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A laser back-lighting based metal transfer monitoring system for robotic gas metal arc welding

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ABSTRACT

Gas metal arc welding (GMAW) can be considered the most widely used process in automated welding due to its high productivity. However, its solid to liquid metal transfer also complicates the process and causes fumes and spatters. It needs to be better understood and controlled for assured weld quality, improved process stability, and reduced fumes, spatters, and energy consumption. For automated robotic gas metal arc welding, automatic and efficient image processing algorithms are required to extract the metal transfer robustly. In addition, the machine vision apparatus in real welding environments should be compact and easy to handle. To this end, a simplified laser back-lighting based monitoring system is proposed to measure the metal transfer in this paper. To facilitate the image analysis, the arc light and the image are modeled based on the physical laws. A double-threshold method is proposed to segment the image robustly with a linear membership assigned to the fuzzy edge region. To compute the two thresholds accurately and simultaneously, slope difference is calculated for the histogram distribution and the gray-scale positions with the largest and second largest peaks are selected as the two thresholds respectively. Experimental results verified the effectiveness of the on line monitoring system and the subsequent automatic image processing methods.

1. Introduction

Gas metal arc welding (GMAW) is the most widely used process in automated welding industry. Because of its consumable electrode, GMAW has a higher productivity than another widely used arc welding process – gas tungsten arc welding (GTAW). However, although the consumable electrode increases the productivity, its solid to liquid metal transfer complicates the process. Especially, the metal-transfer process plays an important role in determining the arc stability, resultant weld quality, and production of fumes and spatters. To better understand and control GMAW process, the metal transfer process has been studied widely. A lot of metal-transfer sensing methods have been proposed [1–10]. In [7], a technique named as laser back-lighting is proposed to image the metal transfer with good quality and contrast. This back-lighting technique has been adopted by many other researchers to conduct metal transfer research [8–10]. In [8], the back-lighting apparatus is used to determine the surface tension of the metal transfer droplets. In [9], the back-lighting apparatus is used to image and classify the metal transfer modes by setting different welding parameters. In [10], the back-lighting apparatus is used to image and control the metal transfer. However, none of them addressed the issue of automatic image processing algorithms for automated robotic welding. Instead, the past efforts were focused on the study of the relationship between the metal transfer and the welding parameters. Since machine vision has been widely recognized as the important component part of the next generation intelligent welding robots, automatic and robust image processing algorithms become essential for the potential applications of the related robotic welding techniques. To fill in the research gap and be well prepared for the next generation machine vision guided robotic welding, a series of image processing algorithms are proposed to automatically and robustly extract the useful metal transfer information in this paper.

In [10], the authors developed a closed loop control system that controls the metal transfer by the detaching of the droplet imaged by the back-lighting apparatus. Fig. 1 shows the 16 adjacent images with both droplet and undetached liquid metal from the video captured by the back-lighting apparatus developed in [10]. The detaching of the droplet is determined by the droplet's downward momentum that is mainly affected by the current ejection level and the mass of the droplet. The trajectory of the droplet and current phase can be matched. The authors tried to achieve one droplet per pulse by switching the current to base current after the droplet's detachment. The position of the droplet was extracted in pixel and its trajectory was matched with the current phase to

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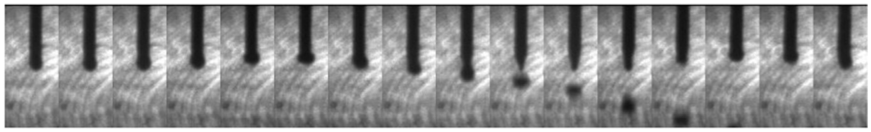

Fig. 1. Illustration of droplet formation/detaching and undetached liquid metal with images captured in [10].

achieve one droplet per pulse. The conclusion was drawn that the droplet with greater size results in slower oscillation. Their monitoring system calculated the detaching of the droplet whose frequency was mainly determined by the mass of the droplet. Unfortunately, the mass of the imaged droplet was not calculated at that time due to the lack of automatic and robust image processing algorithms. For more accurate control, both the size of the droplet and the undetached liquid metal are required, which was not addressed by any past research adequately. In addition, the authors stated that "a significant limitation of the developed control system is the use of the imaging system. To actually apply the proposed metal transfer control principle to GMAW, a low cost compact sensor must be developed." As can be seen, the complex back-lighting apparatus is not suitable for the practical robotic welding. To solve this issue, a simplified back-lighting based monitoring system was developed. In addition, automatic and robust image processing algorithms were proposed to extract the metal transfer information on line.

This paper is organized as follows. First, the proposed monitoring system is described in Section 2. Some typical images captured by the proposed monitoring system are shown. In Section 3, the captured images are analyzed. In Section 4, state of art segmentation methods are evaluated and analyzed. In Section 5, double-threshold method is proposed to segment the droplet and the undetached liquid metal. Effective methods are also developed to extract the metal transfer information. More experimental results are shown in Section 6 to demonstrate the effectiveness of the proposed monitoring system and image processing algorithms. Finally, conclusions are drawn and future work is discussed in Section 7.

2. Simplified laser back-lighting based monitoring system

Fig. 2 shows the diagram of the proposed monitoring system installed on a pulsed welding system which is powered by an adaptive pulse GMAW machine whose welding voltage and current are shown in Fig. 3(a) and (b). The mild steel electrode wire with the diameter 1.2 mm is used. The used shielding gas is 95% Argon and 5% CO_2 with a flow rate of 17 L/min. The pulsed GMAW system controls the welding current and wire feed speed through the central controller and obtains the metal transfer information through the developed laser backlighting system. A high speed camera connected with a high speed frame grabber is aimed at the imaging plane orthogonally and recorded the images in real time for on line feedback control. A 20 milliwatt laser centered at 685 nm with 10° divergent angle is projected across the metal transfer process and reaches the imaging plane placed on the other side. As pointed out in [10], the complex optical lens is difficult to set up in practical welding environments. In addition, the complex optical lens could not avoid the bad effect of arc light which fails the segmentation by a global threshold. Most importantly, effective image processing algorithms could extract the metal transfer information robustly no matter the images are captured with or without the complex optical lens. Hence, they are removed in the developed monitoring system. Without parallel rays, the imaged metal transfer will be enlarged and off-line calibration is needed to compute a scalar which is then used to transform the enlarged coordinate back to the real one. The wire with known width W_1 in mm is imaged at the imaging plane and its width W_2 in pixel in the camera view is computed. The scalar is computed by W_1/W_2. During on line monitoring, the computed width will be multiplied by W_1/W_2 and the computed size/area will be multiplied by $(W_1/W_2)^2$. A potential advantage of the divergent laser is that images with larger droplets are captured, which might increase the image processing accuracy.

As shown in Fig. 2, the imaging plane is placed at a distance $d2 = 300$ mm from the welding torch where the intensity of the arc radiation has been sufficiently reduced while the laser is still strong enough. The laser projector is placed at a distance $d1 = 250$ mm from the torch on the other side to ensure that the metal transfer can be imaged fully by the laser beam and the beam is also strong enough when reaching the imaging plane.

Three examples of typical metal transfer images are shown in Fig. 4(a)–(c). The droplet exists in (a) and the wire tapering is insignificant. In (b), there is no droplet and the wire tapering is still

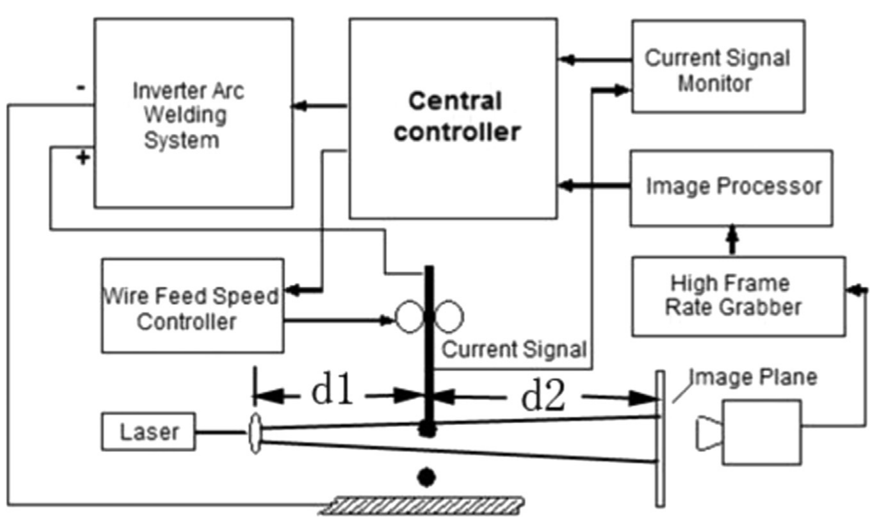

Fig. 2. Diagram of the proposed Monitoring System.