A Critical Investigation on Weld Bead Defect Detection System Using IoT

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Abstract:
Welding is a process of joining two metals under the application of heat. During the welding process, there is a chance for the occurrence of an undesired irregularity in the form of a defect. Detection of defects formed during Welding is crucial. Under service conditions, these defects lead to the failure of structures and loss of property. Nowadays there is tremendous growth in the field of Internet-of-things. It has many advantages and created a great effect in the manufacturing Industry. By using the Internet-of-Things (IoT) the inspection is done without human intervention and can monitor the defects of weld using the sensors, analyzing and uploading the data into the cloud and visualizing it in the web on any device, anytime, anywhere. The implementation of IoT in welding for weld bead defect defection decreased the inspection time thereby increased production. By analyzing the data through the Internet-of-things the process is automated and can identify the defects using different sensors for measuring the various performance parameters that govern the weld bead quality. This paper describes the various sensing methods based on infrared, radiography, vision, Ultrasonic, acoustic, spectrography techniques and analyzing the data obtained from the sensors, and visualizing the data onto the Thing Speak website by sending it to Cloud using the Internet-of-Things. The weld bead defect detection using IoT can be implemented in the Manufacturing Industry for real-time weld defect monitoring during the welding process.
Keywords– Infrared, Radiography, Machine-Vision, Ultrasonic, Acoustic, Spectrography

1. INTRODUCTION:

Welding is an intrinsic process applied in the field of manufacturing. It is a fabrication process that refers to the joining of metals with the application of heat [1]. There are many heat energy sources for melting such as electric arc, electron beam, friction, and so on. Based on the material to be welded and considering other parameters, many types of welding evolved and used in the industry [2]. The quality of the weld should be high. During the welding process, there is a chance for the occurrence of an undesired irregularity in the form of a defect [3]. These defects not only reduce the ductility of the weldment but also serve as a threat to the system. For the safe operation of the structure joined by welding, the weld bead should not contain any defects. The poor quality welding causes the break or leak. Slag inclusion, improper fusion, cracks, excessive penetration, undercut, porosity are some of the commonly occurring defects [4]. These defects have to be eliminated for safe operation. The inspection of welding involves monitoring the weld bead for defects and other conditions that govern the quality of the weld bead [5]. It is necessary to detect such defects and take remedial measures immediately so that the performance of the weld can be improved. The detection system must not damage the weld or workpiece. Non- Destructive methods can be implemented to determine the defects formed during welding without and inspected without any damage to the weldment.

Due to the advent of the Smart Sensors and Transducers, the data is collected from the environment and is used to analyze, control, investigating various weld parameters that determine the quality of the weld bead [6]. The Weld monitoring system embedded with the Sensors can acquire information from the environment. The various sensing techniques such as infrared, radiography, vision, ultrasonic, acoustic, spectrography, and so on can be implemented. The raw data obtained from the sensors is analyzed and extract necessary features that can describe the weld bead quality. This makes the system make better decisions even without human intervention.

Nowadays there is tremendous growth in the Internet-of-things. There are many real-world applications of the Internet of things. It also has a great contribution in several sectors like transportation, Industry, market, educational institutions, healthcare, agriculture. Internet of things (IoT) can be introduced in the monitoring process. The IoT makes a system automated and the device can be controlled over the internet [7, 37]. The state of the system and the data obtained during the inspection can be sent to the cloud and the data can be visualized on the website such as the Thing Speak website and the welding system can be monitored from any device anytime and anywhere. In this paper, the various sensing methods based on Infrared, Radiography, Vision inspection, Ultrasonic, Acoustic, Spectrography techniques have been discussed in section 2.1. The data-driven to the cloud and visualizing on Thing Speak website is discussed in section 2.2.

2. WELD BEAD DEFECT DETECTION SYSTEM

2.1. Data acquiring and processing:

Various sensing methods based on Infrared, Radiography techniques, and so on are used to acquire the data from its environment and by using the Algorithms, the data is processed. Some of these techniques have been discussed in this paper.

2.1.1. Infrared based:

Shreedhar et al. [1] proposed a real-time weld monitoring system to detect the porosities that occurred during the TIG welding using thermal analysis of the thermal images obtained from the Infrared cameras. The welding of two circumferential shells of Aluminium Alloy 2219 is implemented in two passes. In the first pass, the welding is done with no filler material added. In the second pass, the AA 2319 filler material is added. The infrared camera focuses on a certain area of the front face, at a distance from the weld pool. The data is sent for thermal image data registration and processed using the algorithms. The cooling curves are obtained from the algorithms, can differentiate the defect and defect-free regions. The cumulative effort of infrared 1st, 2nd pass can detect the significant defects of about 80% of the defects identified by the Radiography technique, and the test results obtained from the infrared thermal analysis are satisfactory.

Sadek et al. [2] incorporated infrared sensing for detection of the weld defects in the Gas Tungsten Arc Welding (GTAW) process for joining SAE1020 plates. The infrared sensor TL-S-25, current clamp i1010 model is used to measure the weld parameters. An experiment was conducted to compare the data given by these two sensors for detecting the defects in the welding. The infrared sensor gave satisfactory results compared to the current clamp. The DC portions of the signal generated from the infrared signal are associated with the weld penetration depth and whereas the AC portions of it are associated with the surface irregularities. The Kalman filter in conjunction with the Mahalanobis distance is used as a change detection algorithm for detecting the weld defects.

Wanchuck Woo et al. [3] developed a weld bead defect detection system using the infrared thermal imaging method in resistance spot welding of dual-phase steel (DP 590) and an Indigo Phoenix mid-IR camera is utilized for capturing the changes in the surface temperature. Various sets of weld samples are used in the thermal analysis to evaluate the defects. Various cooling and heating methodologies are assessed. The heat flow pattern is simulated using the Finite Element Analysis (FEA). The results obtained from this process are satisfactory and can be implemented in real-time weld defect inspection.

M. Vasudevan et al. [4] developed an infrared thermography analysis for the detection of defects formed during the Gas Tungsten Arc Welding (GTAW) of 316LN stainless steel plates. In addition to the infrared sensor, a thermocouple is used to capture the temperature distribution of the top surface of weldment and the images obtained are analyzed for defects. The relationship between the weld parameters is determined and satisfactory results are obtained in implementing this process.

WikleIii H. C et al. [5] presented a weld bead defect inspection system by implementing the numerical model to monitor the changes in the temperature distributions on the top surface caused by perturbations using an infrared sensor during the arc welding. With the feedback control from the weld parameters, the system varies the weld heat input to reduce the formation of weld defects.

2.1.2. Radiography Based:

N. Nacereddine et al. [6] explained the detection of defects in weld by digital image processing technique based on radiography. In this study, the scanned radiography films were first digitalized and then the Region Of Interest (ROI) is selected followed by the reduction of noise. Then segmentation is done in a way that the image is condensed by the thresholding technique. Finally, morphological operations were done to remove the small residual spots and the defect region can be extracted.

YanHanbing et al. [7]analyzed and proposed a Binary decision tree method for the classification of defects by the evaluation of radiography testing. The binary decision tree comprises five layers. The first layer determines the classification of defects as bright and dark. The next four layers distinguish the type of defects. This paper makes use of a Supporting Vector Machine (SVM) for the classification of defects. This helped the classifier to classify seven types of defects by the use of certain features and the results show that the classification of defects by radiography testing is a significant one.

IoannisValavanis et al. [8] demonstrated a method for the detection and classification of defects in weld radiographs. Three classifiers such as Support Vector Machine, Neural Network, K-NN were used in this method. A set of geometrical and texture-based features were utilized as an input parameter to the multi-class classifier for the classification [36] of defects in seven different classes. An experiment was conducted to compare the results obtained from the classifiers and to verify the effectiveness of this approach. The results were compared and it was found that the efficiency of the Neutral network and Support vector machine was high compared to the K-NN classifier.

Alireza Azari Moghaddam et al. [9] discussed a method for the detection of weld defects from the radiographic image. The defect in the radiographic image appears darker since it absorbs more energy. This method makes use of a two-dimensional left median filter for noise reduction and improvement of the image. An experiment was conducted where 32 greyscale radiographic images were tested and 90% of those with defects were segmented correctly by the use of two dimensional left median filter. The experimental results revealed that this method is efficient for detecting defects in low contrasted radiographic images.

N. Ramou et al. [10] explained a level set-based image segmentation method for the defection of defects from radiographic images. The level set method is a numerical and theoretical tool for image processing. Total Variation Diminishing (TVD) Runge Kutta (RK) method was used to get greater accuracy in temporal discretization. Experiments without re-initialization steps were conducted and satisfactory results were obtained. The simulation covers the weld defects in radiographic images.

2.1.3. Ultrasonic based:

Setsu Yamamoto et al. [11] investigated the Laser Ultrasonic Testing System (LUTS) for the detection of weld defects. Longitudinal acoustic waves produced by a Q-switched Nd:YAG laser irradiation and the detected surface vibration is used for the detection of defects. The sensitivity of LUT can be improved by a modified synthesis aperture focus signal processing technique (m-SAFT). By the use of an in-process testing system, a defect that was smaller than the original criteria was detected successfully.

Stephen W. Kercel et al. [12] uses the Laser-Based Ultrasonic (LBU) system for the online monitoring of weld defect detection. Sensor contact with the workpiece is not required since LBU allows in-process measurements. Laser-generated plate (Lamb) waves were used and the reflected signals from the weld zone were processed to get the results. As a result, this method can detect the localized weld defects using the laser-based ultrasonic system.

I.J. Stares et al. [13] investigated the real-time monitoring of the weld pool during TIG welding and the detection of defects formed during incorrect welding conditions by using ultrasonic compression and shear waves. An experiment was conducted using a TIG welder with a mobile workpiece and fixed welding torch. The size of the weld pool and the defects were measured accurately and the results reported that this method provides a way to control the welding process to reduce the occurrence of defects.

J. M. A. Rebello et al. [14] evaluated the reliability of ultrasonic testing for the detection of weld defects in steel pipelines. An experiment was done where a steel pipeline specimen with two classes of defects such as lack of fusion and lack of penetration was subjected to inspection by manual and automatic ultrasonic testing methods. The inspection was done by the use of Probability Of Detection (POD) curves. The results obtained from the POD curves by the automatic ultrasonic testing [34-36] were found to be much superior compared to the manual method.

D. Lévesque et al. [15] described the use of the Laser Ultrasonic Testing (LUT) method along with the Synthetic Aperture Focusing Technique (SAFT) for the detection of a defect in thick butt weld joints. Complete and partially welded butt joints of steel are taken as specimens for inspection. Lack of fusion was stimulated in the specimens by EDM slits and a CCD line camera was used for correction in SAFT. The specimens were investigated and the results show that usage of LUT combined with SAFT for the defect detection was of good potential. It also showed that the process can be done at a speed of 1cm/s for a 1 kHz laser repetition rate.

2.1.4. Acoustic based:

Mohamad G. Droubi et al. [16] explained that welding detection is a priority in every welding process. There are many methods to detect the defects, here they have explained with the acoustic detection method. The experimental setup is based on Acoustic emission. They have taken four certified carbon steel samples, among these one has been used as a defect-free reference and the remaining three samples were with defects called slag, crack, porosity. The stimulated AE sources were generated by the Pencil Lead Break test. The AE source was on one side of the joint and the AE sensor was placed on the other side to capture the Acoustic Emission signal.

M Loman et al. [17] investigated the potential of Acoustic Emission technology to detect defects in welding. The experimental setup is where two mild pieces of steel were welded in the middle part of the steel. Here they have taken two welding specimens one with defects and another is defects-free. This experimental setup has a piezoelectric sensor, located on both specimens and pressurized to form a crack. During this experiment, the Acoustic Emission signatures were generated using the AE node acoustic emission data acquisition system. These signals were subjected to AEW in software to analyze and verify the defects. As a result, the specimen with defects has a higher value of acoustic emission parameters such as peak amplitude and Root Mean Square.

Sumesh et al. [18] explained weld quality detection using acoustic signatures. Here they have considered the defect as lack of fusion and burn through. They correlated arc sound with the weld quality. Raw data points from the arc sounds were converted to amplitude signals. They have used algorithms such as J48 and Random forest to classify the defects. Statical features of raw data were extracted by using data mining software.

RanganayakuluS.V et al. [19] have shown defect detection in Nuclear Grade SS 316L materials. For experimental purposes, defects were implanted in materials. Here TIG (Tungsten Inert Gas) welding is conducted to weld stainless steel nuclear grade material and the AE signatures are studied (pre-loading condition). Once the load is applied to the weld region, the deformed specimen will experience acoustic emission signals from the defect region. The Liner Location Technique (LLT) is used for AE signal studies and these signals are processed by a 2-channel USB-AE node and AE-WIN software.

Yong Tao et al. [20] explained difficulties in structural components of track cranes. Here Acoustic emission is used to detect the difficulty, that is, welding porosity and incomplete penetration. The weld defect was pre-set for the detection and it is added to the boom surface, so that defect could cause without any operational influence. Then, the rudimentary location analysis is done by Linear Location Method and AE parameters such as amplitude and centroid frequency will distinguish the two kinds of welding defects.

2.1.5. Spectroscopy:

J Mirapeix et al. [21] have used the plasma optical spectroscopy method to monitor the weld quality. Here plasma electronic temperature is used as a spectroscopic parameter to determine the defects. Including plasma emission line identification, there are several processing stages to be considered and significant in computer operation performance. The wavelength of the new monitoring signals is associated with the maximum intensity of plasma background emission. It speaks that there is a correlation between the weld quality and parameter.

Zhifen Zhang et al. [22] explained the monitoring system in pulsed Gas Tungsten Arc Welding (GTAW) using the spectroscopy signal. The parameters of Spectrum bands Of Interest (SOI) such as root mean square (R), variance (D), kurtosis (K), these parameters are selected for the output monitoring. The emission lines from the chemical elements are analyzed based on different disturbances. The correlation between the seam defect and the parameters is investigated. Here from the above-mentioned parameters D and K in SOI have shown great sensitivity based on Signal to Noise Ratio (SNR), an evaluation criterion. After this, Wavelet Packet Transform (WPT) is carried out for pulse interface removal in the monitoring curves.

J Mirapeixet al. [23] implemented a spectroscopic analysis method in arc welding. The plasma spectra produced during the welding process are the technique to monitor the weld quality. In some cases, the automatic defect detection complex is performed by statistical studies of the electronic temperature. Here Principal Component Analysis (PCA) and Artificial Neural Network (ANN) are proposed for defect detection. The plasma spectra captured during the welding process are processed with the PCA, performs the data compression in spectral dimension to avoid the complexity in the process. Then the data training is allowed into the designed ANN for automatic defect detection.

P. Beatriz Garcia-Allende et al. [24] have said that plasma optical spectroscopy is the common online weld diagnosis process. Here the plasma electron temperature is the parameter that is typically an output monitoring parameter. Here they added a method called the line-to-continuum method for the detection, a feasible alternative spectroscopic approach and it is noted for its computational efficiency.

Zhang et al. [25] discussed the weld defect detection of AL alloy in arc welding. We know that for monitoring we need parameters, here the emission line of the hydrogen atom (656.3 nm) and argon atom (641.63) was analyzed to produce multiple feature parameters, from that more feature parameters were selected for monitoring.

2.1.6. Vision-based:

Yuxiang Hong et al. [26] proposed a weld defect monitoring system to detect the lack of fusion during the Microplasma Arc Welding (MPAW) welding using the micro vision sensor. During welding, this sensor captures the images of the weld pool and this image is processed to obtain the features that represent the weld pool geometric characteristics such as the position of the centroid in the weld pool and so on. The significant variations in the features obtained can indicate the presence of lack of fusion in the weld bead. Finally, the results obtained from this system are satisfactory.

Jun Sun et al. [27] developed a method for real-time weld monitoring of thin-walled metal canisters by vision. An algorithm was implemented based on a Gaussian mixture to obtain the features from the visual images. Using these features an algorithm was developed that can detect and also classify the defects, and having more than 99% accuracy of detection and classification of the defects occurred in the weld bead continuously, thereby giving satisfactory results for implementing this method for real-time weld monitoring systems.

Hui-Hui Chu et al. [28] presented a method for processing the image obtained from the CCD camera capturing the reflected structured light emitted by laser onto the weld bead for detection of defects during welding. A 3d reconstruction of the weld surface is generated and is used for detecting the defects in the post-weld defect monitoring system. The results obtained from this system are satisfactory and can detect the defects online.

Marek Fidali et al. [29] proposed a weld monitoring system based on the fusion of the vision and infrared images. The infrared and visual images are preprocessed and fused and it is post-processed for the image analysis to obtain the features. From the obtained features, feature selection is done that determines and identifies the weld defects. Using the classifier the defects are identified and shown satisfactory results.

Yuan Li et al. [30] presented a weld bead defect detection and measurement of the weld bead based on machine vision using the structured light from a laser projector. The image obtained from the vision sensor is processed, extracted for features, and can be used for the detection of defects in the weld bead. The weld defects such as undercut, plate displacement, and misalignment of the weld bead are identified and giving satisfactory results to detect defects online

2.2. Data Visualization Using Internet-of-Things:

Arduino Uno is a microcontroller board consists an Atmega328P microcontroller [31]. Arduino IDE is Integrated development software that helps to code Arduino and perform operations by collecting the data from the sensors with the help of library functions. The board consists of

Analog and Digital Input/Output (I/O) pins. Using these pins the board can be connected to the sensors and also to the various expansion boards also known as shields [32].

Mazuin et al. [33] obtained the data from the weld inspection system after extracting features from the sensor data is sent to the microcontroller such as Arduino Uno R3. The data is processed and needs to be uploaded to the cloud. To do so, the microcontroller needs to be connected to the Internet. ESP8266 Wi-Fi module can be utilized to provide the internet to the microcontroller and send the data to the cloud. With the help of the Application Program Interface (API), the data can be sent to the Thing Speak Website, an IoT web service, visualizes the data on the website. Once the welding process is started, the system gets turned on, thereby activates the sensors. The sensors continuously monitor the weld bead and simultaneously sends the data to the microcontroller for processing. The data can be locally displayed using the LCD module connected to the Arduino. With the Internet, the data is uploaded to the cloud and then to the Thing Speak Website. The User can monitor the welding system from the website. Once the data is on the Thing Speak
Figure 1 illustrates the process of data uploaded to the cloud.

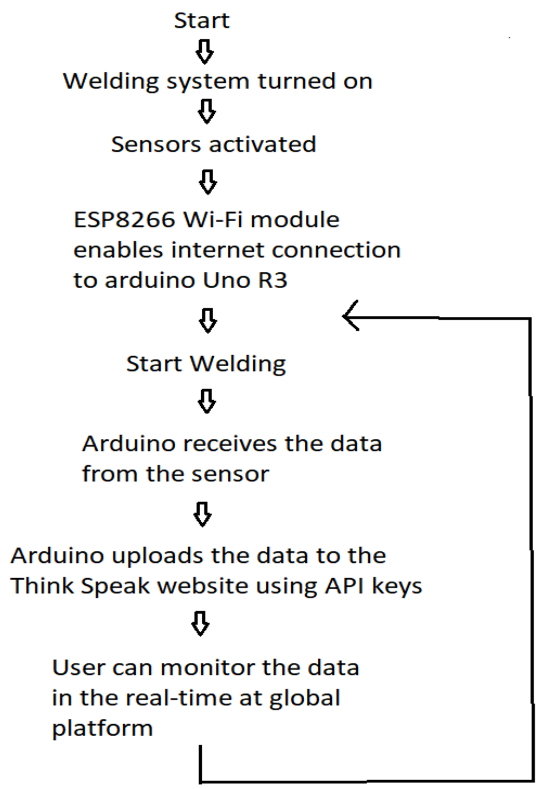

Figure 1: Methodology of data uploaded to the Cloud

3. DISCUSSION:

The defects are determined using various sensing techniques such as Infrared, Radiography, Vision inspection, Ultrasonic, Acoustic, Spectrography, and so on. In Infrared sensing, infrared sensors are used and capture thermal images and are processed by algorithms to extract features. By analyzing these features, the formation of defects can be identified. In Vision sensing the camera is used to capture the image of the weld pool over the top surface and the image is processed and analyzed using algorithms and the features are extracted. In Acoustics, the acoustic emission sensor is used and the acoustic emission signature was generated by using an acoustic emission node and the signals were analyzed. In acoustics, the acoustic emission sensor is used and the acoustic emission signature was generated by using an acoustic emission node and the signals were analyzed. In spectroscopy, the parameters like plasma electronic temperature are considered for output monitoring and the plasma emission line is considered for the computer operation and then the wavelength of signals is associated with a maximum intensity of plasma background emission and tells the correlation between weld quality and the parameters. In ultrasonic sensing, the ultrasonic waves incident on the workpiece, and the reflected waves are captured and analyzed. In radiography, the radiographic sensors are used to capture the radiographic film and it is processed to make it digitalized and analyzed. Microcontrollers like Arduino can be used and the Wi-Fi module is attached for connecting to the internet. With the help of the Application Program Interface (API), the data can be sent to the Thing Speak Website, an IoT web service, visualizes the data on the website.

4. CONCLUSION:

In this paper, a critical investigation on the real-time monitoring weld bead defect detection system has been made and various sensing techniques based on infrared, radiography, vision, ultrasonic, acoustic, spectrography, and analyzing the raw data acquired from these sensing techniques are discussed. The data visualization using Internet-of-Things (IoT) is also discussed. An attempt has been made to explain the working of IoT in monitoring by various sensing techniques with the use of an Arduino and a Wi-Fi module. Reduction of human effort and saving time are the main advantages of IoT over other mechanical methods. Other advantages of IoT are its efficiency and enhanced data collection. IoT research is emerging as a major one to connect more and more things to the digital world and will help mankind more in the future. Thus, the usage of IoT in a detection system is a smart idea.

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