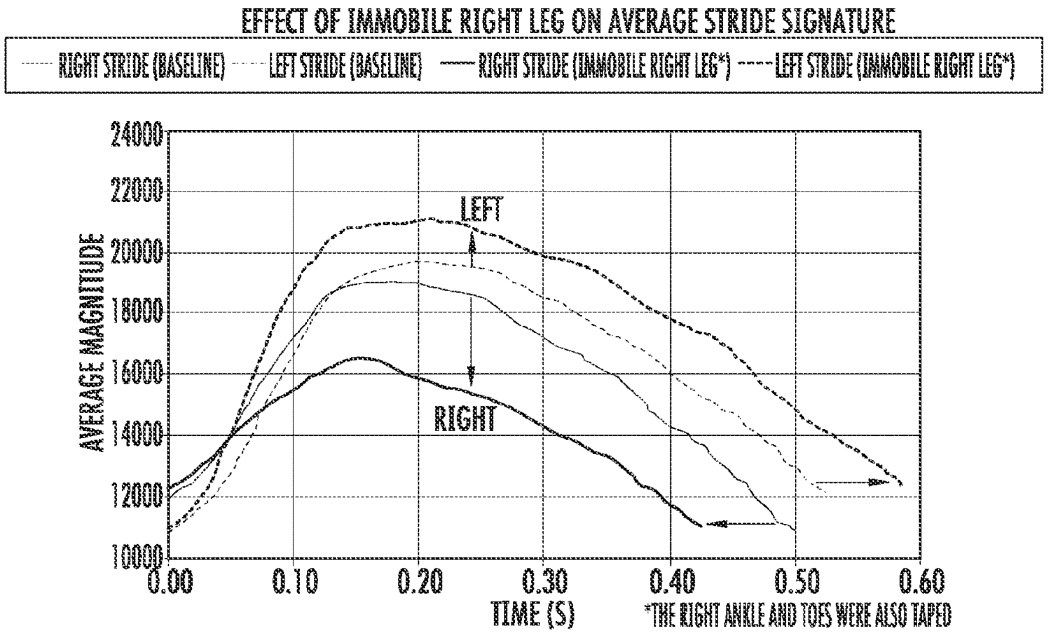
EFFECT OF IMMOBILE RIGHT LEG ON AVERAGE STRIDE SIGNATURE
RIGHT STRIDE (BASELINE)
LEFT STRIDE (BASELINE)
RIGHT STRIDE (IMMOBILE RIGHT LEG*)
LEFT STRIDE (IMMOBILE RIGHT LEG*)
AVERAGE MAGNITUDE
24000
22000
20000
18000
16000
14000
12000
10000
LEFT
RIGHT
0.00
0.10
0.20
0.30
0.40
0.50
0.60
TIME (S)
*THE RIGHT ANKLE AND TOES WERE ALSO TAPED

FIG. 14

ELECTRICAL SIGNAL ANALYSIS TO ASSESS THE PHYSICAL CONDITION OF A HUMAN OR ANIMAL

CROSS REFERENCES TO RELATED APPLICATIONS

This application is a Divisional Application of currently pending U.S. patent application Ser. No. 11/688,893 filed Mar. 21, 2007, entitled: "ELECTRICAL SIGNATURE ANALYSIS TO QUANTIFY HUMAN AND ANIMAL PERFORMANCE ON FITNESS AND THERAPY EQUIPMENT SUCH AS A TREADMILL."

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

This invention was made with United States Government support under Contract No. DE-AC05-00OR22725 between the United States Department of Energy and U.T. Battelle, LLC. The United States Government has certain rights in this invention.

BACKGROUND OF THE INVENTION

Gait analysis usually involves the measurement and interpretation of sequential events that occur in the gait cycle. The gait cycle includes all of the events occurring from one heel strike to the repeated heel strike of the same foot. Essential gait measurement parameters include space, time, and compressive forces. These measurements must be accurate, reproducible and related in time to be of value. Additional value results from real time data analysis to allow training for gait style modification, or adjustments of gait devices like shoes or braces.

Various types and methods of gait analysis exist today ranging from measured distances and a stopwatch to computerized 3-D video gait analysis systems. The cost, utility and efficacy of each system may limit their application in various settings. The Electrical Signature Analysis (ESA) system described herein provides a highly objective, comprehensive gait performance analysis.

BRIEF SUMMARY OF THE INVENTION

The invention is a human and animal performance data acquisition, analysis, and diagnostic system for fitness and therapy devices having an interface box removably disposed on incoming power wiring to a fitness and therapy device, at least one current transducer removably disposed on said interface box for sensing current signals to said fitness and therapy device, and a means for analyzing, displaying, and reporting said current signals to determine human and animal performance on said device using measurable parameters.

One unique and valuable aspect of the ESA system is its simple and direct ability to measure many of the fundamental characteristics of gait patterns using a standard treadmill. ESA requires no restrictive or sophisticated instrumentation and poses no risk to subjects other than walking on the treadmill at comfortable speeds. The system has an excellent market potential for demonstrating gait aberrations in rehabilitation settings, sports performance for coaches and athletes, and gait enhancements for footwear manufacturers.

ESA can be used to monitor physical condition and performance of human and animals. ESA has long been used as a tool for monitoring the condition and performance of pumps, valves and other electromechanical machinery, but has never been applied as a tool for analyzing human and animal condition and quantifying performance.

To further investigate this concept, electric voltage and current signals were recorded from an AC-powered treadmill as a person walked on the treadmill normally and in several irregular ways that simulated various physical impairments. The variations in walking styles produced many noticeable changes in the treadmill's electrical signatures, and demonstrated this new approach for sensing and measuring variations in human and animal physical condition. These results can serve as a foundation for further development of ESA-based methods and ultimately lead to the creation of new tools for measuring the physical rehabilitation progress of people recovering from injuries and surgeries that alter flexibility, mobility, strength, and balance.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic of the general method of electrical signature analysis.

FIG. **2** is a photograph of the electrical interface box to a treadmill power source.

FIG. **3** is a schematic of a treadmill embodiment having a simplified interface box and a computer means for analyzing, displaying, and reporting the current signals.

FIG. **4** is a schematic of a treadmill embodiment having a simplified interface box and an integrated treadmill means for analyzing, displaying, and reporting the current signals.

FIG. **5** is a schematic of the treadmill test setup.

FIG. **6** is a graphical output of the voltage (top) and current (bottom) signals while a person is walking on a treadmill.

FIGS. **7**A-**7**D are sample computer screens from the treadmill ESA software.

FIG. **8** is a graph showing the raw current waveform (top), full-wave rectified waveform with peaks identified (middle), and stride profile waveform constructed from rectified peaks (bottom).

FIG. **9** is a graph showing the average stride profile for a user walking with a normal gait.

FIG. **10** is a sample output of measurable parameters from the "A" (right) and "B" (left) stride profiles.

FIG. **11** is a graph showing the effect of added weight on an average left stride profile.

FIG. **12** is a graph showing the effect of added weight on an average right stride profile.

FIG. **13** is a graph showing the effect of a taped right ankle on the average stride profiles.

FIG. **14** is a graph showing the effect of an immobilized right leg on the average stride profiles.

DETAILED DESCRIPTION OF THE INVENTION

This invention is a device and method for detecting and monitoring physical condition and performance of humans and animals. It exploits the treadmill's and other electromechanical device's electric motor as a transducer for sensing load variations caused by a person or animal walking on the treadmill, and is a variation of Electrical Signature Analysis (ESA) technologies that were initially developed for assessing the condition of electromechanical machinery.

Treadmill electric voltage and current signals were recorded as a person walked on the treadmill normally and in several irregular ways that simulated various physical impairments. Using current and voltage measurements enables a calculation of power which can be used as an additional analysis parameter. The variations in walking styles produced many noticeable changes in the treadmill's electrical signatures, thus demonstrating the sensitivity needed to perform human and animal gait analysis.

With further development, ESA-based instrumentation can be developed and combined with conventional treadmills and other electrically-powered health equipment to provide new

inexpensive tools for monitoring and quantifying the physical rehabilitation progress of people recovering from injuries and surgeries that have affected their gait, flexibility, mobility, strength, and balance. Other than clinical settings, applications of the invention include biomechanics sports conditioning and rehabilitation, direct results measurement for reporting progress and billing support to medical insurance companies, racehorse training and rehabilitation, athletic shoe and orthotic design, and prosthetic research and design.

Gait analysis is essential in physical medicine and is a fundamental tool of the orthopedist, physical therapist, and orthotist/prosthetist. The ability to assess and correct inefficient or dysfunctional gait patterns is fundamental to sound clinical practice. Gait aberrations can result from pain, neurological disorders, and musculoskeletal impairments and can lead to premature joint wear, myotendinous pain and functional disability. Long term, gait disorders may result in permanent disability, loss of balance, loss of independence, and increased fall potential.

ESA gives clinicians a new analysis tool that can be used independently or with other gait analysis techniques to increase accuracy and objectivity of gait analysis. The physical therapist may use this technology to enhance gait efficiency and balance with a large variety of cases in geriatric populations, post-fracture or post-surgical cases, injured athletes, and general sprains or strains. The orthotist may use this technology to study the effects of various braces and orthoses. The prosthetist could study gait efficiency and use this technology to modify prosthesis to enhance the desired gait characteristics.

Beyond the realm of rehabilitation, ESA may prove to be very useful with analysis of athletic performance, particularly with runners. One could establish characteristic 'signatures' of elite runners with the ESA process and compare them with other developing runners. The developing athlete can learn to model, and then feel the differences with more efficient running motions using the ESA process. Coaches could use the process to train young runners and to analyze workouts in real time.

Athletic foot wear manufacturers may use the ESA process to study the effect of various shoe modifications with running performance, motion control for stability, and force attenuation. The ESA process could provide objective data for sport specific foot wear related to athletic performance.

The ESA technology was originally invented and developed as a tool for assessing the condition of a wide variety of military, industrial, and consumer electromechanical equipment. ESA can be used to detect equipment defects and degradation, and unwanted changes in process conditions. ESA is truly non-intrusive and does not interfere with the operation of the equipment being monitored.

FIG. **1** illustrates the general ESA method. Load and speed variations in electromechanical systems generally produce correlated variations in current and voltage. ESA analyzes these small perturbations and matches them to their source. The resulting time and frequency signatures reflect loads, stresses, and wear throughout the system and provide the basis for assessing the operational condition of the monitored equipment.

Many machines and electrical appliances have been designed to directly interact with human and animals. The manner in which the human and animal uses the appliance determines how hard the appliance must work, and how much electrical energy is required. For example, if a power saw is not used correctly, additional friction and binding can occur between the saw blade and the material being cut. This results in the saw motor having to work harder; which causes it to draw more current. When used correctly, the motor does not have to work as hard, and the electric current is lower. Thus, by measuring the magnitude of the electric current used by the saw, the manner in which the saw is being used is also measured.

Other examples of machines whose operations are affected by how they are used include treadmills, exercise bikes, elliptical machines, and other fitness equipment used in gyms and physical therapy centers. While these machines have been designed to promote physical fitness, their designs are inherently sensitive to the physical attributes, health, and abilities of the user. Like the saw example, it is believed that by obtaining the electrical signatures of these exercise devices as they are being used, certain signature features will be present that are indicative of the physical condition and abilities of the user. After identifying and correlating these features, they can be used to track improvement or degradation in the user's physical condition over time.

FIG. **3** is a schematic of a treadmill embodiment having a simplified interface box and a computer means for analyzing, displaying, and reporting the current signals. The simplified interface box **39** includes a current transducer for obtaining current signals.

FIG. **4** is a schematic of a treadmill embodiment having a simplified interface box and an integrated treadmill means for analyzing, displaying, and reporting the current signals. The simplified interface box **39** includes a current transducer for obtaining current signals and the data is displayed on the treadmill stand itself. Other anticipated embodiments include a fully integrated treadmill wherein all components of the invention are built into the treadmill.

In the test setup of FIG. **5**, treadmill electrical signals were obtained using an electrical interface box **31** that was plugged into the treadmill **30** and then into a 120 V wall outlet. The interface box **31** contains an external loop **32** for accessing the treadmill electric current using a standard clamp-on current transducer **33**. The interface box **31** also provides access to the full line voltage used by the treadmill **30**. A 20:1 splitter **34** was then used to reduce the voltage levels so that they could be safely recorded on a data recorder **35**. This interface box **31** makes it possible to easily and safely acquire electrical signals from any electrically powered exercise device such as a treadmill, an exercise bicycle, or an elliptical trainer.

FIG. **5** illustrates the general test setup. Electrical signals were obtained with a digital data recorder **35** and subsequently analyzed using a computer **36** and software that was specially developed for this application. Treadmill data were acquired under a variety of conditions. Table 1 summarizes the test conditions and walking styles that were recorded.

TABLE 1

Date	Treadmill Speed (mph)	Treadmill Incline (%)	Walking Style
Nov. 17, 2005	4	0	Normal walking
Nov. 17, 2005	4	5	Normal walking
Nov. 17, 2005	4	10	Normal walking
Nov. 22, 2005	3	0	Normal walking

TABLE 1-continued

Date	Treadmill Speed (mph)	Treadmill Incline (%)	Walking Style
Nov. 22, 2005	3	0	Walking, but with extended strides
Nov. 22, 2005	3	0	Walking normal, but using the rails for support
Nov. 22, 2005	3	0	Walking with a scissor gait
Nov. 22, 2005	3	0	Walking with a sore toe
Nov. 22, 2005	3	0	Walking with a stiff knee
Nov. 22, 2005	3	0	Walking normally, but pointing toes out
Nov. 22, 2005	3	0	Walking on toes only
Nov. 22, 2005	4	0	Normal walking
Nov. 22, 2005	5	0	Normal walking
Nov. 22, 2005	5	0	Running
Dec. 2, 2005	3	0	Normal walking with running shoes
Dec. 2, 2005	3	0	Normal walking with no shoes
Dec. 2, 2005	3	0	Normal walking with street shoes
Dec. 2, 2005	3	0	Normal walking with taped ankle
Dec. 2, 2005	3	0	Normal walking with taped ankle and toes
Dec. 2, 2005	3	0	Normal walking with taped ankle and toes, and immobilized leg
Dec. 2, 2005	3	0	Normal walking with taped ankle and toes, and restricted (taped) knee
Dec. 2, 2005	3	0	Normal walking with restricted (taped) knee only
Dec. 2, 2005	3	0	Normal walking while carrying 30 lbs of extra weight

Treadmill voltage and current signals were recorded for all tests. To minimize variables, the same treadmill was used for all tests, and the same person served as the test subject for all tests. Several of these tests are further described later.

The recorded voltage and current signals were initially played back and examined using Adobe Audition, a commercially-available software package designed to record, edit, and play audio signals. As shown in FIG. **6**, walking on the treadmill produced very little impact on the magnitude of the voltage signals, but produced dramatic variations in the magnitude of the electric current. For this reason, all additional analysis efforts focused on the current signals.

To analyze the electric current signals in more detail, a data analysis "virtual instrument" was developed using LabVIEW, a graphical data acquisition and analysis platform. The software controls and displays evolved as methods were identified to extract useful details (signatures) from the electric current data. Presently, the software is designed to apply a variety of ESA-based methods on treadmill electric current data that has been saved in the popular Windows sound file (WAV) format.

FIGS. **7**A-**7**D illustrate sample screen information from the software, and shows (in the upper left corner of the screen) various controls that provide the ability to input the treadmill speed (in miles-per-hour) and a range within which the users stride falls. For the example, the data shown is taken from a test when the treadmill was operating at 3.0 miles per hour. The stride range of the user is selected to be between 15 and 45 inches.

The software provides a tool for converting the "raw" electric current data into a revealing stride profile by first full-wave rectifying the current signal, and then using the rectified peaks to build the stride profile waveform. FIG. **8** illustrates this process where the software begins with "raw" data (top graph). After full-wave rectifying, the envelope peaks are automatically identified (middle graph) and used to construct the stride profile (bottom graph). This example shows the normal left-right stride signature of the user. The software then performs a frequency-analysis of the stride waveforms and calculates the overall stride frequency (in steps per second). The individual stride waveforms are then separated into two groups representing the left and right strides.

In order to identify which group is associated with which leg, the user consistently stepped on the treadmill first using his right foot. As this ESA-based system is further developed, a more positive method of identifying right from left is needed. One method of accomplishing this is to have the user wear a sensor on one leg that is preferably more sensitive only to one stride (e.g., their right) and transmit a signal to the data acquisition computer with each right step via a wireless link. The computer can then use this reference signal to positively identify the right stride waveform data from the left. Instruments such as foot switches are available which would positively identify left and right feet.

The load on the treadmill (and hence the current drawn by the treadmills motor) is sensitive to several factors, such as the weight of the user, the surface area of the belt that is in contact with the user, and the frictional losses between the treadmill mechanical surfaces. The software calculates an average stride profile, based on analyzing numerous stride waveforms and after accounting for the slight differences in the stride-to-stride durations in each leg. This averaging process is intended to "average out" the effects of the treadmill itself, since the user contacts a different section of the treadmill belt with each step. The average stride profiles are thus believed to be predominantly influenced by the gait of the user, and thus provide a suitable and sensitive signature for performing gait analysis.

Typical average stride profiles are shown in FIG. **9** for the user walking in a normal gait. As can be seen in the FIG. **9**, differences exist between the right and left stride profile of the user. For example, the average left stride is characterized by a larger overall magnitude (thus indicating a larger load to the treadmill) and is about 5 percent longer in duration than the average right stride. The specific causes for the profile differences are not presently completely understood; however, they are repeatable and thus are believed to reflect user-specific conditions.

To better quantify the differences, the software also measures a variety of parameters that are present in the stride profiles. These parameter measurements are shown in FIG.

10. Several of these parameters were judged to be very sensitive indicators of gait anomalies such as stride profile, average stride profile, average cycle fraction difference, stride length unbalance, estimated weight unbalance, difference in max location, and difference in slope max location.

Average stride profiles are provided to illustrate the ability of ESA methods to characterize gait variations. The following "abnormal" conditions are presented; normal walking with additional weight, normal walking with taped right ankle, and taped right ankle and toes plus immobilized right leg.

FIGS. 11 and 12 show the effect of the user carrying an additional 30 lbs while walking on the treadmill. When carrying the additional weight, the magnitudes associated with the right stride increased an average of 12.1 percent, and was relatively consistent throughout the entire stride. Similarly, the left side magnitudes increased an average of 11.0 percent. Since both right and left strides were affected approximately the same, the "balance" between the right and left strides was undisturbed.

A test was performed after taping the user's right ankle. This removed the normal flexibility normally associated with the foot. When walking with a taped ankle, the balance between the two strides is significantly disturbed and is dramatically seen in the average stride profiles shown in FIG. 13. The right profile duration is noticeable shortened, and its magnitudes during the majority of the stride are significantly decreased. In contrast, the duration of the left profile increased, along with an increase in magnitudes throughout most of the stride. Thus, what is seen is a "spreading" of the two profiles as they move in opposite directions. This unbalance between the two strides is indicative of the differences in left and right strides, caused by the restricted movement of the right foot.

A test was performed with several concurrent restrictions: the user's right toes and ankle were taped to prevent motion, and their right leg was immobilized by taping their knee. In this condition, the user walked on the treadmill, thus producing the average stride profiles shown in FIG. 14. The addition of the taped toes and immobilized leg to the already taped ankle further accentuated the unbalance between the two strides, as shown by the increased spreading between the left and right profiles. In this extreme case, the user spent only 42 percent of the time on their right foot, and 58 percent of the time on their left foot. The differences between the profile magnitudes were substantial. One method of quantifying the profile magnitudes is by measuring the average profile magnitudes and subtracting the minimum magnitude. In this manner, the average increase in treadmill running load associated with each stride is measured.

For the immobile leg case, the average profile magnitude minus the profile minimum for the compensating leg was 6525, which is almost double the magnitude of the right immobilized leg, which was 3344. This measure, along with the change in stride duration, and other measurable parameters are all indicative of the severe unbalance between the two strides, due to the imposed restrictions.

The average stride profiles that have been illustrated are only one way of visualizing and quantifying the treadmills electrical signature changes resulting from a person walking on it. The profiles themselves have many measurable characteristics that should correlate with known gait patterns.

Initial treadmill ESA tests were performed using a test subject who walked in various ways to simulate several foot and leg problems, including a "sore toe" and a "stiff knee." The 'sore-toe' and 'stiff knee' gaits represent common clinical gait patterns seen in rehabilitation. The sore-toe or antalgic gait is often seen in cases with pain problems related to the toes, foot or ankle. Examples might include a sprained ankle, bunion, turf toe, osteoarthritis, fracture, or other foot injury. Gait aberrations would be seen throughout the weight-bearing phase of the gait cycle from heel strike, through early, mid and late stance, as well as toe-off. The characteristic pattern is limited compressive loading, apropulsive toe-off, reduced stance time and reduced step and stride length on the affected side.

The 'stiff knee' gait would represent an individual who may have had surgery on the knee, wears a knee brace or immobilizer, has osteoarthritis of the hip or knee, or is post fracture and in a cast for immobilization. The characteristic gait abnormalities with the stiff knee are seen from mid-stance to toe-off and through the swing phase. These include reduced step and stride length, reduced swing time, circumduction of the hip to clear the foot, and limited toe-off and propulsion. The immobile extremity would have to be carried forward, which increases loads on the hip and the low back.

Normal gait can be divided into a stance phase, which takes roughly 60% of cycle time, and a swing phase, which takes 40% of the cycle time. Different gait abnormalities affect these phases of the gait pattern differently. The sore toe will want to minimize the time in compressive loading to protect the injured foot, where the stiff knee must be carried forward rather than being propelled forward. The resulting gait aberrations might reflect in the temporal, spatial and compressive measurements of the gait. The ESA process is sensitive to these gait patterns as well as being capable of identifying differences between normal left and right strides.

While there has been shown and described what are at present considered the preferred embodiments of the invention, it will be obvious to those skilled in the art that various changes and modifications can be made therein without departing from the scope.

We claim:

1. A human and animal performance data acquisition, analysis, and diagnostic system for fitness and therapy devices comprising:

an interface box removably connected between a source of electrical power and incoming power wiring to a fitness and therapy device,

at least one current transducer removably disposed adjacent said interface box for sensing current signals to said fitness and therapy device, and

a means for analyzing, displaying, and reporting said current signals to determine human and animal performance on said device using a measurable parameter selected from the group consisting of at least one of stride profile, average stride profile, average cycle fraction difference, stride length unbalance, estimated weight unbalance, difference in max location, and difference in slope max location and wherein said measurable parameter is derived from a plurality of waveform peaks for each of a plurality of strides taken by the subject.

2. The system of claim 1 wherein said fitness and therapy device is selected from the group consisting of at least one of treadmill, exercise bike, and elliptical machine.

3. The system of claim 1 wherein said at least one current transducer is a clamp-on type.

4. The system of claim 1 wherein said means for analyzing, displaying, and reporting further comprises full-wave rectifying of said current signals.

5. A human and animal performance data acquisition, analysis, and diagnostic system for fitness and therapy devices comprising:

an interface box removably connected between a source of electrical power and incoming power wiring to a fitness and therapy device,

at least one current transducer removably disposed on said interface box for sensing current signals to said fitness and therapy device,

at least one voltage transducer removably disposed on said interface box for sensing voltage signals to said fitness and therapy device,

a data recorder for recording said current signals and said voltage signals, and a computer having a means for analyzing, displaying, and reporting said current signals and said voltage signals to determine human and animal performance on said device using a measurable parameter selected from the group consisting of at least one of stride profile, average stride profile, average cycle fraction difference, stride length unbalance, estimated weight unbalance, difference in max location, and difference in slope max location and wherein said measurable parameter is derived from a plurality of waveform peaks for each of a plurality of strides taken by the subject.

6. The system of claim **5** wherein said fitness and therapy device is selected from the group consisting of at least one of treadmill, exercise bike, and elliptical machine.

7. The system of claim **5** wherein said at least one current transducer is a clamp-on type.

8. The system of claim **5** further comprising a loop extending externally from and back to said interface box for accessing said current signals to said fitness and therapy device by said at least one current transducer.

9. The system of claim **5** wherein said interface box further comprises a voltage splitter.

10. The system of claim **5** wherein said means for analyzing, displaying, and reporting further comprises full-wave rectifying of said current signals and a power measurement.

11. A method of determining human and animal performance on a fitness and therapy device comprising the steps of:

coupling an interface box in series between a source of electrical power and incoming power wiring for a fitness and therapy device,

securing at least one current transducer to said interface box for sensing current signals to said fitness and therapy device, and

connecting a means for analyzing, displaying, and reporting said current signals to determine human and animal performance on said device using a measurable parameter selected from the group consisting of at least one of stride profile, average stride profile, average cycle fraction difference, stride length unbalance, estimated weight unbalance, difference in max location and difference in slope max location and wherein said measurable parameter is derived from a plurality of waveform peaks for each of a plurality of strides taken by the subject.

12. The method of claim **11** wherein said fitness and therapy device is selected from the group consisting of at least one of treadmill, exercise bike, and elliptical machine.

13. The system of claim **11** wherein the step of securing at least one current transducer comprises removably securing said at least one current transducer and wherein said at least one current transducer is a clamp-on type.

14. The method of claim **11** wherein said means for analyzing, displaying, and reporting further comprises full-wave rectifying of said current signals.

15. A method of determining human and animal performance on a fitness and therapy device comprising the steps of:

coupling an interface box between a source of electrical power and incoming power wiring for a fitness and therapy device,

securing at least one current transducer to said interface box for sensing current signals to said fitness and therapy device,

securing at least one voltage transducer to said interface box for sensing voltage signals to said fitness and therapy device,

connecting a data recorder for recording said current signals and said voltage signals, and connecting a computer having a means for analyzing, displaying, and reporting said current signals and said voltage signals to determine human and animal performance on said device using a measurable parameter selected from the group consisting of at least one of stride profile, average stride profile, average cycle fraction difference, stride length unbalance, estimated weight unbalance, difference in max location, and difference in slope max location and wherein said measurable parameter is derived from a plurality of waveform peaks for each of a plurality of strides taken by the subject.

16. The method of claim **15** wherein said fitness and therapy device is selected from the group consisting of at least one of treadmill, exercise bike, and elliptical machine.

17. The system of claim **15** wherein the step of securing at least one current transducer comprises removably securing said at least one current transducer and wherein said at least one current transducer is a clamp-on type.

18. The method of claim **15** wherein the step of securing at least one current transducer to said interface box comprises securing at least one current transducer to a loop extending externally from and back to said interface box.

19. The method of claim **15** wherein said interface box further comprises a voltage splitter.

20. The method of claim **15** wherein said means for analyzing, displaying, and reporting further comprises full-wave rectifying of said current signals and a power measurement.

21. The system of claim **1** wherein the interface box is removably connected between a source of electrical power and incoming power wiring to a fitness and therapy device by:

an electrical power cable extending from a power outlet to the interface box, and

an electrical power cable extending from the interface box to the fitness and therapy device.

22. The system of claim **5** wherein the interface box is removably connected between a source of electrical power and incoming power wiring to a fitness and therapy device by:

an electrical power cable extending from a power outlet to the interface box, and

an electrical power cable extending from the interface box to the fitness and therapy device.

23. The system of claim **1** wherein the interface box comprises a first power connector for plugging in the source of electrical power and a second power connector for plugging in the power wiring to the fitness and therapy device.

24. A method of determining human and animal performance on a fitness and therapy device selected from the group consisting of at least one of treadmill, exercise bike, and elliptical machine, the method comprising the steps of:

coupling an interface box in series between a source of electrical power and incoming power wiring for a fitness and therapy device by plugging in a first power connector extending from the interface box into the source of electrical power and plugging in a second power connector extending from the fitness and therapy device into the interface box,

securing at least one current transducer to said interface box for sensing current signals to said fitness and therapy device, and

connecting a means for analyzing, displaying, and reporting said current signals to determine human and animal performance on said device using measurable parameters.

25. A method of determining human and animal performance on a fitness and therapy device selected from the group consisting of at least one of treadmill, exercise bike, and elliptical machine, the method comprising the steps of:

coupling an interface box between a source of electrical power and incoming power wiring for a fitness and therapy device by plugging in a first power connector extending from the interface box into the source of electrical power and plugging in a second power connector extending from the fitness and therapy device into the interface box,

securing at least one current transducer to said interface box for sensing current signals to said fitness and therapy device,

securing at least one voltage transducer to said interface box for sensing voltage signals to said fitness and therapy device, and

connecting a data recorder for recording said current signals and said voltage signals, and connecting a computer having a means for analyzing, displaying, and reporting said current signals and said voltage signals to determine human and animal performance on said device using measurable parameters.

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