Video Enhancement for Visual Assessment of Welding

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Welder's visual assessment and control of welding are major factors in ensuring high-quality welding in various types of welding, including Gas Metal Arc Welding (GMAW). However, this visual monitoring is less effective in defect monitoring and detection because the formation of defects may not have a clear indication for visual assessment by welders. On the other hand, vision-based monitoring represents a significant portion of the total labor costs for industrial products, accounting for over 10% [1], and is therefore critical for manufacturing.

To address this limitation toward better automation, we propose using Eulerian Video Magnification (EVM) [2] to enhance the video of the weld pool during GMAW. EVM is a video processing technique that magnifies temporal subtle movements of molten metal, making changes easier to detect through visual monitoring during welding. The EVM method [2] estimates the motion signal by using the first-order Taylor expansion of two consecutive video frames and generates magnified video by adding the magnified motion signal to the original frames.

By magnifying the movements of the melt pool, EVM provides more effective visual monitoring of melt flow behavior resulting in better porosity detection during the welding. To assess the effectiveness of our proposed approach, we conducted a subjective video quality test, reporting mean opinion score (MOS) to evaluate the visibility of melt flow behavior in the enhanced videos compared to the original ones.

In summary, our study demonstrates the potential application of the EVM method [2] to improve the welding quality by enhancing the visual monitoring of the weld pool toward more precise defect detection.

Keywords

Visual welding defect detection, Porosity, Motion magnification, video enhancement, Eulerian Video Magnification method.

1. Introduction

Welding is an important technology that is widely used in manufacturing. Video recording and processing is important in vision-based seam tracking and quality control in welding industry. Welding defects cause quality degradation by declining the strength, stiffness and toughness of the products [3] which be costly and even result in serious injuries. The explosion of gas pipelines in San Bruno in 2010 is an example of the huge costs caused by low-quality welded pipes which has set 103 houses into fire and threatened 66 people's life [4].

Thus, quality control plays an important role in welding industry to improve the quality of industrial production [5].

Non-Destructive Tests (NDT) such as visual assessment, radiography, and ultrasound are used for quality control [6]. Vision based defect detection methods are categorized as: (1) visual inspections of an experienced human inspectors [3], and (2) Automated vision-based inspection [7] in industrial welding. Most of the automatic vision-based methods are still only used for post-weld inspections [8]. However, visual assessment by a human inspector provides the possibility of defect detection to diagnose defects during the welding process which is crucial to control the weld quality in real-time [8]. But, visual assessment of welding quality by human inspector is error-prone, and inefficient [3]. Thus developing automatic defect detection method is necessary. Real-time defect detection is a crucial step in the automatic defect detection process for developing intelligent welding [9].

Porosity is one of the most common types of welding defects which is challenging through visual assessment with the naked eye. Porosity may happen when the weldment is greasy, or the gas valve is not adjusted appropriately. Porosity may cause pores on the surface and inside the weldment and consequently result in propagating cracks and failure of the weldment [10]. There are some visual signs that enable human inspectors to detect porosity during the welding process such as the irregular shape of the molten metal or the spatters around the arc [11].

Eulerian vidoe magnification (EVM) technique is a method which reaveals subttle temporal variations in a video which is hard or impossible to see with the naked eye [12]. The EVM method gets the video frames as input and applies spatial decomposition, followed by temporal filter to estimate the subtle differences between consecutive frames, and amplify them to make them visible [12]. Temporal filtering in the EVM method amplifies both of the subtle color variation, and low-amplitude motion [12]. The EVM method has previously used in various applications such as heart rate estimation via magnifying subtle colour variations of the face skin, and also magnifying the subtle motion on the wrist caused by human pulse [12].

Defect detection via visual assessment by a human inspector or via automatic vision-based inspection is challenging specially for porosity and Lack Of Fusion (LOF), where negligible visuale features may not be detectable from welding video frames. For example, the dissolved gases in weld metal cause porosity and may not be easily detectable via visual assessment [13]. Solidification rate of the molten metal is also a visual clue that helps to detect porosity which is hardly detectable by manual or automatic visual assessment [13]. We hypothesize that enhancing the welding videos by magnifying the changes that happens during the welding process will result in improving the quality control via both of the manual and automatic vision-based defect detection. We propose applying EVM method on the welding videos to amplify subtle visual features that are used for defect detection (e.g. irregular shape or density of the molten metal or the spatters around the arc).

The remainder of the manuscript is organized as follows: we summerize the EVM method [12] and its specifications for the welding video enhancement in section 2. The proposed method is evaluated and discussed in section 3. Finally, the conclusion and future works are presented in section 4.

2. EVM-based welding video enhancement method

2.1 Data acquisition

Video recording is done by using a collaborative spool welding robot (SWR) shown in figure 1. Details of the digital camera and setup specifications for data capturing is the same as what has been reported in [15]. We captured 9 welding videos which included normal welding data, and also various defects including LOF, lack of penetration (LOP), porosity, cold lap, and undercut.

Figure 1 Collaborative spool welding robot used for video recording.

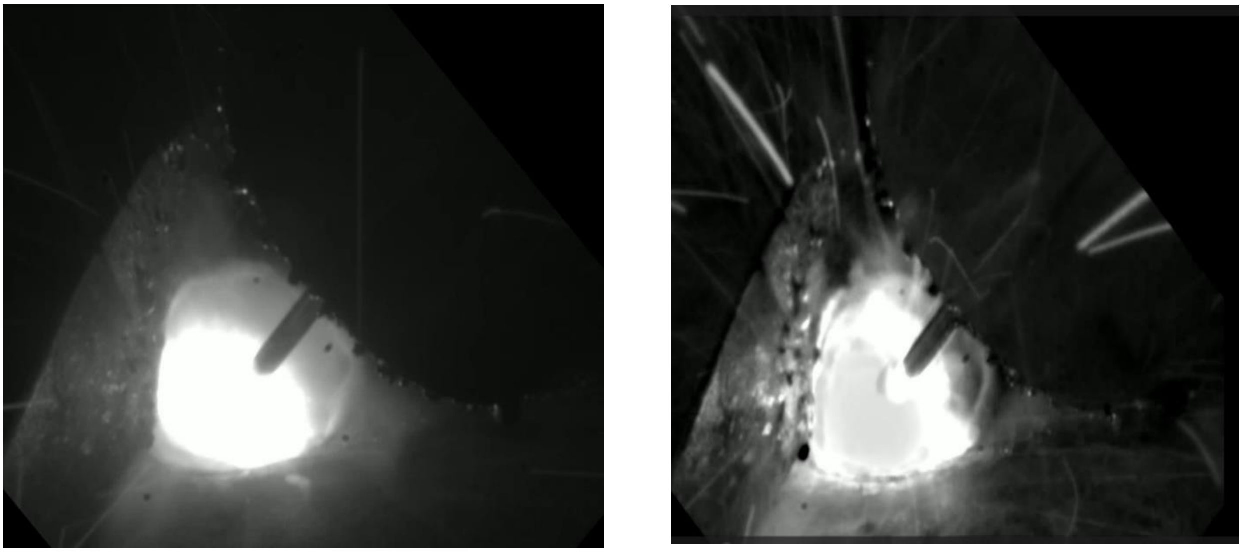

Figure 2 Original sample video frame (left) and its magnified version (right)

2.2 EVM based video enhancement

There are lots of details and visual nuances that may help human inspector to detect defects, especially porosity, such as:

- loss of fluidity/tinning, creating more erratic viscosity,
- the edges of the puddle struggle to create smooth radius or soft curves,
- smoother bottom of the puddle as the puddle consumes the impurities faster,
- lines of spatter emission flares,
- lack of arc intensity.

The EVM method tracks and amplifies changes in the pixel intensity values of video frames during the time [12]. It is best suited for small spatial displacement [12] such as welding application.

The EVM method uses the first-order Taylor series expansion combiened with a temporal bandpass filter to estimate the motion signal [12]. Let suppos $I(x,t)$ is the video frame intensity at position x and time t. The motion signal $B(x,t)$ is an estimation of the changes that occur between two consecutive frames which is estimated by temporal filtering of the first-order Teyalor series approximation of $I(x,t)$. The estimated motion signal is magnified by using an implification factor α and added to the original video frame intensity to provide the magnified video frame intensity $\tilde{I}(x,t)$ as:

$$\tilde{I}(x,t) = I(x,t) + \alpha\, B(x,t). \qquad (1)$$

For the EVM method details please refer to [12]. There is a trade-off for setting the amplification factor α. Although the larger values of α results in more visibility of the subtle variation, it may result in inaccurate approximation of the video frame with its first-order Taylor series expansion.

3. Results and discussion

Our data set includes 9 videos, the length of each video is approximately 3 minutes. The data recording process involved both the interior and exterior of fillet joints for four pipes and flanges with a diameter of 6 inches. To introduce various defects intentionally, we provided a comprehensive test plan. Each pipe was divided into six sections, with each section comprising 60 degrees. The welder performed normal and intentionally defective welding in a predetermined order across the six sections. Table 1 shows details of our test plan. Our recorded data set includes porosity, LOF, LOP, cold lap, and undercut defects. Figure 2 shows a sample video frame from the original video and its magnified version. As it is visible in the figure, lines of spatter emission are more visible in the magnified version compared to the original one. The edges of the puddle are more visible, which will let the human inspector assess the fluidity of molten metal more accurately compared to the original video. We set the implification factor $\boldsymbol{\alpha}$ emprically to 5, which results in a magnified video such that it is possible to visually detect defect related features.

Table 1 Test plan used for data recording.

Equipment		Section 1	Section 2	Section 3	Section 4	Section 5	Section 6
Pipe 1 (6”)	inner	Normal	LOP	Normal	LOP	Normal	LOP
	outer	Normal	LOP	Normal	LOP	Normal	LOP
Pipe 1 (6”)	inner	Normal	Porosity	Normal	Porosity	Normal	Porosity
	outer	Normal	Porosity	Normal	Porosity	Normal	Porosity
Pipe 3 (6”)	inner	Normal	LOF	Normal	LOF	Normal	LOF
	outer	Normal	LOF	Normal	LOF	Normal	LOF
Pipe 4 (6”)	inner	Normal	Undercut	Normal	Undercut	Normal	Undercut
	outer	Normal	Undercut	Normal	Undercut	Normal	Undercut

We evaluate the proposed video enhancement by using mean opinion score (MOS) which is popular subjective test [14]. MOS is a single rational number in the range of 1 to 5, which are representative of bad to excellent, as detailed in table 2 [14]. We asked 4 reviewers who are working or doing research in the field of welding to rate our original video, and the modified version. We also asked their opinion regarding the quality of the modified video in relation to the quality of the original one. Table 3 represent MOS for the original videos, the motion magnified videos, and also the rational score for the modified video versus the original video. We have also reported MOS rated by each reviwer individually. As it is reported in table 3, total MOS for the original and magnified videos are 3.69 and 3.64 respectively, which indicates the qualiy of both of the original and magnified videos are similar. The rational MOS 3.83 which means quality of the magnified version in relation to the original version is fair and very close to 4 which indicates that EVM video enhancement improves the quality of the magnified video compared to its original version.

Table 2 Mean Opinion Score (MOS) rating definition.

Rating	1	2	3	4	5
Label	Bad	Poor	Fair	Good	Excellent

As reported in table 3, the largest discriminancy are between the first and third reviewers. The reason of such a discriminancy between the first and third reviewer ratings is because they emphezized on two different criteria for their ratings. The first reviewer rated the videos based on their quality for defect detection, while the third reviewer mostly focused on the quality of videos for control of the complete welding process, including seam tracking . Based on the first reviewers ratings, the magnified videos has good quality in avarage while the original videos quality rated some how fair quality. The first reviewer rated that the quality of magnified video comparing to the original one is enhanced for defect detection purposes. Based on the third reviewer’s ratings, although the original and magnified videos have fairly similar quality, the original videos are found more helpful for seam tracking purposes.

4. Discussion and conclusion

This priliminary study shows that the EVM method [12] can enhance the quality of welding video for defect detection purposes in the GMAW fillet welding process.

We will evaluate the proposed application of EVM video enhancement for defect detection by using the deep learning based defect detection models in the future. We will also optimize the magnification factor α for various types of welding joints including fillet and butt joints in GMAW welding based on the results of the deep learning defect detection models.

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Table 3 Comparison of MOS ratings between the original and magnified videos, and evaluation of the quality of magnified video in relation to the original.

Video / MOS	Original video	Magnified video	Rational
Reviewer 1	2.89	4.11	5.0
Reviewer 2	3.33	3.33	3.67
Reviewer 3	3.67	3.0	3.22
Reviewer 4	4.88	4.11	3.44
Total MOS	3.69	3.64	3.83

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