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(54) Title: SYSTEM AND METHOD FOR MANUAL WELDER TRAINING
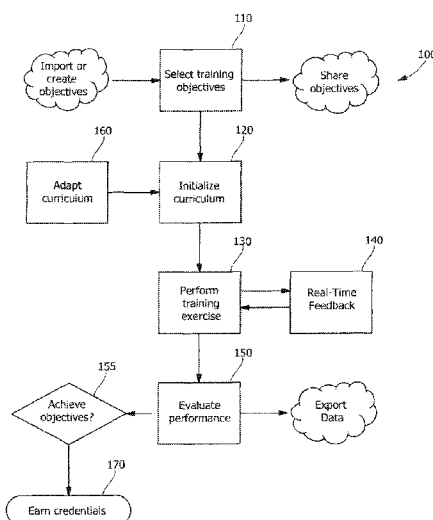
FIG. 1

(57) Abstract: A method for manual welder training that includes providing a welding training apparatus that includes both hardware and software components and that is operative to gather and process data in real time, wherein the data is derived from an actual training exercise conducted by a welding trainee; selecting training objectives from a predetermined number of predefined objectives; initializing a curriculum, wherein the curriculum is based on the selected training objectives; performing at least one training exercise, wherein the training exercise is a component of the curriculum; providing real-time feedback to the trainee, wherein the real-time feedback is based on the performance of the trainee during the training exercise; evaluating the performance of the trainee based on data gathered and processed during the training exercise; optionally, adapting the curriculum based on the trainee's performance evaluation; and awarding credentials or certifications to the trainee following successful completion of the curriculum.

SYSTEM AND METHOD FOR MANUAL WELDER TRAINING

BACKGROUND OF THE INVENTION

5   [0001] The invention proposes a method for manual welder training, according to claims 1, 5 or 7. Preferred embodiments are disclosed in the subclaims in the description and/or in the drawings. The described invention relates in general to a system for characterizing manual welding operations, and more specifically to a system for providing useful informa- tion to a welding trainee by capturing, processing, and presenting in a viewable format,

10 data generated by the welding trainee in manually executing an actual weld in real time.

[0002] The manufacturing industry's desire for efficient and economical welder training has been a well-documented topic over the past decade as the realization of a severe shortage of skilled welders is becoming alarmingly evident in today's factories, shipyards, and con-

15 struction sites. A rapidly retiring workforce, combined with the slow pace of traditional in- structor-based welder training has been the impetus for the development of more effective training technologies. Innovations which allow for the accelerated training of the manual dexterity skills specific to welding, along with the expeditious indoctrination of arc welding fundamentals are becoming a necessity. The characterization and training system dis-

20 closed herein addresses this vital need for improved welder training and enables the moni- toring of manual welding processes to ensure the processes are within permissible limits necessary to meet industry-wide quality requirements. To date, the majority of welding processes are performed manually, yet the field is lacking practical commercially available tools to track the performance of these manual processes. Thus, there is an ongoing need

25 for an effective system for training welders to properly execute various types of welds un- der various conditions.

SUMMARY OF THE INVENTION

30 [0003] The following provides a summary of certain exemplary embodiments of the present invention. This summary is not an extensive overview and is not intended to identify key or critical aspects or elements of the present invention or to delineate its scope.

[0004] In accordance with one aspect of the present invention, a method for manual welder

training is provided. This method includes the steps of providing a welding training apparatus, wherein the training apparatus further includes both hardware and software components, wherein the training apparatus is operative to gather and process data in real time, and wherein the data is derived from an actual training exercise conducted by a welding trainee; selecting training objectives from a predetermined number of predefined objectives; initializing a curriculum for the trainee, wherein the curriculum is based on the selected training objectives; performing at least one training exercise, wherein the training exercise is based on or is a component of the curriculum; providing real-time feedback to the trainee, wherein the real-time feedback is based on the performance of the trainee during the training exercise; evaluating the performance of the trainee based on data gathered and processed during the training exercise; optionally, adapting the curriculum based on the trainee's performance evaluation; and awarding credentials, certifications, or the like to the trainee following successful completion of the curriculum.

[0005] Additional features and aspects of the present invention will become apparent to those of ordinary skill in the art upon reading and understanding the following detailed description of the exemplary embodiments. As will be appreciated by the skilled artisan, further embodiments of the invention are possible without departing from the scope and spirit of the invention. Accordingly, the drawings and associated descriptions are to be regarded as illustrative and not restrictive in nature.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] The accompanying drawings, which are incorporated into and form a part of the specification, schematically illustrate one or more exemplary embodiments of the invention and, together with the general description given above and detailed description given below, serve to explain the principles of the invention, and wherein:

[0007] FIG. 1 is a flow chart of the training methodology of an exemplary embodiment of the system and method for manual welder training of the present invention;

[0008] FIG. 2 is a diagram of a cloud-based server with a breakout of training objectives;

[0009] FIG. 3 is a screenshot of a curriculum sequence of 12 welding procedure specifica-

tions, with welding procedure specifications 1-5 complete and welding procedure specification 6 active;

[0010] FIG. 4 is a screenshot of an example welding procedure specification for GMAW fillet welds in the horizontal position;

[0011] FIG. 5 is a diagram of a cloud-based server with a breakout of training data;

[0012] FIG. 6 is a flowchart of general real-time feedback provided by this invention;

[0013] FIG. 7 is a flowchart of the automated audio coaching component of this invention;

[0014] FIG. 8 is a flowchart of the remote instructor coaching component of this invention;

[0015] FIG. 9 is a flowchart of the transfer mode feedback component of this invention;

[0016] FIG. 10 is a flowchart of the augmented reality component of this invention;

[0017] FIG. 11 is a diagram of a cloud-based server with a remote data processing breakout; and

[0018] FIG. 12 is a flowchart of an exemplary embodiment of the credentialing aspect of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0019] Exemplary embodiments of the present invention are now described with reference to the Figures. Reference numerals are used throughout the detailed description to refer to the various elements and structures. In other instances, well-known structures and devices are shown in block diagram form for purposes of simplifying the description. Although the following detailed description contains many specifics for the purposes of illustration, a person of ordinary skill in the art will appreciate that many variations and alterations to the following details are within the scope of the invention. Accordingly, the following embodiments of the invention are set forth without any loss of generality to, and without imposing limita-

tions upon, the claimed invention.

[0020] In some embodiments, the present invention incorporates and expands upon the technology disclosed in U.S. patent application Ser. No. 13/543,240, which is incorporated by reference herein, in its entirety for all purposes. U.S. patent application Ser. No. 13/543,240 discloses a system for characterizing manual welding operations, and more specifically a system for providing useful information to a welding trainee by capturing, processing, and presenting in a viewable format, data generated by the welding trainee in manually executing an actual weld in real time. More specifically, the system disclosed in U.S. patent application Ser. No. 13/543,240 includes a data generating component; a data capturing component; and a data processing component. The data generating component further includes a fixture, wherein the geometric characteristics of the fixture are predetermined; a workpiece adapted to be mounted on the fixture, wherein the workpiece includes at least one joint to be welded, and wherein the vector extending along the joint to be welded defines an operation path; at least one calibration device, wherein each calibration device further includes at least two point markers integral therewith, and wherein the geometric relationship between the point markers and the operation path is predetermined; and a welding tool, wherein the welding tool is operative to form a weld at the joint to be welded, wherein the welding tool defines a tool point and a tool vector, and wherein the welding tool further includes a target attached to the welding tool, wherein the target further includes a plurality of point markers mounted thereon in a predetermined pattern, and wherein the predetermined pattern of point markers is operative to define a rigid body. The data capturing component further includes an imaging system for capturing images of the point markers. The data processing component is operative to receive information from the data capturing component and then calculate the position and orientation of the operation path relative to the three-dimensional space viewable by the imaging system; the position of the tool point and orientation of the tool vector relative to the rigid body; and the position of the tool point and orientation of the tool vector relative to the operation path. With regard to the system components and operational principles discussed above (i.e., how the data which characterizes the welding operation is obtained), the present invention provides means for taking advantage of the acquired data, whether that be in the welder training realm or the production monitoring realm and provides various methods for utilizing manual welding characterization data to accelerate the process of obtaining predetermined training objectives.

[0021] FIG. 1 provides a flow chart that details a system and method in accordance with the present invention for achieving predetermined training objectives, starting with the selection of a specific set of training objectives and ending with the earning of certain welding credentials. Within this system and method 100, a number of novel techniques are including for helping a user achieve the objectives in an effective and efficient manner. Step 110, which is the initial step in the inventive method disclosed herein, includes selecting an individual or set of training objectives. These objectives, which may be associated with industry welder training standards (e.g., American Welding Society (AWS) D1.1), may be tied directly to qualified or customized welding procedure specifications (WPS) or linked to specific levels or measures of weld quality (e.g., bead size, convexity, defect formation, weld bead tie-in, etc.). A virtual curriculum is then generated at step 120 based on the selected training objectives to guide the user through the training progression. This curriculum is initialized at the onset of training, but typically adapts to the user throughout the process. When in use, the core of this method typically includes a recurring sequence of performing training exercises (step 130); with or without real-time feedback assistance (step 140); evaluating performance (step 150); and adapting or modifying the curriculum based on performance (step 160). Training exercises may be defined as manual welding exercises where the user either makes a weld according to the selected curriculum criteria (e.g., welding process, position, joint type, tool manipulation targets, arc parameters, etc.), or mimics the tool manipulation dynamics without the presence of the welding arc. Throughout the training exercise real-time feedback on an array of performance variables can be utilized to keep the user from straying too far from the objectives. At the conclusion of each training exercise an array of performance measurements (based on the training objectives) may be studied to judge or rate progress. The degree of progress or regression may then be utilized to adapt to the user's needs, whether that be an adjustment to move the user forward in the curriculum or backwards in the curriculum for remedial training. Once the final objectives are met at decision point 155, the user 'graduates' at step 170 by earning the desired credentials or badges, obtaining the job, passing the course, etc.

[0022] As indicated above, step 110 includes selecting an individual or set of desired training objectives, which may vary based on the end user of the system. Table 1 lists several typical environments for training and the respective objectives.

[0023] **TABLE 1.** Typical Environments and Objectives for Manual Welder Training

Environment	Example Objective
High school welding class	Develop the ability to perform a set of welds while maintaining essential variables within an envelope defined by a welding instructor via a set of customized WPSs
Trade school welding class	Develop the ability to perform a set of welds while maintaining essential variables within an envelope defined by prequalified WPSs
Union training program	Become a certified welder under AWS D1.1 structural code
Manufacturer-based qualification	Demonstrate the ability to perform a set of manufacturer-specific welds per a manufacturer-defined quality standard

[0024] A number of steps within the training methodology outlined in FIG. 1 involve some interaction with a cloud-based server or the like. This interaction is necessary in such cases for the selection of a training objective as all objectives are stored on the server whether they are publicly shared or privately managed. FIG. 2 illustrates the data management partitions of the server along with a breakout of training objective specifics. Training objectives can be managed in two different ways; as public objectives, sharable throughout a global community of users, or as private objectives, accessible only by users with rights to the objective. Examples of public objectives are those which may be standardized across an industry. This could be for obtaining a standardized certification, for example. If the user subscribes to a certain industrial sector or organization (e.g. AWS, IIW) the objective may simply be imported. Additionally, custom objectives could be public if the maker of the objective designates them to be public. The server manages the market of standardized or customized training objectives for the global user community, importing and exporting objectives, and tracking metrics for active objectives. Training objectives may also be private and fully customizable for the user. For example, a high school instructor may want to tailor the objectives to fit a time period allowed in a semester, or a manufacturer may want to tailor the objectives around weld types specific to their product. These objectives again may be managed in a secure cloud-based server, and may be imported by users with per-

mission to import. Ultimately, the user either takes advantage of the global community to
select a training objective or develops a user-customized objective. In FIG. 2, an exemplary
embodiment of data management partitions 200 includes remote data processing compo-
nent 210; training data component 220; and training objectives component 230 (all of which

5   are cloud-based), which are accessible by and in communication with other aspects of the
system to provide public objectives 240 and private objectives 250, which are imported at
step 260 or exported at step 270 with regard to local machine 280.

[0025] As indicated above, a virtual curriculum is generated at step 120 based on the se-

10   lected training objectives to guide the user through the training progression. Each selected
objective is accompanied by a corresponding curriculum to guide the user through the
training process, wherein a curriculum is typically comprised of one or more tasks to com-
plete. Typically these tasks are in the form of welding procedure specifications, meaning
that the task is directed toward mastering a specific welding procedure. For example, if the

15   objective is to pass a high school welding course, the curriculum (see FIG. 3) will track pro-
gress on mastering all of the welding procedure specifications that are required for that
particular course. Each welding procedure specification within the curriculum describes a
specific welding procedure in terms of its form variables and execution variables for gener-
ating a quality weld. FIG. 4 provides an example welding procedure specification for

20   GMAW fillet welds in the horizontal position and Table 2 lists examples of form variables
and Table 3 lists examples of execution variables.

[0026] **TABLE 2.** Examples of Form Variable

Form Variables	Typical Values
Process	SMAW, GMAW, FCAW, GTAW
Joint Type	Fillet, Lap, Groove
Position	Flat, Horizontal, Vertical, Overhead
Material	Steel, Aluminum, Titanium
Thickness	0.25, 0.5, 1 [in]
Root Gap	0.03, 0.06, 0.125 [in]
Root Landing	0.03, 0.125, 0.25 [in]
Included Angle	10, 15, 20 [°]

25

[0027] **TABLE 3.** Examples of Execution Variables

Execution Variables	Typical Values
Polarity	DCEP, DCEN
Electrode Type	ER70S-6
Work Angle	45 ± 5 [°]
Travel Angle	5 ± 5 [°]
Arc Length	0.5 ± 0.125 [in]
Travel Speed	10 ± 2 [lpm]
Tool Placement	0.0 ± 0.1 [in]
Current	180 ± 20 [A]
Voltage	22 ± 2 [V]
Weld Size	0.25 ± 0.025 [in]

[0028] The control limits within the welding procedure specification drive the training meth-
odology as the user is measured upon his or her ability to execute the weld within these
limits. This aspect of the prevention is explained in greater detail under step 160, where the
curriculum is adapted. In addition to welding procedure specification tasks, a curriculum
may also include tasks for quizzes and tutorials to integrate classroom tools into the train-
ing booth, mechanical testing for certification objectives, and cleaning and joint preparation
tasks.

[0029] Once the curriculum is initialized the training commences with the initial welding
procedure specification under a nominal control limit setting. This begins a recursive proc-
ess of performing training exercises (step 130); with or without real-time feedback assis-
tance (step 140); evaluating performance (step 150); and adapting or modifying the curricu-
lum based on performance (step 160). Training exercises are defined as the execution of
tool manipulation along a welding joint according to the control limits provided in the weld-
ing procedure specification. These exercises can be carried out in two different modes, arc-
off and arc-on. At an introductory level this exercise is typically performed without the pres-
ence of the arc. As increasing aptitude is observed by the system the training exercises are
shifted to arc-on welding. The data obtained from each training exercise, like the training
objectives, is typically stored in a remote server. If the data needs to be called back into the
local system for any reason (e.g., to evaluate performance) it is pulled from the server, and

processed and displayed locally. FIG. 5 illustrates an exemplary embodiment of the data storage partition 500 of the cloud-based server, wherein remote data processing 510; training data 520; and training objectives 530 (all of which are cloud-based) which are accessible by and in communication with other aspects of the system to provide public date 540 and private data 550, which are imported at step 560 or exported at step 570 with regard to local machine 580.

[0030] As with the training objectives, training data includes a hierarchy of privacy rights. Data may be shared universally for comparison with a global community of users. This is typically implemented when training toward a public objective toward which many users are actively training. For example, AWS may manage an objective for gaining D1.1 certification. Any user who is training toward this objective may choose to share their data for the purpose of comparing their performance to that of others. Additionally, a user may wish to share data with a subset of users such as a high school class, for example. In this situation, data is shared within the class, but not with the global community at large. Other scenarios may require data to be maintained as private information. For example, a user may be training toward a certain manufacturing objective where maintaining a job or position is dependent on performance. In this case, data may only be available to the individual trainee and the instructor.

[0031] As previously discussed, throughout the execution of a training exercise the user may or may not exploit the use of real-time feedback mechanisms at step 140. If real-time feedback is employed, the mechanism is carried out according to the general flow diagram of shown in FIG. 6. In an exemplary embodiment of this invention, real time feedback component 600 includes starting an exercise at step 610; measuring execution variables at step 620; ending the exercise at step 630 or evaluating performance at step 640; and providing a feedback response at 650. Performance is measured, analyzed, and a feedback response is generated to the user in real-time. The purpose of this mechanism is to (i) highlight the differences between acceptable and unacceptable performance while visualizing the execution task; (ii) prevent the user from manipulating the tool in a manner far-removed from the proper technique; and (iii) assist in guiding the user to the proper technique. This assists the user in building muscle memory for proper technique while avoiding bad habits that must eventually be eliminated. Four mechanisms of real-time feedback are included in this invention: (i) automated audio coaching; (ii) instructor-assisted audio coaching; (iii)

transfer mode feedback; and (iv) augmented reality weld rendering. Each mechanism is described in greater detail below.

[0032] With reference to FIG. 7, automated audio coaching entails a real-time feedback mechanism which provides feedback to the user through automated voice commands. In an exemplary embodiment of this invention, automated audio coaching component 700 includes starting an exercise at step 710; measuring execution variables at step 720; ending the exercise at step 730 or determining a limit breach at 740; determining a high priority breach at 750; and playing a corrective audio file at step 760. Prerecorded files are played depending which variables are outside of the control limits. As shown in Table 4 below, a hierarchy is established by which high-priority variables take precedence over lower priority variables. At any given data interpretation frame only one coaching command is executed based on the priority hierarchy (e.g., tool placement takes precedence over tool angle, which takes precedence over travel speed, etc.) Commands are direction-based, meaning that the commands coach the user into the direction of compliance (e.g. if the performance is breaching a lower boundary, the commands with coach the trainee to increase the given variable).

[0033] **TABLE 4.** Automated Audio Coaching Hierarchy

Rank	Variable
1	Tool Placement
2	Tool Offset
3	Travel Speed
4	Work Angle
5	Travel Angle

[0034] With reference to FIG. 8, remote instructor coaching is an interactive real-time feedback mechanism wherein the instructor remotely views live through-the-lens video of the trainee's performance and provides through-the-helmet audio feedback. In practice, a camera or set of cameras capture live images matching the welder's view through the welding lens. These images are transferred to a viewing portal operated by the instructor. The instructor can then view and analyze the trainee's technique. Based on the welder's performance, the instructor may relay live audio feedback from a microphone to a wireless headset

within the trainee's welding helmet. This emulates an instructor 'looking over the shoulder' of the trainee. As shown in FIG. 8. in an exemplary embodiment of this invention, remote instructor coaching component 800 includes starting an exercise at step 810; capturing through-the-lens imagery at step 820; ending the exercise at step 830 or having an instruc-

5   tor view a captured video remotely at step 840; having the instructor provide voice feedback at step 850; and transmitting instructions by way of a headset at step 860.

[0035] With reference to FIG. 9, transfer mode feedback is a real-time feedback mechanism that helps the trainee learn the differences between transfer modes. In an exemplary

10   embodiment of this invention, transfer mode feedback component 900 includes starting an exercise at step 910; measuring a sound signature at step 920; ending the exercise at step 930 or analyzing the sound signature at step 940; determining a transfer mode at step 950; and transmitting the existence of a poor transfer mode by headset at step 960. This mechanism is only applicable in wire-fed arc welding processes like Gas Metal Arc Welding

15   (GMAW) and Flux Cored Arc Welding (FCAW), as these processes manifest a transfer mode. The means of measuring the transfer mode is provided by a microphone integrated into the welding helmet. The sound signal signature is analyzed to determine the transfer mode as either short-circuit, globular, spray, or pulsed-spray.

20   [0036] With reference to FIGS. 10-11, augmented reality provides a means of real-time feedback for both arc-off and arc-on training. In both cases, sensors provide real-time position and orientation values of both the welding helmet and the welding tool in addition to processing data to a cloud-based server. This server performs processor intensive rendering calculations and/or finite element calculations, feeding back to the local system image

25   data to be superimposed over the trainee's view of the welding joint. FIG. 10 outlines the sensor and data flow for augmented reality. In an exemplary embodiment of this invention, augmented reality component 1000 includes starting an exercise at step 1010; measuring process, tool, and helmet variables at step 1020; ending the exercise at step 1030 or sending data to the server at step 1040; processing augmented reality renderings at step 1050;

30   and returning rendered data at step 1060. For arc-off welding the superimposed imagery may include: a virtual welding arc and pool; 3D renderings of a virtual weld bead superimposed on the real weld joint; highlights of the welding joint root location; a pencil trace of the intersection location between the welding tool vector and the workpiece; and/or other features. For arc-on welding the superimposed imagery may include: target and actual

weld pool shape and position (this is the first step is learning to manipulate a weld pool);
target and actual arc placement within the joint; target and actual tool angles; target and
actual tool offset; target and actual travel speed; live indication of defect formation along
the weld; and/or other features. Like the training objectives, a cloud-based server is typi-

5   cally utilized to manage the data for augmented reality feedback. Specifically, the process-
ing power of the server is utilized to take low data count information (process, tool, and
helmet) in, to output image renderings that can be immediately superimposed on the user's
see-through display. FIG. 11 illustrates remote data processing functionality 1100 of the
present invention, wherein training objectives 1110, training data 1120, and remote data

10   processing 1130 (all of which are cloud-based) are accessible by and in communication
with aspects of the system that receive a live data stream at 1140; process selected ren-
derings at 1150; and output a rendered data stream at 1160.

[0037] As indicated above at step 150, at the end of each training exercise the user is given

15   the opportunity to evaluate welding performance. The type of performance evaluation may
include: compliance with training goals; compliance with qualified procedure essential vari-
ables; variability compliance; compliance with weld quality specifications; compliance with
standardized certification specifications; comparison to relative population; performance
over time; work ethic; and/or other factors and measures of performance.

20
[0038] Assessing compliance with training goals may include upper and lower control limits
for each variable, wherein deviations are flagged for analysis. Limits may vary along the
length of the weld, for example, different start/stop regions on a straight weld or continu-
ously changing angles for a 5G pipe weld. Limits may vary for different weld passes, for

25   example, work angle, tip to joint distance and tip to joint offset may vary by pass on a hori-
zontal fillet weld. Training goals may also include welding directions and sequence such as
vertical up versus down. For example, backing up to fill a crater for aluminum welding;
block welding, or "back-up" sequences to control distortion; sequence of joints to be welded
on a complex part with multiple joints; and/or multi-bead overlays. The system is typically

30   programmed by creating a series of vectors relative to the weld joint location by physically
moving the torch from the vector start to the vector stop. For each vector has a position
(with +/− tolerance on start location), direction (with tolerance on the angular direction rela-
tive to the joint), and length (with +/− tolerance). Training goals may also include weave
parameters. Three parameters are used to characterize the weave: weave width, weave

advancement, and weave frequency. A low-pass filter (e.g., averaging) is applied to the positional data to smooth the data and then extreme side to side variations (relative to the overall direction of travel). These three weave parameters are then compared to upper and lower limits like any other parameter. With regard to analysis, all parameters must be simul-

5   taneously within acceptance limits for that portion of weld to be deemed in compliance. The percentage of the weld (by length or time) that all parameters are in compliance is used to assess the overall score and the start time/distance necessary to achieve the steady-state may be calculated.

10   [0039] Assessing consistent compliance with qualified procedure essential variables may include an archive of welding standards and approved procedures for particular applications which may be stored in a database, accessible across a network, and take the form of a procedure qualification record (PQR) or a welding procedure specification (WPS). Welding standards may impose limits on particular parameters (essential variables) to meet

15   weld property, quality, or productivity requirements and fields within the database record identify the restrictions for a given procedure. Examples include welding range of current, range of voltage, range of speed, wire-feed speed, travel speed, weave width, maximum heat input (calculated), range of weld bead size (calculated), mode of metal transfer (inferred from arc signal). The system also measures actuals and identifies deviations beyond

20   the limits. For example, actual welding heat input is above the maximum allowable welding heat input. Welding heat input is calculated from the measured welding current, voltage, and travel speed. The system also statistically analyzes the data. Any deviation from an essential variable makes the weld "rejectable". Deviations identified for a given weld and location are identified. Results from multiple welds are used to evaluate trends (e.g., the

25   trainee must demonstrate consistent compliance with the procedure requirements over time to score highly). The system also archives the result and displays to the user, which may be used to send warning to welder/supervisor, and trigger an inspection on a particular weld. Ongoing deviations flag performance issue to be rectified (e.g., additional training) and scores reflect the ability to comply with essential variables over time. The system also

30   provides tutorials on the importance of the parameter for the procedure, and how performance should be adjusted to comply with the procedure requirements.

[0040] Assessing variability involves the variation in the motion measurements gives an indication of the trainee's fluidity of motion. A score is based on normalized maximum varia-

tion of each parameter from a mean. This may be calculated over a moving time window (e.g., 5 seconds) or the entire weld. Alternatively, frequency analysis methods (e.g., FFT) may be applied to identify the high-frequency components in the power spectrum. This may be compared with a preferred frequency distribution. In this case, gradual changes in torch positioning (e.g., changes to travel angle for 5G pipe welding) would be ignored in the calculation. Also, an optimum weave frequency could be used as a base-line for comparison. Transient areas (start/stops) would be ignored in these calculations.

[0041] Assessing weld quality directly includes various methods for capturing weld quality information. The trainee/instructor is asked to visually inspect the weld, and the result is archived. This may include a displayed image of the weld, and the user dropping icons on the weld to record quality indications (e.g., porosity, weld size, etc.). The data is automatically archived. Alternatively, laser profilometry may be used to inspect the surface of the weld and the data is archived. Another alternative includes capturing a digital photo/video of weld and archiving the data. Post weld non-destructive inspection of a serialized weld may also be completed and the result may be linked to the database record. With regard to the overall analysis, the measurements may be compared with targets to assess the ability of the welder to achieve desired weld bead characteristics. By relating these quality measurements to the welder technique, the welder can learn the relationship between technique and quality. When direct weld quality measurements are available, these may be used to automatically adapt the control limits over time to map-out the range of techniques which produce acceptable welds (i.e., the system learns the optimal combinations which produce acceptable welds). For example, if many welds are made with slightly different techniques, the techniques which result in unacceptable weld quality would be judged to be outside of optimal performance criteria.

[0042] Assessing weld quality with compliance to a training certification links the training performance with mechanical testing and NDE results in one database and walks the trainee through the entire qualification process. Assessing weld quality with compliance to a training certification may also include types of welds to be practiced (parameters, etc.); testing coupons; mechanical testing results, etc. An authorized official typically performs the sign-off on acceptance of the certification results. With regard to assessing performance relative to a population, data is compared with online databases including information from individual in the following types of groups: class, grade level, industry sector, etc. With

regard to assessing performance improvement over time, data is compared to a bench-mark learning speed; data from one time period is compared to a pervious time period to measurement improvement or lack thereof; and the rate of learning is used to determine an aptitude for a particular manual welding technique. With regard to assessing work ethic, the system measures time spent manipulating a tool versus the total time allocated for training and the system differentiates tool manipulation time into 'arc off' and 'arc on' durations.

[0043] As previously indicated, the curriculum component of the present invention may be adapted as step 160. In addition to providing the user with exercise-by-exercise perform-ance evaluations, the training methodology also uses the trainee's performance to dynami-cally adjust targets exercise-by-exercise. The training methodology uses intelligent learning functions to customize the training progression to the trainee's actual progress. The objec-tive of the adaptive curriculum is to guide the trainee's development, providing both a means for fast-tracked learning and remedial training where necessary. This is carried through a number of mechanisms, including: dynamic control limits; dynamic adjustment of active WPS; dynamic variable enablement; dynamic mode enablement; dynamic tutorials; disparate segments within the weld; position-based dynamic control limits; and integrated quizzes.

[0044] With regard to dynamic adjustment of active WPS, as the trainee masters a given welding procedure, the system automatically advances the trainee to the next WPS in the curriculum. If the trainee is struggles with the active WPS, the system automatically shifts the trainee backwards to a previous WPS for remedial training (moving from 'world' to 'world'). With regard to dynamic variable enablement, if the trainee is struggling specifically with one or more variables, the system recognizes this and automatically shifts the en-ablement of variables to be one at time, two at time, etc. With regard to dynamic mode en-ablement, the system forces the trainee to first master the optimal performance criteria in the arc-off mode prior to enabling the arc-on mode. Regarding dynamic tutorials, the sys-tem recognizes the student struggling with compliance on certain variables and automati-cally offers tutorials on focused on the variables (i.e., travel speed is always too high, offer a tutorial on posture for stabilizes speed, or a macro of a weld with high speed, etc.). Addi-tionally, as the trainee progresses to a new WPS with a new joint, position, process, etc., tutorials are offered on those new welding situations. Additionally, the system will recognize defect formation and offer tutorials on what the defects are and how they can be mitigated.

Quizzes may be integrated into the system to test classroom comprehension of basic weld-
ing principles.

[0045] As previously indicated, the trainee may earn credentials at step 170. The final
stage in the training methodology is realized once all of the training objectives have been
completed. Like other aspects of the methodology of this invention, the acquired creden-
tials are dependent on type of training objectives selected. Table 5 below lists various types
of credentials.

[0046] **TABLE 5.** Typical Environments and Credentials for Manual Welder Training

Environment	Example Credential
High school welding class	Obtain a passing grade for high school credit
Trade school welding class	Obtain a passing grade for trade school credit
Union training program	Industry-based certifications and job place-ment
Manufacturer-based qualification	Job placement

[0047] The credentialing aspect of this invention includes a methodology that allows for
portable credentialing sanctioned by numerous credentialing agencies, but managed by
way of a single system that measures one or more key performance metrics of welding
proficiency. These credentials or "badges" are mobile, meaning they can be used as a dis-
closure of skill wherever they are recognized. They may also carry some form of equiva-
lency from one credentialing agency to the next. The core constituents of this methodology
include badge earners, badge event generators, badge issuers, and badge presenters.
FIG. 12 illustrates one embodiment of this methodology and the respective role of each
constituent. In this embodiment, credentialing component 1200 includes identifying an ob-
jective achieved by a badge earner at step 1210; notifying a badge issuing entity of the
occurrence of a badge-generating event at step 1220; making a decision (by the badge
issuer) regarding issuance of a badge at step 1230; notifying (by the badger issuer) the
badge earner of the achievement at step 1240; denying the issuance of a badge at 1250 or
acknowledgement (by the badger earner) of the achievement at step 1260; receiving (by

badger presenters) updated badge information at step 1270; and applying the badge at step 1280. When a badge earner achieves the sanctioned welding objective, an email is formatted by the badge generating device with all the pertinent information on the objective including (i) the badge earner's name; (ii) the badge earner's email address; (iii) the badge

5   earner's unique ID; (iv) the objective; and (v) relevant performance data. The badge issuer then examines the performance data and makes the determination as to whether or not the performance data meets the criteria for generating the badge. Badge issuers may typically be any entity that sanctions, requires, or approves of the obtaining of welding proficiency (e.g., AWS, IIW, trade schools, high schools, and industrial manufacturer, etc.). If the per-

10 formance data is satisfactory, a notification is provided to the badge earner on the success-ful achievement. This notification typically then involves an affirmative acceptance by the badge earner before the badge is officially sanctioned and badge presenters receive up-dated badge information on the badge earner. These presenters include entities similar to various social media, the issuers themselves, or other appropriate entities.

15

[0048] While the present invention has been illustrated by the description of exemplary em-bodiments thereof, and while the embodiments have been described in certain detail, it is not the intention of the Applicant to restrict or in any way limit the scope of the appended claims to such detail. Additional advantages and modifications will readily appear to those

20 skilled in the art. Therefore, the invention in its broader aspects is not limited to any of the specific details, representative devices and methods, and/or illustrative examples shown and described. Accordingly, departures may be made from such details without departing from the spirit or scope of the applicant's general inventive concept.

REFERENCE NUMBERS

100	system and method	650	step
110	step	700	automated audio coaching com-
120	step		ponent
130	step	710	step
140	step	720	step
150	step	730	step
155	decision point	740	step
160	step	750	step
170	step	760	step
200	management partitions	800	remote instructor coaching com-
210	remote data procession		ponent
	component	810	step
220	data component	820	step
230	objectives component	830	step
240	public objectives	840	step
250	private objectives	850	step
260	step	860	step
270	step	900	transfer mode feedback
280	local machine		component
500	data storage partition	910	step
510	data processing	920	step
520	training data	930	step
530	training objectives	940	step
540	public date	950	step
550	private data	960	step
560	step	1000	augmented reality component
570	step	1010	step
600	real time feedback component	1020	step
610	step	1030	step
620	step	1040	step
630	step	1050	step
640	step	1060	step

1100	remote data processing functionality
1110	training objectives
1120	training data
1130	remote data processing
1140	live data stream
1150	step
1200	credentialing component
1210	step
1220	step
1230	step
1240	step
1250	step
1260	step
1270	step
1280	step

CLAIMS

1.   A method for manual welder training, comprising:

        (a) providing a welding training apparatus, wherein the training apparatus further in-
        cludes both hardware and software components, wherein the training apparatus is
        operative to gather and process data in real time, and wherein the data is derived
        from an actual training exercise conducted by a welding trainee;

        (b) selecting training objectives from a predetermined number of predefined objec-
        tives;

        (c) initializing a curriculum for the trainee, wherein the curriculum is based on the
        selected training objectives;

        (d) performing at least one training exercise, wherein the training exercise is based
        on or is a component of the curriculum, and wherein the at least one training exer-
        cise further includes at least one execution task;

        (e) providing real-time feedback to the trainee, wherein the real-time feedback is
        based on the performance of the trainee during the training exercise;

        (f) evaluating the performance of the trainee based on weld quality data gathered
        and processed during the training exercise;

        (g) optionally, adapting the curriculum based on the trainee's performance evalua-
        tion; and

        (h) awarding credentials, certifications, or the like to the trainee following successful
        completion of the curriculum.

2.   The method of claim 1, wherein the training objectives further includes public objec-
        tives, private objectives, or both public and private objectives.

3.   The method of claim 1, wherein the curriculum further includes a series of prede-
        termined tasks, and wherein the tasks are in the form of welding procedure specifi-
        cations.

4.   The method of any one of the claims 1 to 3, wherein the at least one training exer-
        cise is performed in either arc-off mode or arc-on mode.

5.   A method for manual welder training, comprising:

(a) providing a welding training apparatus, wherein the training apparatus further includes both hardware and software components, wherein the training apparatus is operative to gather and process data in real time, and wherein the data is derived from an actual training exercise conducted by a welding trainee;

5   (b) selecting training objectives from a predetermined number of predefined objectives, wherein the training objectives further includes public objectives, private objectives, or both public and private objectives;

(c) initializing a curriculum for the trainee, wherein the curriculum is based on the selected training objectives, wherein the curriculum further includes a series of pre-

10   determined tasks, and wherein the tasks are in the form of welding procedure specifications;

(d) performing at least one training exercise, wherein the training exercise is based on or is a component of the curriculum, wherein the at least one training exercise further includes at least one execution task, and wherein the at least one training

15   exercise is performed in either arc-off mode or arc-on mode;

(e) providing real-time feedback to the trainee, wherein the real-time feedback is based on the performance of the trainee during the training exercise, wherein the real-time feedback further includes automated audio coaching; instructor-assisted audio coaching; transfer mode feedback; augmented reality weld rendering; or

20   combinations thereof;

(f) evaluating the performance of the trainee based on weld quality data gathered and processed during the training exercise;

(g) optionally, adapting the curriculum based on the trainee's performance evaluation; and

25   (h) awarding credentials, certifications, or the like to the trainee following successful completion of the curriculum.

6.   The method of claim 1 or 5, wherein the welding training apparatus further includes:

(a) a data generating component, wherein the data generating component further

30   includes:

(i) a fixture, wherein the geometric characteristics of the fixture are predetermined;

(ii) a workpiece adapted to be mounted on the fixture, wherein the workpiece includes at least one joint to be welded, and wherein the vector extending along the joint to be welded defines an operation path;

(iii) at least one calibration device, wherein each calibration device further includes at least two point markers integral therewith, and wherein the geometric relationship between the point markers and the operation path is predetermined; and

(iv) a welding tool, wherein the welding tool is operative to form a weld at the joint to be welded, wherein the welding tool defines a tool point and a tool vector, and wherein the welding tool further includes a target attached to the welding tool, wherein the target further includes a plurality of point markers mounted thereon in a predetermined pattern, and wherein the predetermined pattern of point markers is operative to define a rigid body; and

(b) a data capturing component, wherein the data capturing component further includes an imaging system for capturing images of the point markers; and

(c) a data processing component, wherein the data processing component is operative to receive information from the data capturing component and then calculate:

(i) the position and orientation of the operation path relative to the three-dimensional space viewable by the imaging system;

(ii) the position of the tool point and orientation of the tool vector relative to the rigid body; and

(iii) the position of the tool point and orientation of the tool vector relative to the operation path.

7.   A method for manual welder training, comprising:

(a) providing a welding training apparatus for use by a welding trainee, wherein the welding apparatus further includes:

(i) a data generating component, wherein the data generating component further includes:

a) a fixture, wherein the geometric characteristics of the fixture are predetermined;

b) a workpiece adapted to be mounted on the fixture, wherein the workpiece includes at least one joint to be welded, and wherein the vector extending along the joint to be welded defines an operation path;

c) at least one calibration device, wherein each calibration device further includes at least two point markers integral therewith, and wherein the geometric relationship between the point markers and the operation path is predetermined; and

d) a welding tool, wherein the welding tool is operative to form a weld at the joint to be welded, wherein the welding tool defines a tool point and a tool vector, and

wherein the welding tool further includes a target attached to the welding tool, wherein the target further includes a plurality of point markers mounted thereon in a predetermined pattern, and wherein the predetermined pattern of point markers is operative to define a rigid body; and

5 (ii) a data capturing component, wherein the data capturing component further includes an imaging system for capturing images of the point markers; and

(iii) a data processing component, wherein the data processing component is operative to receive information from the data capturing component and then calculate:

a) the position and orientation of the operation path relative to the three-dimensional

10 space viewable by the imaging system;

b) the position of the tool point and orientation of the tool vector relative to the rigid body; and

c) the position of the tool point and orientation of the tool vector relative to the operation path; and

15 (b) selecting training objectives from a predetermined number of predefined objectives, wherein the training objectives further includes public objectives, private objectives, or both public and private objectives;

(c) initializing a curriculum for the trainee, wherein the curriculum is based on the selected training objectives, wherein the curriculum further includes a series of pre-

20 determined tasks, and wherein the tasks are in the form of welding procedure specifications;

(d) performing at least one training exercise, wherein the training exercise is based on or is a component of the curriculum, wherein the at least one training exercise further includes at least one execution task, and wherein the at least one training

25 exercise is performed in either arc-off mode or arc-on mode;

(e) providing real-time feedback to the trainee, wherein the real-time feedback is based on the performance of the trainee during the training exercise, wherein the real-time feedback further includes automated audio coaching; instructor-assisted audio coaching; transfer mode feedback; augmented reality weld rendering; or

30 combinations thereof;

(f) evaluating the performance of the trainee based on weld quality data gathered and processed during the training exercise;

(g) optionally, adapting the curriculum based on the trainee's performance evaluation; and

(h) awarding credentials, certifications, or the like to the trainee following successful completion of the curriculum.

8.   The method of any one of the claims 1 to 7, wherein the welding training apparatus is in communication with at least one cloud-based server.

9.   The method of any one of the claims 1 to 8, wherein the curriculum further includes form variables, and wherein the form variables further include: process type; joint type; position; material type; thickness; root gap; root landing; included angle; and combinations thereof.

10. The method of any one of the claims 1 to 9, wherein the curriculum further includes execution variables, and wherein the execution variables further include: polarity; electrode type; work angle; travel angle; arc length; travel speed; tool placement; current; voltage; weld size; or combinations thereof.

11. The method of any one of the claims 1 to 10, wherein the curriculum further includes tasks for quizzes and tutorials; mechanical testing for certification objectives; and cleaning and joint preparation tasks.

12. The method of any one of the claims 2 or 6 to 11, wherein the real-time feedback is operative to highlight the differences between acceptable and unacceptable performance while allowing to the trainee to visualize the execution task; prevent the trainee from manipulating the welding tool in a manner far-removed from the proper technique; and guide the trainee to proper welding technique.

13. The method of any one of the claims 1 to 4 or 6 to 12, wherein the real-time feedback further includes automated audio coaching; instructor-assisted audio coaching; transfer mode feedback; augmented reality weld rendering; or combinations thereof.

14. The method of claim 13, wherein automated audio coaching further includes real-time feedback in the form of automated voice commands, and wherein the automated voice commands further includes prerecorded audio files that are played to the trainee based on predetermined variables being outside of set control limits.

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15.   The method of claim 14, wherein the predetermined variables are arranged in a hierarchy of high-priority variables to low-priority variables, and wherein the variables include in descending order of priority: tool placement; tool offset; travel speed; work angle; and travel angle.

16.   The method of claim 13 wherein the instructor-assisted audio coaching further includes interactive real-time feedback wherein an instructor remotely views the trainee during a training exercise through a welding lens used by the trainee, and wherein the instructor relays live audio feedback from a microphone to a wireless headset within a welding helmet worn by the trainee.

17.   The method of claim 13, wherein the transfer mode feedback provides real-time feedback for helping the trainee learn differences between transfer modes when transfer modes are present, wherein a microphone integrated into a welding helmet worn by the trainee measures the transfer mode by detecting a sound signal signature, and wherein the sound signal signature is then analyzed to determine if the transfer mode is short-circuit, globular, spray, or pulsed-spray.

18.   The method of claim 13, wherein the augmented reality weld rendering further includes the use of sensors that provide real-time position and orientation values of both a welding helmet worn by the trainee and a welding tool used by the trainee in addition to processing data gathered during the training exercise to a cloud-based server, wherein the server performs rendering calculations or finite element calculations, and wherein image data is generated based on these calculations and is superimposed over the trainee's view of a welding joint being created during a welding exercise.

19.   The method of claim 18, wherein the training exercise is performed in arc-off mode, and wherein the superimposed imagery further includes a virtual welding arc and pool; 3D renderings of a virtual weld bead superimposed on the real weld joint; highlights of the welding joint root location; a pencil trace of the intersection location between the welding tool vector and the workpiece; or combinations thereof.

20. The method of claim 18, wherein the training exercise is performed in arc-on mode, and wherein the superimposed imagery further includes target and actual weld pool shape and position; target and actual arc placement within the joint; target and actual tool angles; target and actual tool offset; target and actual travel speed; live indication of defect formation along the weld; or combinations thereof.

21. The method of any one of the claims 1 to 20, wherein the performance evaluation further includes an assessment of compliance with training goals; compliance with qualified procedure essential variables; variability compliance; compliance with weld quality specifications; compliance with standardized certification specifications; comparison to relative population; performance over time; work ethic; or combinations thereof.

22. The method of claim 21, wherein assessing compliance with training goals further includes assessing upper and lower control limits for predetermined variables; welding directions and sequence; weave parameters; or combinations thereof.

23. The method of claim 21 or 22, wherein assessing compliance with qualified procedure essential variables further includes use of an archive of welding standards and approved procedures for particular applications which are stored in a database, accessible across a network, and take the form of a procedure qualification record or a welding procedure specification.

24. The method of any one of the claims 21 to 23, wherein assessing variability further includes assessing variations in motion measurements taken from the trainee, and wherein the variations provide an indication of the trainee's fluidity of motion.

25. The method of any one of the claims 21 to 24, wherein assessing weld quality further includes visual inspection of a completed weld; laser profilometry; capturing digital photos or videos of the completed weld; post weld non-destructive inspection; or combinations thereof.

26. The method of any one of the claims 1 to 25, wherein the curriculum is adaptive, and wherein the adaptive curriculum further includes dynamic control limits; dy-

namic adjustment of active WPS; dynamic variable enablement; dynamic mode en-
ablement; dynamic tutorials; disparate segments within the weld; position-based dy-
namic control limits; integrated quizzes and combinations thereof.

5   27.   The method of any one of the claims 1 to 26, wherein awarding credentials further
includes the awarding of portable badges, wherein the portable badges are awarded
to a welding trainee based on the successful completion of one or more aspects of
the curriculum, and wherein the successful completion of one or more aspects of
the curriculum is recognized by one or more credentialing agencies or entities as
10   representing at least one measurement of key performance metrics of welding profi-
ciency.

FIG. 1

FIG. 2

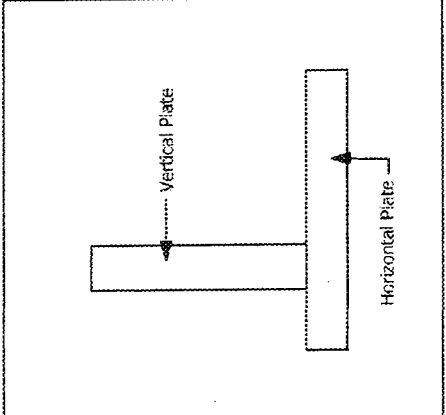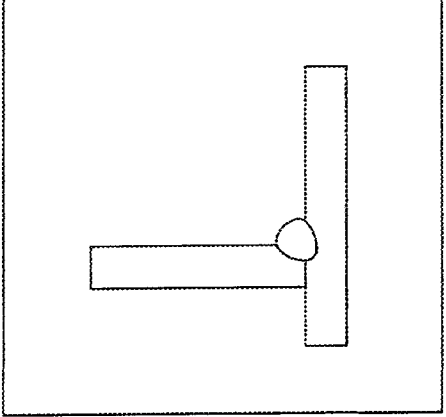| CURRICULUM STATUS	
✓ 1	1G Stringer Single Pass - GMAW
✓ 2	1F Fillet Single Pass - GMAW
✓ 3	1F Lap Single Pass - GMAW
✓ 4	1G Butt Single Pass - GMAW
✓ 5	2G Stringer Single Pass - GMAW
○ 6	2F Fillet Single Pass - GMAW
7	2F Lap Single Pass - GMAW
8	2G Butt Single Pass - GMAW
9	3G Stringer Single Pass - GMAW
10	3F Fillet Single Pass - GMAW
11	3F Lap Single Pass - GMAW
12	3G Butt Single Pass - GMAW

FIG. 3

WELDING PROCEDURE SPECIFICATION

Procedure Documentation

Job Title:	2F Fillet Single Pass - GMAW
WPS Number:	5
Client:	EWI
Type:	Single Pass

Basics

Process(es):	GMAW
Joint Type:	Fillet
Position:	Horizontal:
Technique:	

Joint Details

Vertical Plate:	Steel	0.250 in
Horizontal Plate:	Steel	0.250 in

Process Extras

GMAW	Transfer Mode:	Short Circuit
	Shielding Gas:	100 Az	30 cfh
FCAW	Transfer Mode:	
	Shielding Gas:	
GTAW	Electrode:	
	Shape:	
	Shielding Gas:	

Heat Treatment

Preheat Temperature:	0 F
Interpass Temperature:	0 F
Postheat Temperature:	0 F
Preheat Time:	0 F

Joint Design

Vertical Plate

Horizontal Plate

Weld Sequence

Pass Details

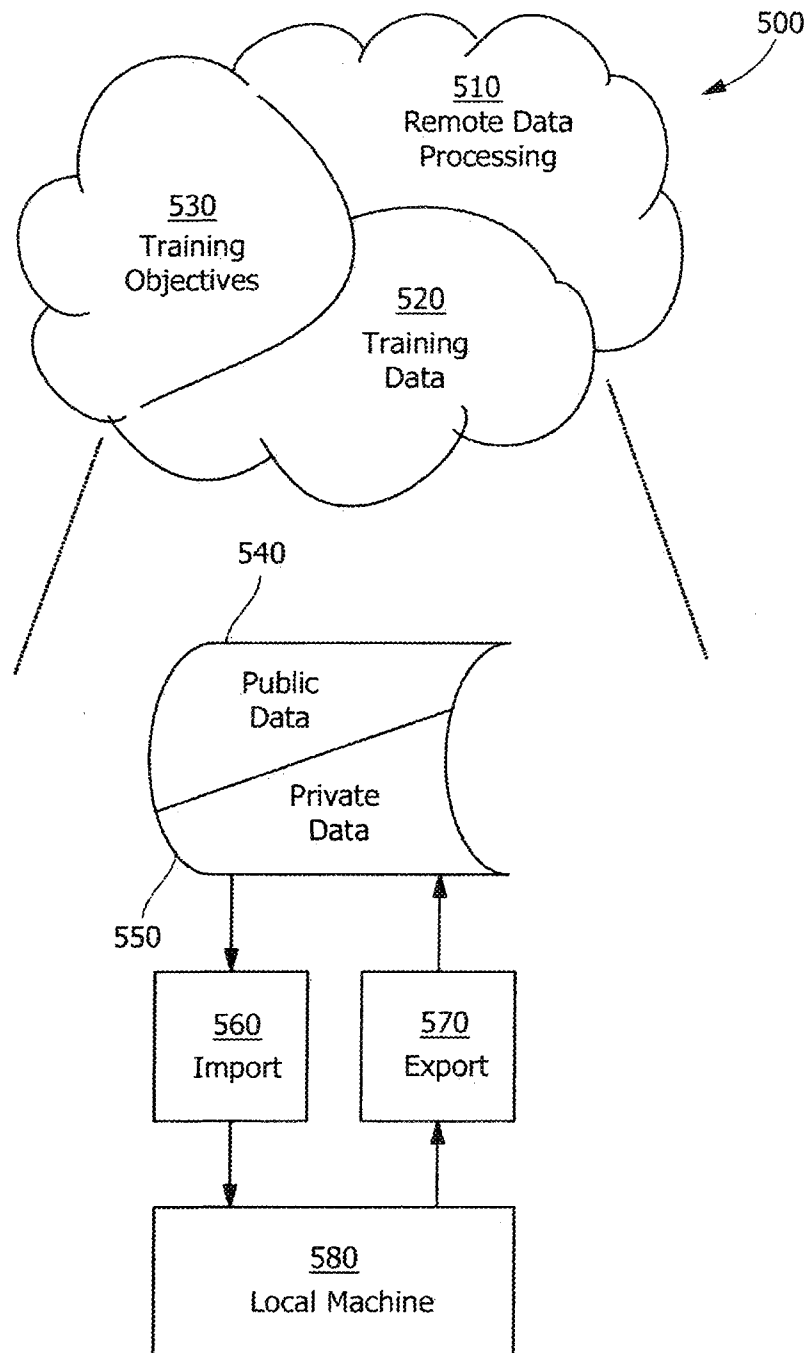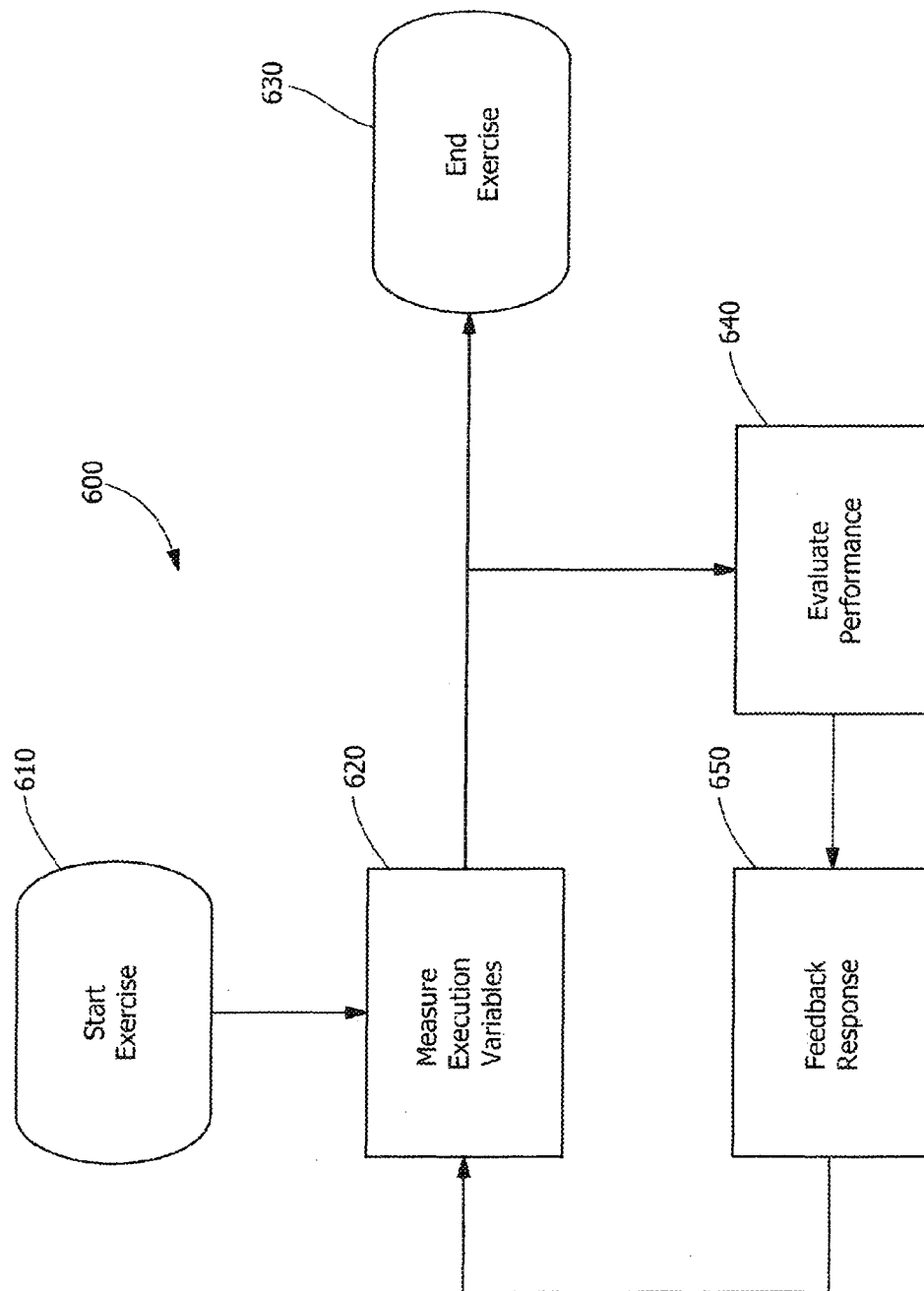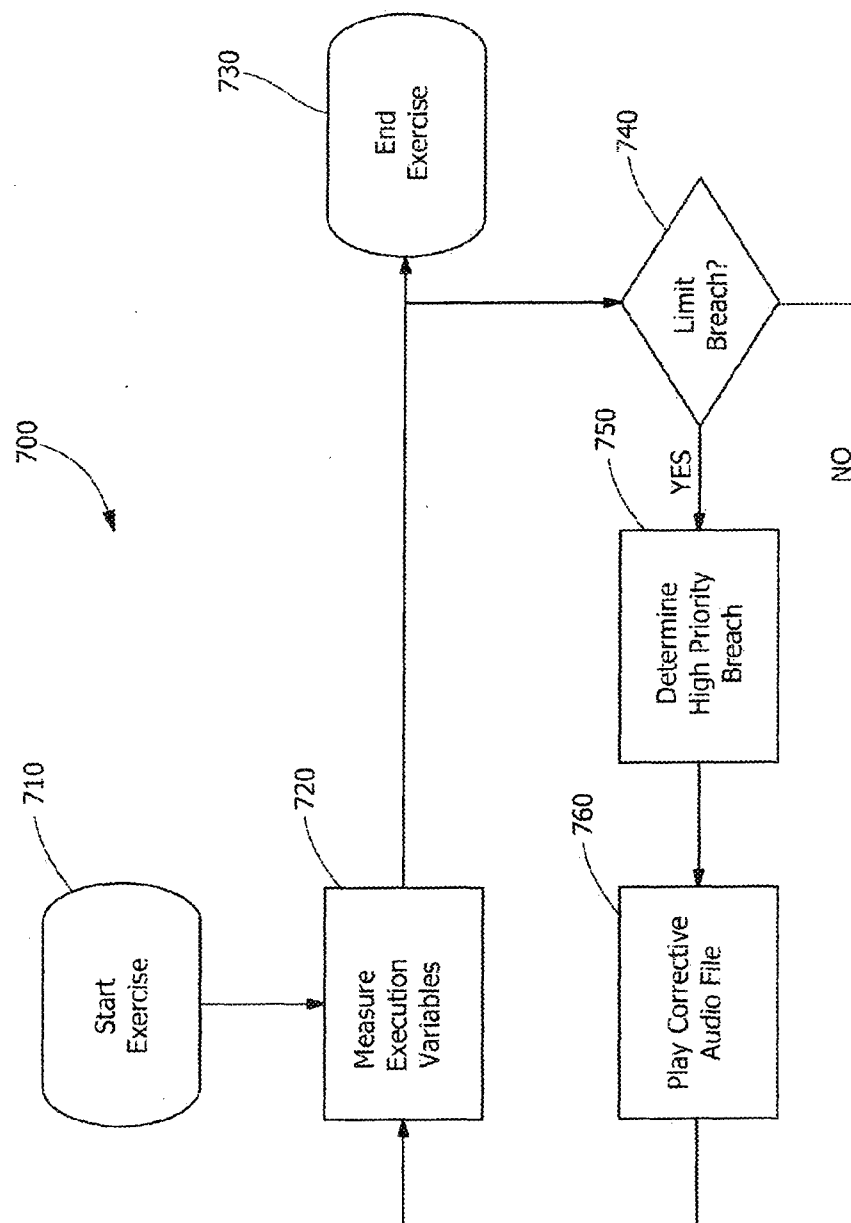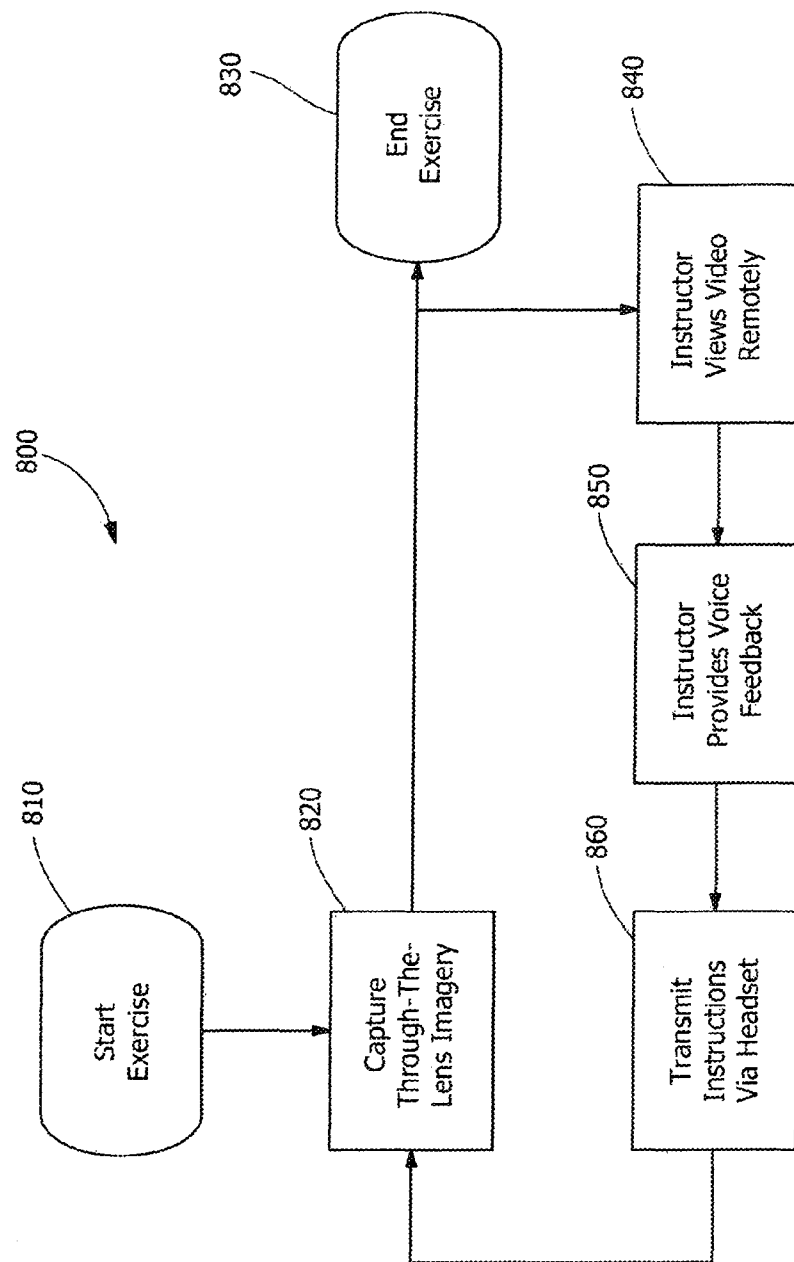| Passes	Process	Polarity	Electrode	Work Angle (deg)	Travel Angle (deg)	CTWD (in)	Travel Speed (ipm)	Proximity (in)	Current (A)	Voltage (V)	Wire Feed Speed	Wire Size (in)
1	GMAW	DCEP	ER70S-6 0.035 in	40.00 - 50.00	2.00 - 8.00	0.25 - 0.75	2.50 - 10.00	-0.20 - 0.20	160 - 200	17.0 - 20.0	220 - 240	0.250

FIG. 4

FIG. 5

FIG. 6

FIG. 7

FIG. 8
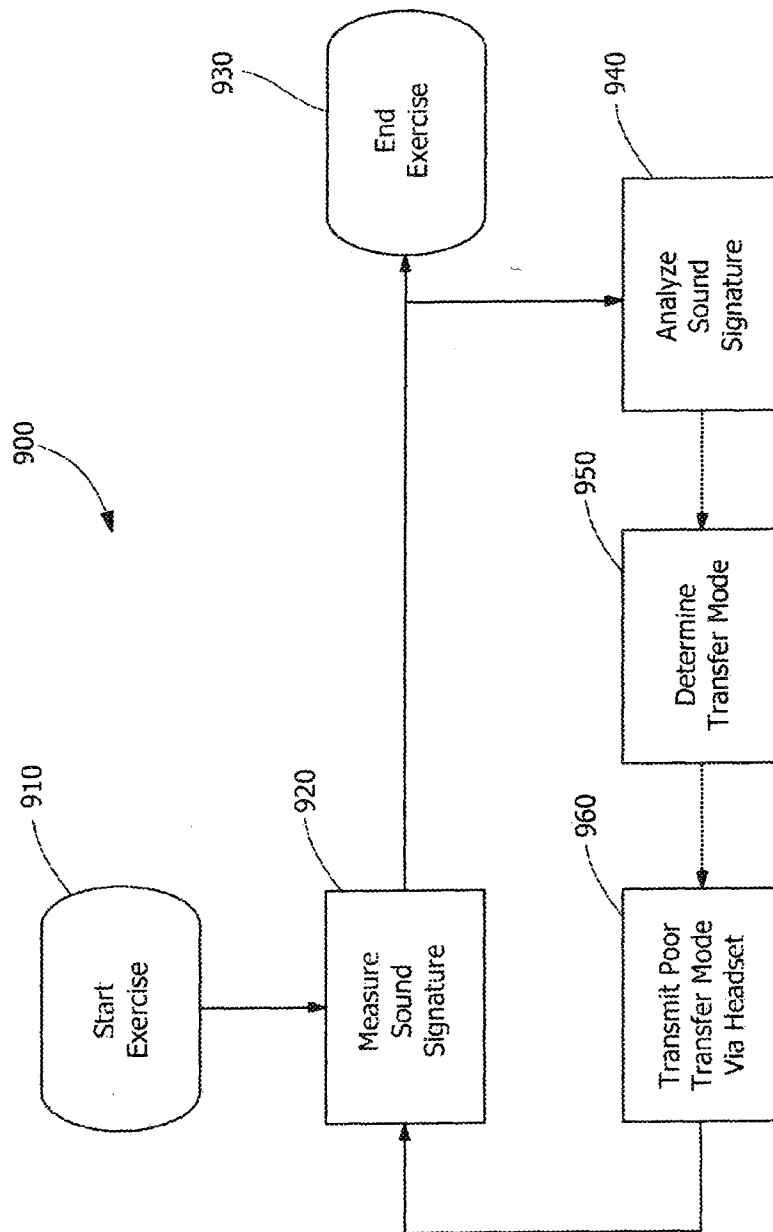
FIG. 9
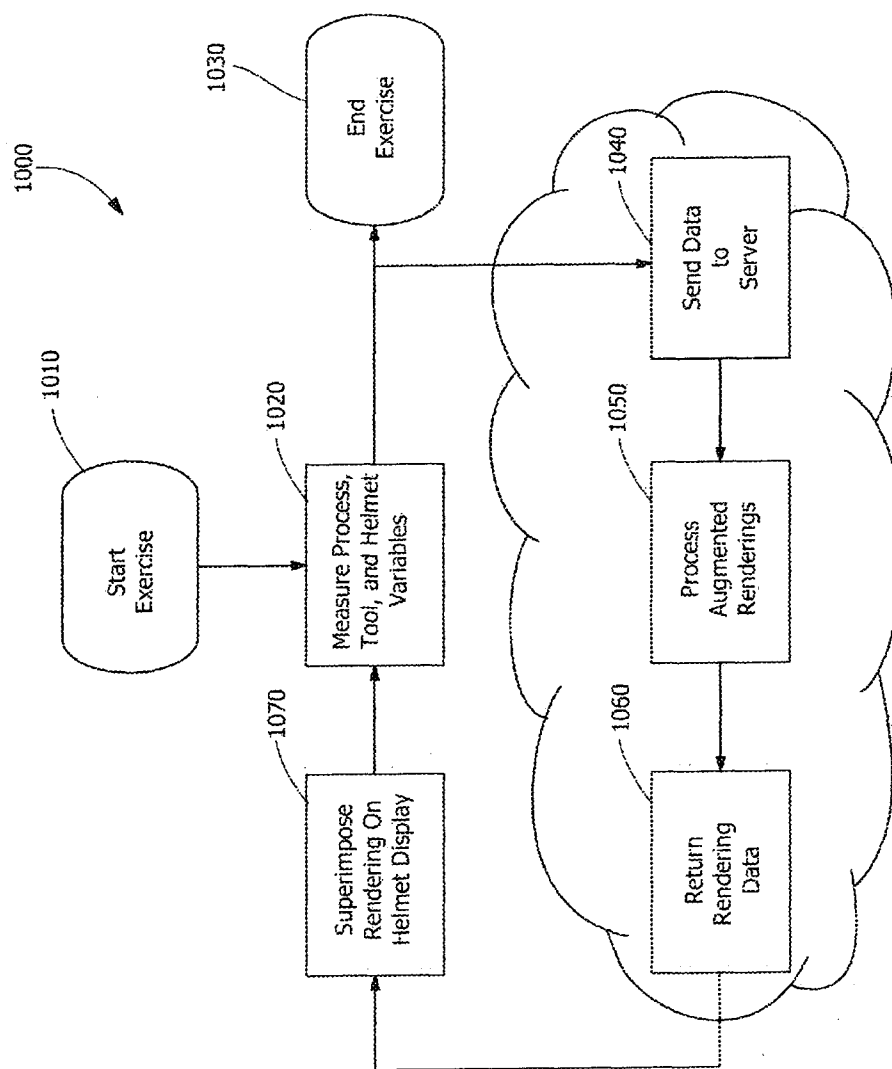
FIG. 10
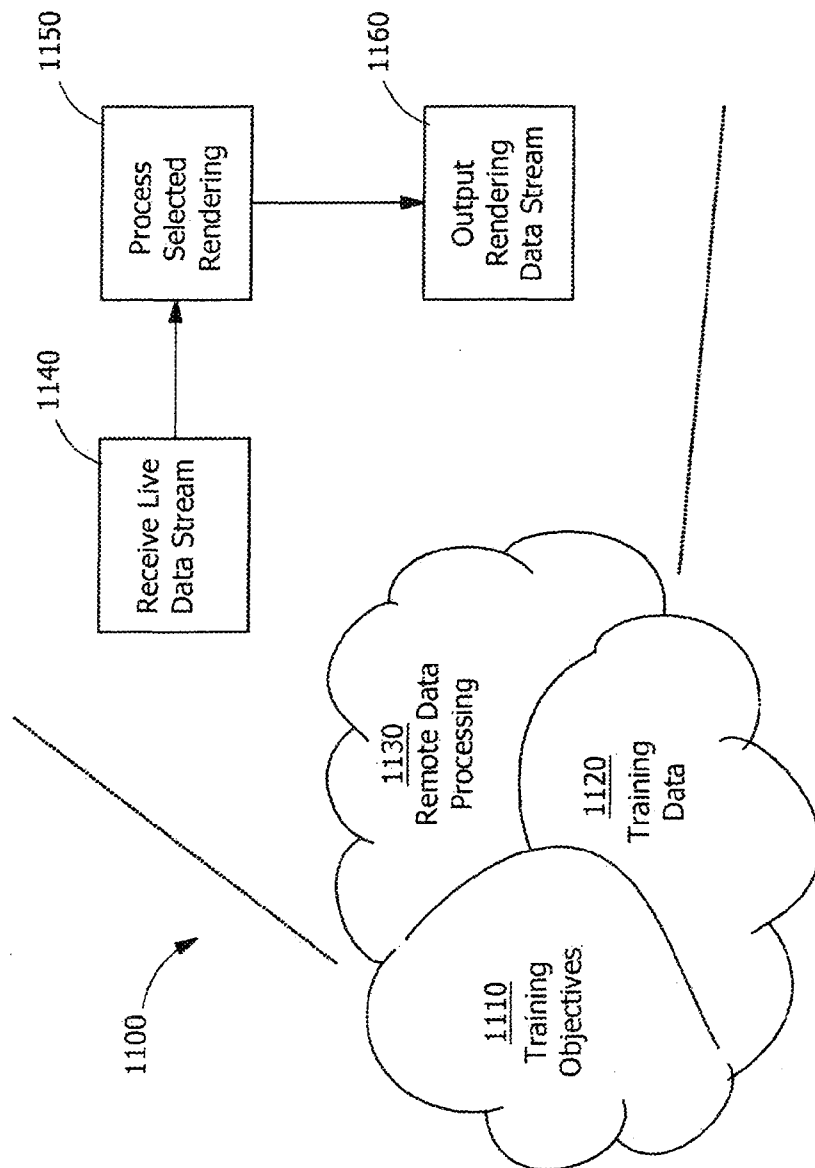
FIG. 11
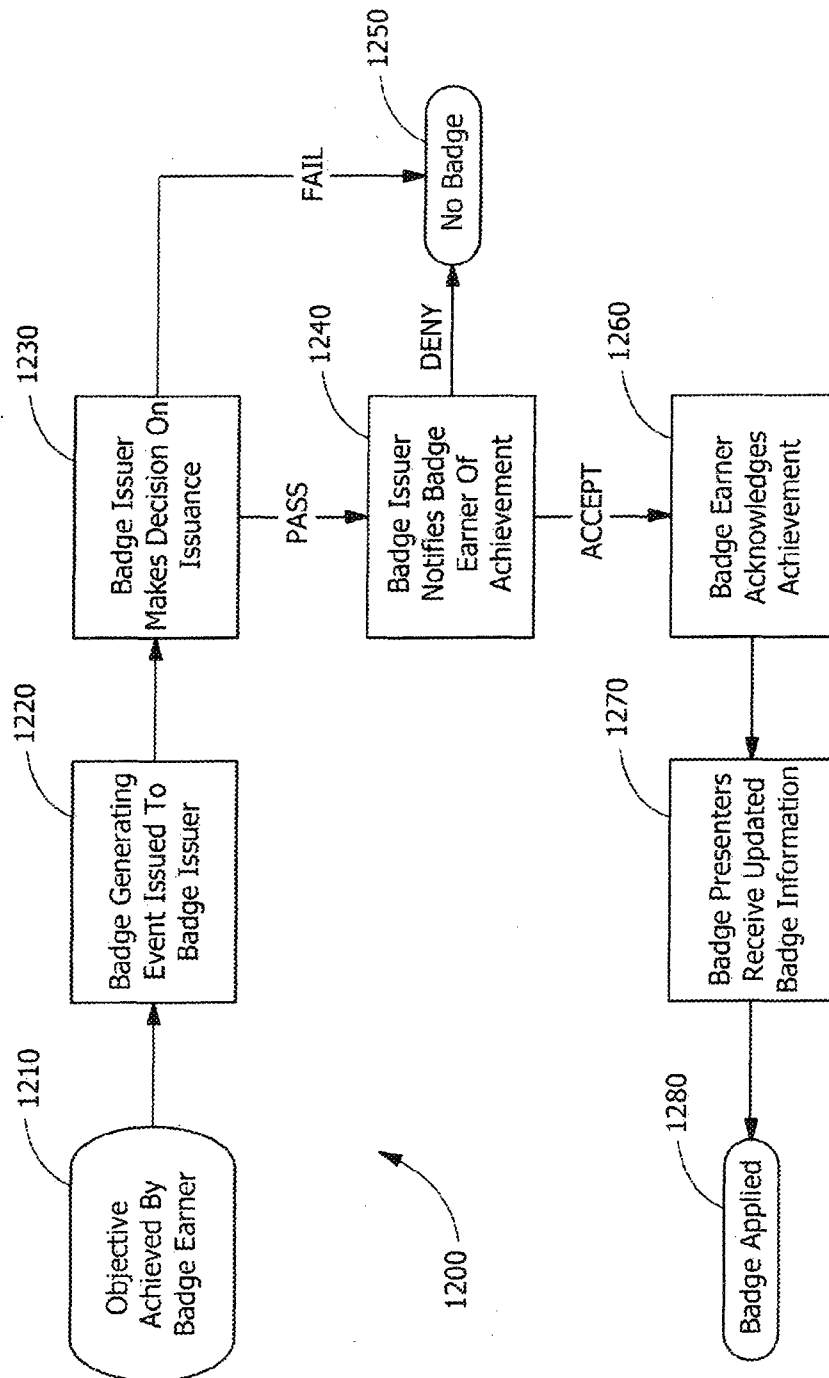
FIG. 12

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
INV. G09B19/24
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G09B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2014/007830 A1 (EDISON WELDING INST INC [US]; CONRARDY CHRISTOPHER C [US]; BOULWARE PA) 9 January 2014 (2014-01-09) paragraph [0005] -----	1-27
A	US 2012/298640 A1 (CONRARDY CHRISTOPHER C [US] ET AL) 29 November 2012 (2012-11-29) claim 1 -----	1-27

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 September 2015	21/09/2015

| Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016 | Authorized officer Beauce, Gaetan |

INTERNATIONAL SEARCH REPORT

Information on patent family members

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
WO 2014007830	A1	09-01-2014	CN 104603860 A	06-05-2015
			DE 202012013151 U1	02-02-2015
			JP 3198723 U	23-07-2015
			KR 20150048715 A	07-05-2015
			WO 2014007830 A1	09-01-2014
US 2012298640	A1	29-11-2012	NONE	