Electrode Consumption Simulation for Shielded Metal Arc Welding in Virtual Welding Training System

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Abstract- **One of the major problems in industry are new welding trainees cost, it drains the budget of many companies, particularly in industrialized countries, through raw material costs for preparation, welding wires, electric and fumes in addition to time spent. Recently a new technique was appeared; it is called virtual welding training system (VWTS) to reduce the training cost. In the present work a VWTS technique was built, a simulation of electrode motion is upgraded by using LVDT to represent the welding arc length while a DC motor with gearbox connect to the steel rode is used to represent welding electrode consumption. A 2D graphs with touch screen monitor are used to represent welding process. All sensors were calibrated to generate a VWTS. Accepted results obtained in training new welding trainees in the shielded metal arc welding (SMAW) training.**

Key wards: Virtual welding, electrode simulator, SMAW, LVDT, VWTS

1. Introduction:

Virtual Reality (VR) is currently being used as a training tool in a number of different application areas including medicine, aviation, and military [1]. In industrial field, Welding simulation development started in earnest during the past decade in three countries: the U.S., Canada, and France. Teams in each country tackled the challenge differently, and each emerged with its own technologies, but all have the same overarching goal: to make weld training more effective [2].
In 2008 C. Choquet [3], president of 123Certification Inc. in Montreal, is a welding engineer who has focused his research on the simulation of manual and semiautomatic processes. The company’s arc+® simulator, first implemented fully in 2006, depicts a virtual environment through 3D glasses inside a welding helmet.
In 2001 a French vocational training organization had the idea of virtual welding training, and contracted with CS [2], a French conglomerate. By 2003, the company had developed its first prototype. Dubbed CS WAVE, the technology differs from arc+ in that it doesn’t use a welding helmet and the welding action happens on a screen that can be moved into the horizontal or flat position.
During the last two decades, there are several patents in virtual welding registered around the world especially in USA [4-11]. These patents are varied between built welding simulators and developments of the helmet.
In the present work, low cost sensors and new techniques are used to get low cost virtual welding machine. Vectornave VN-100 is used to get the welding angles [12], LabJack HV U3 is used as analog to digital convertor [13].

2. Welding Electrode Simulator

The construction Virtual Welding Training Machine (BasVW 1.1) consists from major virtual view system (Helmet and 22" LCD touch screen) and virtual tools system (welding gun & coupons) beside to PC and several types of converters [14]. The converters consist fdof analog to digital converter (ADC) and Video Graphics Array (VGA) converters in addition to several electrical conductors to change the power supply sources. Fig.1 shows the whole system of the present virtual welding training system.

Fig.1Virtual Welding Training Machine (BasVW 1.1)

Fig. 2 shows one of the trainees one the virtual welding training machine (BasVW 1.1).

Fig. 2 Training one the virtual welding training machine (BasVW 1.1)

The construction welding gun simulator consists of several sensors and 12V DC motor. The main purpose of the welding gun simulator is to produce a simulated environment of the real welding process especially in shielded metal arc welding (SMAW). A steel screw shaft with small gearbox connects with 12V DC motor are used to represent the consumption of the real welding electrode as indicated in Fig.3. The arc length sensor, electrode consumption sensor, travel speed sensors and welding angles sensors will be studied.

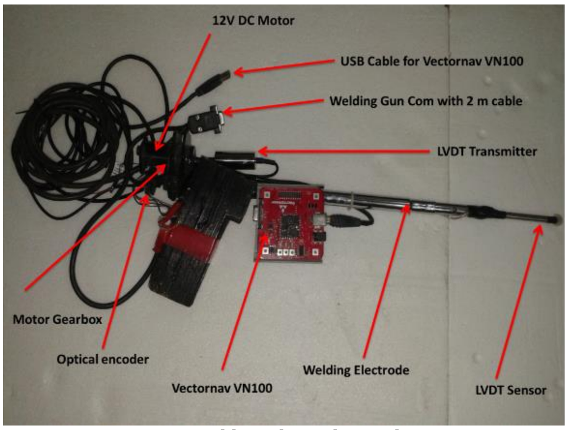

Fig. 3 welding electrode simulator

2.2 LVDT Displacement Sensor

The linear variable differential transformer (LVDT) is an electromechanical device that produces an electrical output proportional to the displacement of a separate nonmagnetic movable core [15]. The LVDT is a high-tech instrument used to measure the elongation, vibration, thickness, expansion and so on. DC LVDT performs excellently from 9-28 voltage DC power supply, suitable for high precision and high repeatability measurements with output standard signal of 0-5v or 4-20mA [15], the widely range of this type of sensor is considered as the cause of using it in this project.

2.3 Arc Length Sensor

The Arc Length is the term used to describe the distance from the tip of the electrode to the base metal and can be varied from lightly touching the metal at an angle sufficient to maintain an arc to a distance far enough from the base metal to extinguish the arc [16].

If the electrode is held in contact with the work using a slight angle to maintain the arc, it is referred to as the drag technique. This technique is often used to weld in the flat and horizontal positions, especially with larger or iron powder electrodes. If contact with the base metal is made too quickly however; the electrode will stick or freeze to the metal. Another method to employ is to allow a slight gap between the electrode tip and the base metal. The length of the arc gap affects the appearance of the weld.

The correct arc length may vary according to the type of electrode and the position of welding [17] .

One of the major difficulties in virtual welding systems is how to represent arc welding to get the actual distance between the tips of electrode and welding coupons.

Several methods are used around the world to represent arc length; the results of these methods depend upon the type of sensors. Ultrasound, infrared (IR) and laser sensors are used for this purpose, in IR and ultrasound sensors the cost of the system considered as accepted or cheap but the results are not quite good since in most types of the IR and ultrasound the accuracy range is ±2 cm while in the laser sensor the results are quite good but the cost is very expensive as compare with the IR and ultrasound types.

2.4 Recommended Arc Length

Controlling the arc length is very important by making sure that the electrode is not too close to the base metal. If the electrode is too close or the arc length is too short, the weld will be bad. [18]

The correct arc length varies with each electrode and application. As a good starting point, arc length should not exceed the diameter of the metal portion (core) of the electrode, e.g. a 3.2 mm (1/8-in.) 6010 electrode is held about 3.2 mm (1/8 in.) off the base material. The optimal arc length, or distance between electrode and puddle, is the same as the diameter of the electrode (the actual metal part within the flux covering) [18].

In the virtual welding training system it is very important to represent the behavior of arc length change. The arc length change is depending upon the feedback of the input voltage value of LVDT to the ADC as illustrated below:

- When the value of the arc length sensor (LVDT) is lower than with minimal recommended arc length value, the system will be indicated (stick), while when the LVDT value is greater than the recommended arc length value, the system will stop the virtual welding process.
- When the value of LVDT is between the maximum and minimum recommended arc length values, the helmet 8" DVD screen will receive data from PC (virtual welding process). In this case, the software provides two parallel lines indicate the variation of arc length as shown in Fig. 4. The distance between the two parallel lines varied according to the value of arc length sensor (LVDT), when the value of arc length sensor (LVDT) within the recommended values, the color of the two parallel lines will be green, otherwise the two parallel lines color will be red which mean in general the trainee must be stopped the process since the maximum recommended value, the software will change helmet 8" DVD screen source from PC (wilding process) to source of AV camera.

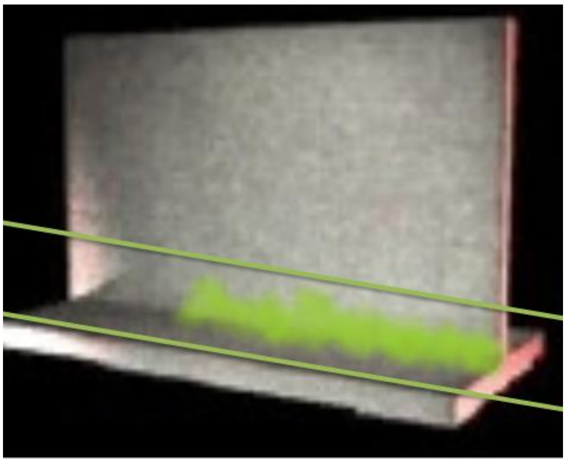
Fig. 4 Two colored parallel lines indicate the recommended arc length

2.5 Electrode Consumption Sensor

The burn off rate or the linear rate of consumption of a consumable electrode is considered as one of the main parameters in the welding process [19].

A 12V DC motor, small gearbox and a rotary optical encoder are used to control a screwed shaft to make a simulation for the welding electrode consumption as indicated in Fig. 5. A rotating optical encoder is connected to the motor shaft to make a feedback for a corrected length of the electrode shaft between any two welding processes; the data is transferred from the optical encoder to the ADC.

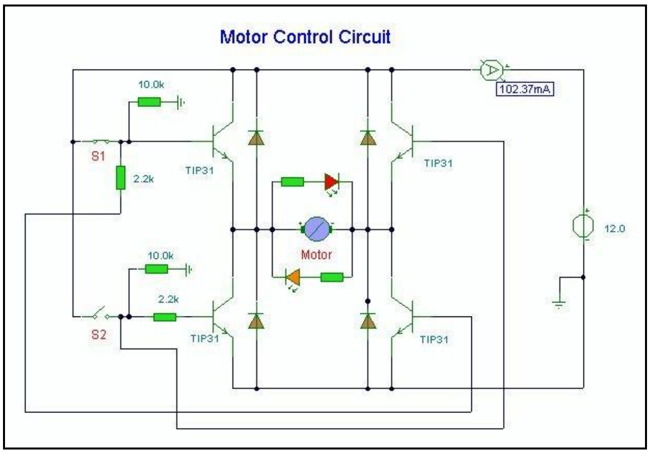

Fig. 5 motor control circuit

The position of the electrode is considered as a function of the electrode length. Thus, when the position of the electrode indicated zero position that means the electrode length is the total length (30 cm) while when the position of the electrode indicates 30 cm that means the electrode must be replaced and between these values it is considered as the present length of welding electrode.

2.6 Travel Speed Sensors

The rate of travel across the joint is called as speed of travel and it is controlled by the welder during welding and greatly affects the appearance and strength characteristics of the weld [17]. Two types of sensors are used to represent the speed of travel, IR and Ultrasound sensors connected with programming timer. LV Max Sensor EZ4 ultrasound from maxbotix.com [15] and Sharp 2D120X infrared are used.

To represent a travel speed in virtual system three types of sensors are used, an ultrasound sensor, infrared sensor, and an image processing obtained from an output welding view.

In the present work, both IR sensor and ultrasound sensor are constructed in the welding gun simulator where the data is received to the PC via ADC.

A package model is built and connected to ADC system be connected with PC.

The overall flowchart of electrode consumption simulation for shielded metal arc welding in virtual welding training system can be shown in Fig. 6.

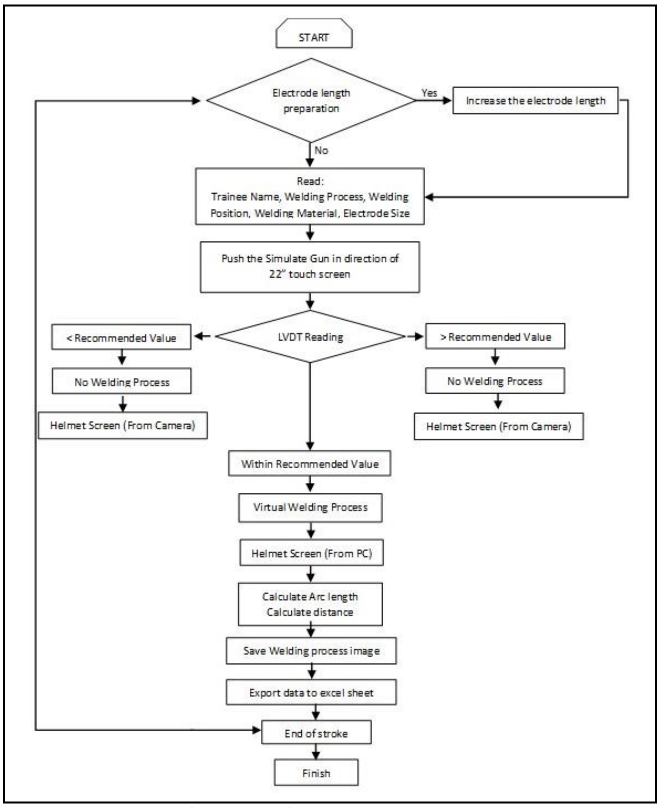

Fig. 6 Overall flowchart of electrode consumption simulation

3. Welding Sensors Calibration

3.1 Arc Length Calibration

A Linear Variable Differential Transformer (LVTD) sensor is used to study the effect of welding arc length. The welding arc length is a major important since it limits the nature of the result welding layer and the spatters. The output voltage is compared with vernier measurement to get the displacement.

Fig. 7 indicates the variation of the arc length relative to the LVDT output voltage.

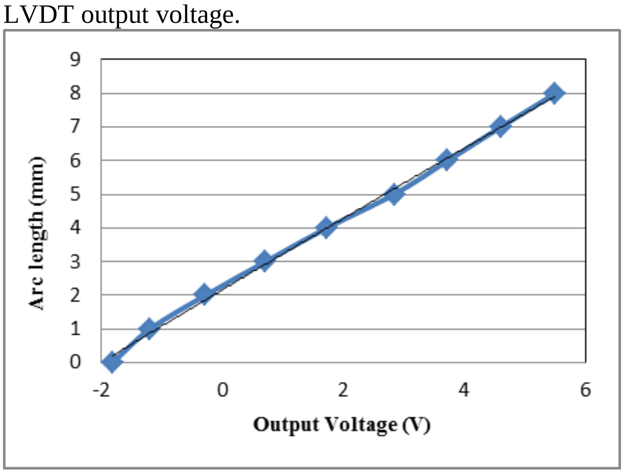

Fig. 7 Relation between welding arc length and output voltage of LVDT sensor.

A polynomial calibration equation can be given to get the required distance from the output voltage of LVDT.

$$Arc\ Length(distance) = -0.004x^2 + 1.0711x + 2.1542 \quad (1)$$

Where x represent the LVDT output voltage, The resulted equation gives a good approach for the real arc welding effect, where the displacement varies between 0 mm and 5 mm that is accepted with most Shielded Metal Arc Welding (SMAW) processes where the recommended value closed with welding electrode diameter [19]. In training courses, the trainees are widely used on welding electrode where the welding electrode diameter do not exceed the 5 mm.

Because of the low change between the maximum and minimum values of the welding arc length, there is a difficult to represent this change in the virtual environments, so that the resulted data from LVDT can be considered one of the advantages of the current project where all ultrasound and infrared sensors failed to represent the arc welding length. Although of the success of laser sensor to represent the arc welding length but their cost is very expensive, so that the LVDT sensor date is accepted as compared between the response to the representation and the cost.

3.2 Travel Speed Sensor Calibration

One of the disadvantages of both Infrared and ultrasound sensors, is a dead region where the sensor does not able to recognize the nearest places to the sensor which is about 8-10 cm, so although the low cost of such sensors but the problems of dead region can be limited the using of such sensors. Since the current project depending upon minimize the whole cost to the lowest price so that the using of such sensors considers as a necessary. In order to overcome the problem of dead region a reflecting wall constructs to reflect the signals of both sensor. MaxSonar®EZ4™ is used as ultrasound range finder sensor while GP2D120XJ00F used as infrared proximity sensor, the purpose of using both sensors is to get the best sensor performance to the construction model.

3.3 Electrode Consumption Calibration

The total length of the constructed rod is 30 cm compatible to the E6010 Carbon Steel Electrode, the electrode is moving in both directions; forward and backward. In backward stroke, the virtual welding occurs while the forward stroke simulated new welding electrode replacement.

An optical rotary encoder with Labjack HV U3 are used to record the 12V DC motor pluses, the virtual welding system designed to read pulses on each 20 ms for 10 ms. The total number of pulses is divided by the total welding electrode length when the electrode from position in length 0 cm to position in length 30 cm and vise verse.

When the trainer prefer to weld and the arc length in accepted range (measured by LVTD sensor) the software send a signal to the DC motor to rotate in backward direction and the welding electrode length begin to decrease till:

- The trainer stops the power to the welding simulated gun.
- The arc length which is measured by LVTD became out of work range.
- The welding electrode length reaches to the 0 cm position.

4. Case study

In this case study, a straight bead on flat plate a plate is used with material Mild Steel of thickness of 3/16" (4.8 mm) and a single process of E6013-1/8"(3.2mm) electrode are used to represent the virtual welding process.

4.1 Effect of Welding Travel Speed

There is no any direct method to get the welding travel speed; there are three approaches depending on divide the resulted welding distance to the time interval. So to find the welding travel speed, the required welding distance must be estimated. In current project three tools are used to get the welding distance; the first which is obtained from ultrasound sensor and the second which obtained from infrared sensor while the third depending upon analyzing the picture of the virtual welding view. In the third method the simulated welding electrode worked as a mouse , when it touch the 22" Screen the system indicated it position and when it is moved to another position the system also indicated the new position , so there is ability to find the difference between the two positions.

It is easy to get a proportion between the real dimensions of the 22" screen and the current picture of virtual welding view, so the dimensions which are obtained from the third method is a real dimensions.

Fig. 8 Welding distance measurement by using ultrasound and infrared and image analysis

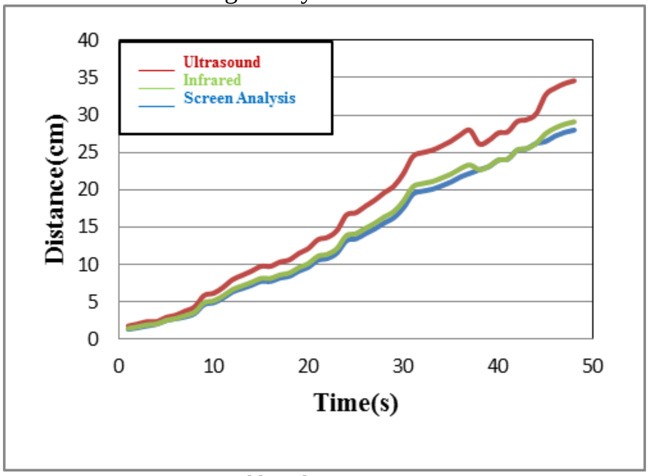

Fig. 8 Welding distance measurement

The change of the welding distance in ultrasound is large than the distance change which measured by infrared and by using direct method by screen analysis. The reason may be belonged to the nature of this type since it is commercial one (less than 10$), while the infrared is about 50$.

In general, both ultrasound and infrared are used at the beginning of this project, but finally the using of touch screen coordinates and considering the simulated electrode as a mouse, so the screen coordinate will be used in the next sections.

In the first case study the trainee or student, learn to run a straight bead on flat plate. It is important to mention here that the constructed software provides 14 welding positions. The system covers Practice Plate, 1G Flat Groove, 2F Horizontal Tee, 2G Horizontal Groove, 2G Schedule40, 2G XXS, 3F Vertical Tee, 3G Vertical Groove, 4F Overhead Tee, 4G Overhead Groove, 5G Schedule40, 5G XXS, 6G Schedule40 and 6G XXS, while the current discussions covered only four positions Practice Plate, 1G Flat Groove, 2F Horizontal Tee, 3F Vertical Tee, and 4F Overhead Tee.

Figures 9-12 indicate the four attempts on virtual welding process of the trainee no.1, the welding parameters changes

will be discussed in next section. Fig. 9 shows a bad welding process with high welding travel speed, the trainee developed his skill in the second attempt and reduced the travel speed as indicated in Fig. 10 but the welding process stills listed within a bad welding process. In the Fig. 11 and 12 the welding process is became quite good.
Although Figures 10-12 give the user primary view about the trainees performance but it does not indicate the correct values of the welding angles, travel speed and welding arc length, which will be discussed in next sections.

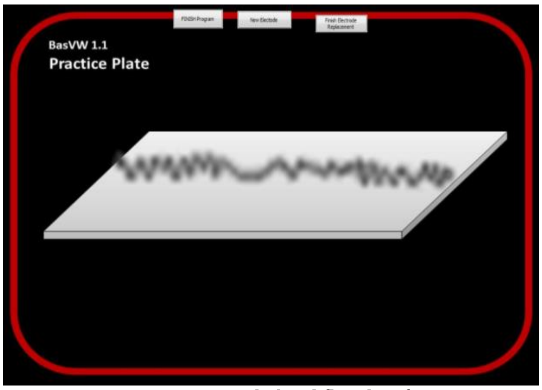

Fig. 9 First attempt on Straight bead flat plate for trainee no.1

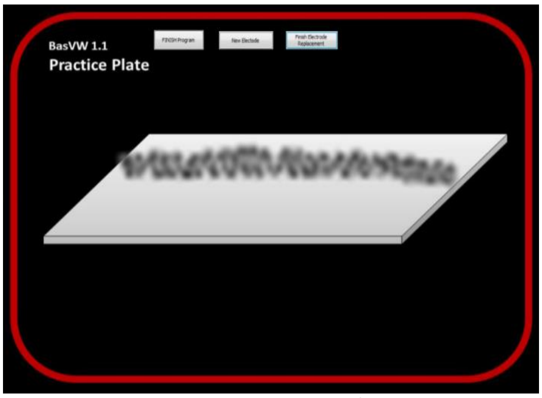

Fig. 10 Second attempt on Straight bead flat plate trainee no.1

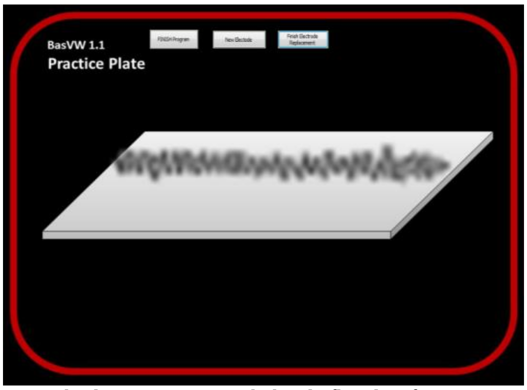

Fig. 11 Third attempt on Straight bead flat plate for trainee no.1

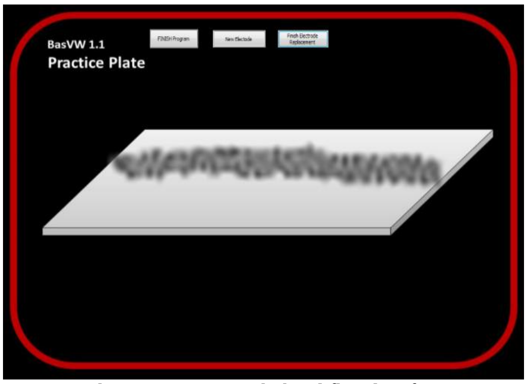

Fig. 12 Fourth attempt on Straight bead flat plate for trainee no.1

In general, overall results of all attempts of trainee no.1 can be in indicated in table 1. The trainee no.1 began with high travel speed and then reduced his speed in second and third attempts but the travel speed still high until the fourth attempt when the trainee reduces the travel speed to the accepted value. It is important to mention here, there is no any recommended values for welding travel speed [19], it is depending on the type of plate flat or groove, diameter of the welding electrode, welding current and dimensions of the welding region area.

Table 1. Overall travel speed values on the first case study

Attempt	Welding Distance (cm)	Welding Time (s)	travel speed (cm/s)
1	30	46	0.652
2	30	126	0.238
3	30	114	0.263
4	30	153	0.196

In the current work, also another two welding travel speed indicators are studied, the first depending on finding the travel speed at each point on the welding workpiece and the anther one depending on the whole view of the virtual welding process after finishing the process.
In the first method, the travel speed is calculated directly by using the formula shown below at any time.

$$Travel\ Speed = \frac{dx}{dt} \tag{2}$$

Where dx is the difference between the current position and the previous position of the welding electrode while dt is the difference between the current time and the previous time of the welding process.
Although the principle is correct but it gives a good results in welding process, since in welding processes, the welding does not occur as pure straight, it is occur on shapes of C, T, J, V, zigzag, etc.
The second method is achieved by using the whole view of virtual welding process, the whole view shows the accepted decision to tell the welding travel speed is fast , low or accepted, it is depending upon the width of the virtual welding in the result picture (see Figures 9-11). Fig. 9 shows the travel speed of the trainee varies from an accepted value at the beginning and then the travel speed is

fast at the middle and return to the accepted value in the last region.

Length of the arc in Shielded Metal Arc Welding (SMAW) is a major parameter in welding process, it is affected on the shape of the welding and finishing of the workpiece, when the arc is too low, the electrode may be stick on the workpiece while when it is too high the spatters will spread on the surface.

5. Conclusions

In general, at the end of the first case discussions, the skills of the trainee no.1 are developed, the same thing occurs to the other four trainees, which lead to say, "The virtual welding training is a good tool as primary teaching for welding training courses". The virtual welding system enables the trainee to acquire the welding motion by practicing several exercises through a progressive learning embedded in the training process, so that by spending only 1 hour per day on this system, the trainees acquire the good gesture quicker and save more quantities of raw material.

References

[1] Waterworth, J. A., "Virtual Reality in Medicine: a Survey of the State of the Art", in "Medicine Meets Virtual Reality 13: The Magical Next Becomes the Medical Now", IOS Press, 1999.

[2] Heston, T., Virtually welding Training in a virtual environment gives welding students a leg up, The FABRICATOR® | An FMA Publication, March 2008.

[3] Choquet, C. "Arc+: Todays Virtual Reality Solution for Welders", In International Conference of Safety and Reliability of Welded components in Energy and Processing Industry on the occasion of the 61th IIW Annual Assembly Conference, 2008.

[4] Harvey B. S and Macy L. A, "Arc Welding Simulator Trainer", U.S. Patent, No. US 3867769, 1975.

[5] Bruce A. B, " Device for Teaching and Evaluating a Person's Skill as a Welder", U.S. Patent, No. US 4124944, 1978.

[6] Boris E. P, Vsevolod V. V, Valentin A. B, Alexandr I. P, Sergei N. D, Viktor A. S, Vladimir A. C, Vitaly I. V, Viktor M. G, and Vsevolod N. B, "Welder's Trainer", U.S. Patent, No. US 4680014, 1987.

[7] Boris E. P, Vsevolod V. V, Valentin A. B, Alexandr I. P, Sergei N. D, Viktor A. S, Vladimir A. C, Vitaly I. V, Viktor M. G, and Vsevolod N. B, "Electric Arc Trainer For Welders", U.S. Patent, No. US4716273, 1987.

[8] Donald H., Richard F., David F., and Bruce, B., "Device for Training Welders", U.S. Patent, No. US4931018, 1990.

[9] Geert K., "A Device for Assisting in Manual Welding Using a Plurality of Mark Light Projecting Units" European Patent Office, No. EP2036648 (A1), 2009.

[10] Zboray D.A., Bennett M. A., Wallace M. W., Hennessey J., Lenker, Z. S., Lundell A. B., Dana P., Preisz E. A., Briggs, L., Droller R. B., And Briggs, E. C., " Virtual Reality Pipe Welding Simulator", U.S. Patent, No. US 062406 Al, 2010.

[11] Peters C., Justice E. L., Gandee C., Zboray D. A., Bennett M. A., Wallace M. W., Manchester J. H. , Zachary Steven Lundell A. P. , Droller R. B. , and Briggs E. C., "Welding Simulator Console", U.S. Patent, No. US D631,074 S, 2011.

[12]http://www.vectornav.com/Downloads/Support/VN100_QuickStartGuide.pdf

[13] http://www.lablack.com

[14] A Study on Design and Construction of Virtual Welding Training System in the Shielded Metal Arc Welding (SMAW), R. Kh. Al Sabur, PhD thesis, Basrah University, Basrah, IRAQ, 2013

[15]http://www.maxbotix.com/documents/MB1040_Datasheet.pdf

[16] American Welding Society, AWS A3.0, "Standard Welding Terms and Definitions," 12th Edition, 2001.

[17] Sacks, R., and Bohnart, E., Welding Principles and Practices, 3rd Edition, McGraw Hill, 2005.

[18] Jiluan, P., Arc welding control, Woodhead Publishing Limited, 1st edition, 2003.

[19] Woodhead, K. W., Welding Processes Handbook Publishing Ltd, 2003.