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COMPUTER VISION AIDED ELECTRODE WEAR ESTIMATION IN ELECTRICAL DISCHARGE MACHINING PROCESS

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Abstract

Electrical Discharge Machining (EDM) is one of the important processes in machining holes, which is used in wide application in industry. The electrode wear measurement in EDM is a crucial parameter for verification of the efficiency of machining process. The main objective of this work is to develop an approach for electrode wear estimation method using a computer vision technique. The proposed method consists of a Coupled Charged Device camera, arranged for images capturing, and a personal computer. The electrode wear is estimated by means of the decrease of electrode length after EDM, accordingly computer vision aided electrode wear estimation method has been proposed and employed to detect the electrode wear along its length using MATLAB package. The estimation method consists of image preprocessing, image segmentation, image overlapping and subtracting. The Experimental results confirmed the validity of the proposed vision method to achieve the required aim compared with some other used methods. Hence, the proposed vision method used in this work is acceptable, within the accuracy limit of the proposed method, to estimate electrode wear measurement, using relatively inexpensive equipment.

Keywords: Computer vision techniques, EDM, Electrode wear.

1. Introduction

Electric discharge machining (EDM) is one of the most efficient manufacturing technologies used in highly accurate processing of all electrically conductive materials irrespective of their mechanical properties. It is a non-contact thermal energy process applied to a wide range of applications, such as in the aerospace, automotive, tools, molds and dies, and surgical implements, especially for the hard-to-cut materials with simple or complex shapes and geometries [1].

In Electrical Discharge Machining (EDM), electrode geometry has a great effect on the machining process of the products. Thus, electrode wear estimating is very important in EDM [2].

Abu Qudeiri et al. [1] provided an overview of the studies related to EDM regarding selection of the process, material, and operating parameters, the effect on responses, various process variants, and new techniques adopted to enhance process performance. This overview (i) pans out the reported literature in a modular manner with a focus on experimental and theoretical studies aimed at improving process performance, including material removal rate, surface quality, and tool wear rate, among others, (ii) examines evaluation models and techniques used to determine process conditions, and (iii) discusses the developments in EDM and outlines the trends for future research. The conclusion section of the article carves out precise highlights and gaps from each section, thus making the article easy to navigate and extremely useful to the related research community.

Bellotti et al. [3] investigated the capability of data-driven regression models for tool wear and material removal prediction. The errors in predicting the MRR and TWR are shown to decrease of about 65% and 85% respectively when using data collected through process monitoring as input of the regression models. Data-driven approaches for in-process tool wear prediction have also been implemented in drilling experiments, demonstrating that a more accurate control of the hole depth (50% average reduction of the depth error) can be achieved by using data-driven predictive models.

Tool wear measurement process is proposed by Malayath et al. [4] which converted the tool of EDM to an image processing algorithm and computer aided wear prediction algorithm. A series of holes were made using this method and compared with hole making without compensation along with other methods.

Maity and Choubey [5] reviewed the research work carried out by the researchers on vibration-assisted EDM, micro-EDM, and wire EDM. The consolidated review of the work enables better understanding of the vibration-assisted EDM process. This study also discusses the influence of vibration parameters such as vibration frequency and amplitude on the material removal rate (MRR), electrode wear rate (EWR), and surface roughness (SR).

Gurupavan et al. [6] described a machine vision method, which is succeeded of presented wire electrode and workpiece pattern data in EDM of aluminium silicon nitride composite material.

Hamedon et al. [7] presented an automatic tool wear inspection system using computer vision. The images of the electrodes are processed using image processing-based MATLAB software to determine electrode wear.

A novel, non-contact method is proposed by Shivanna et al. [8], using vision approach. The system captures images of test surface and calculates 3D surface roughness parameters from the algorithms developed by using MATLAB. These values obtained by vision method are in close agreement compared with those obtained by optical method. It is also found from the experiment that, as the roughness of the specimen increases, the measurement accuracy improves.

An electrode wear compensation method is proposed by Yan et al. [9] measured front wear for drilling and corner wear for milling. Results showed that the machining time can be reduced when using this method, compared to the traditional wear measurement method.

Mathematical models had been developed by Azam and Singh [10] for material removal rate and electrode wear rate to some EDM parameters.

Slătineanu et al. [11] had developed some experiments to illustrate the effect exerted by the workpiece and by the electrode cross section size, respectively, on the electrode wear. The results show an intense wear in the copper which is close to wears in the steels and aluminum.

Khan [12] presented an analysis method to estimate wear along cross section of an electrode compared to the wear along its length in EDM. Results show that wear increases with an increase of current and voltage, but wear along electrode cross section is more compared to wear along its length.

Pham et al. [13] estimated wear based on geometrical data. Electrode geometry variation and the volumetric wear are studied. The proposed method illustrates those variations of wear ratio due to uncontrolled factors are not negligible in micro EDM.

Lin et al. [14] reported the use of the grey relational analysis based on an orthogonal array and fuzzy-based Taguchi method for optimizing the multi-response process. Both the grey relational analysis method without using the S/N ratio and fuzzy logic analysis is used in an orthogonal array table in carrying out experiments for solving the multiple responses in the electrical discharge machining (EDM) process. Experimental results have shown that both approaches can optimize the machining parameters (pulse on time, duty factor, and discharge current) with considerations of the multiple responses (electrode wear ratio, material removal rate, and surface roughness) effectively. It seems that the grey relational analysis is more straightforward than the fuzzy-based Taguchi method for optimizing the EDM process with multiple process responses.

2. Experimental Setup

2.1. Computer Vision System

Computer vision system setup, used in this work, consists of x-y camera setting system, as shown in Fig. 1, to control the position of camera relative to the tested electrode; this setup was used to adjust the movement of camera in two directions. In order to capture electrode images, a computer vision method is proposed. Images were acquired by a Coupled Charged Device (CCD) type SONY Cyber-Shot, connected to PC computer through a USB connection.

The CCD camera data are in pixels and the estimated wear data along electrode length must be determined in mm unit, the scaling factors were determined in mm/pixel unit. These factors were computed by standard block gauges with standard dimensions.

Details of camera calibration used for tool wear estimation is published separately [15]. The developed software was written using MATLAB software using image processing toolbox to analysis the captured electrode images.

The CCD camera captures the electrode images and sends the images data to the computer. Image processing includes image digitization, and image enhancement process. The input of the image captured data by means of the used vision system focused on the image interested area, which is here the electrode length.

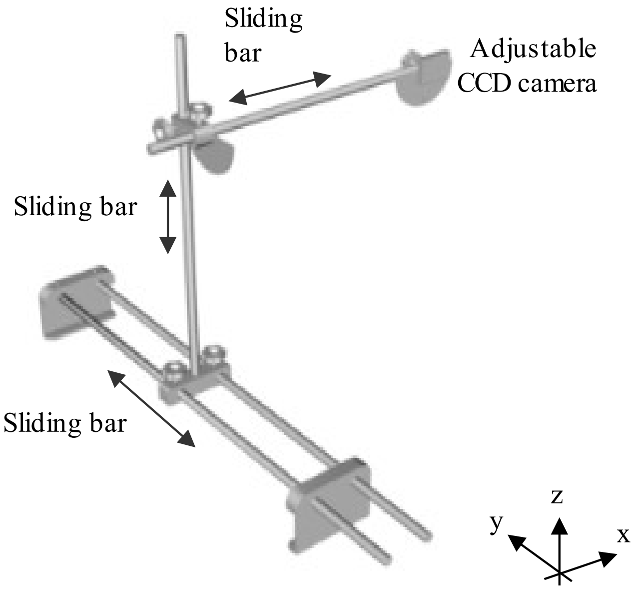


Fig. 1. The camera setting system.

2.2. EDM Process and Materials

Experiments in this work were achieved on CHEMER EDM machine (CM323C), which allows selecting input factors.

In this work, an overall of ten experiments were done using cylindrical copper electrode, as cathode, with (12 mm) in diameter and (30 mm) in length, and dielectric solution (diesel oil) to accomplish (12 mm) hole in a rectangular plate of steel (1005) as workpiece materials with (3 mm) thickness.

The EDM experimental parameters used are listed in Table 1.

Table 1. EDM control parameters.

Parameter	Value
Voltage	240 V
Current	20 A
Pulse on time	200 μs
Pulse off time	100 μs

3. Experimental Work

The copper electrodes length measurement in each test procedure were measured using a digital caliper, before and after EDM process and the average electrodes length were recorded. Each electrode length is scanned over a number of experimental runs before and after EDM process using laser scan device type (Straumann), as shown in Fig. 2, to scan and record the electrodes length measurement, the processed information is then saved in the computer connected with the laser scan device.

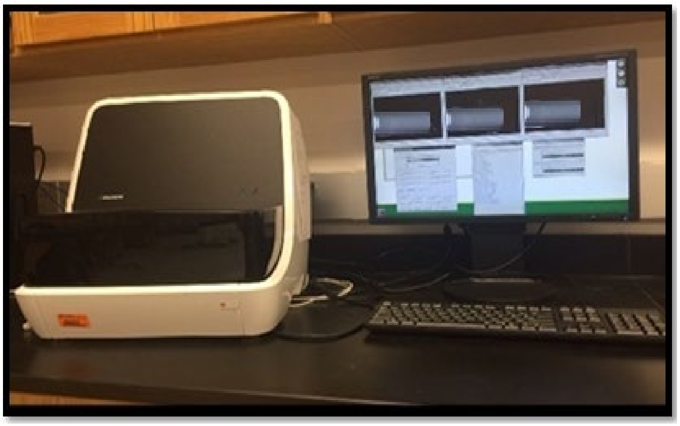


Fig. 2. Straumann laser scan device.

The CCD camera was employed to capture the electrode length before and after EDM process, and the image processing was performed using MATLAB. The processed images were cropped to a resolution 200×200 pixel and processed to gray scale images and then to binary images to minimize the processing time and suppress the unwanted features in the captured images. Figure 3 shows the electrode images before EDM process (reference image) and after EDM process (target image).

Table 2 enlists the average electrodes length measured, before EDM process, using digital caliper, laser scan device, and proposed vision method respectively.

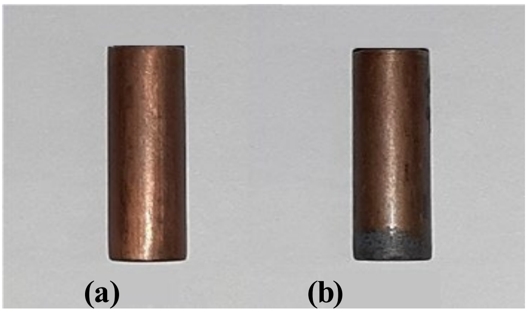


Fig. 3. Electrode images (a) before and (b) after EDM.

Table 2. Electrode's length measurement before EDM process.

No.	Average electrode length (mm)		
	using digital caliper	**using laser scan device**	**using proposed vision method**
1	40.10	40.08	40.11
2	40.13	40.15	40.12
3	40.15	40.13	40.11
4	40.09	40.11	40.14
5	40.11	40.10	40.13
6	39.97	40.05	40.09
7	40.07	40.10	39.98
8	40.10	40.13	40.08
9	40.12	40.15	40.13
10	40.09	40.11	40.05

The electrode image is processed using image thresholding, image filtering, closing, and image filling, as illustrated in Fig. 4.

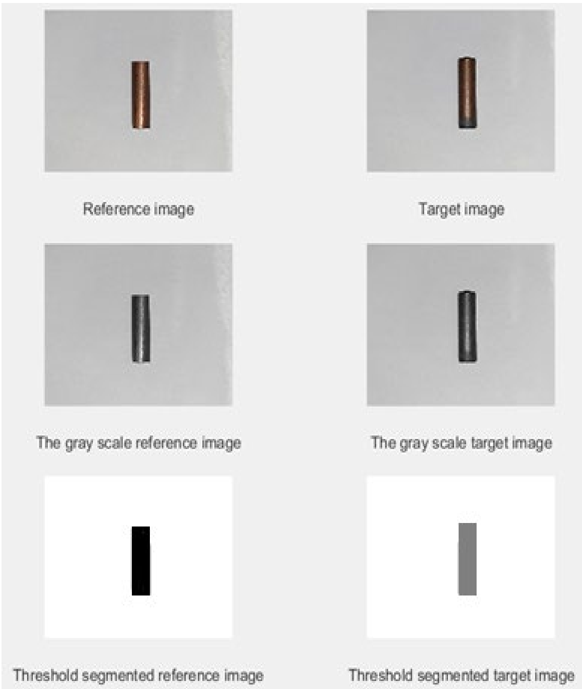
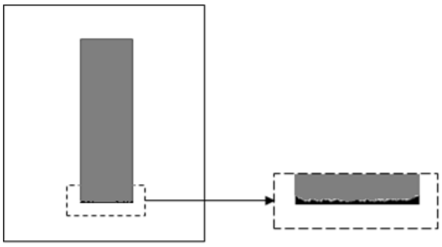


Fig. 4 Electrode images before EDM process (reference) and after EDM process (target).

Overlapping the electrode images before EDM process (reference image) and after EDM process (target image) can give a new electrode image, as shown in Fig. 5. Scanning the image row by row, starting from left to right along the electrode length, to identify the pixel intensity in the tested image, and accordingly indicate the estimated electrode wear results. Fig. 5(a) Shows black area for the estimated wear of electrode.



(a) **(b)**

Fig. 5. (a) Image overlapping process results (b) magnified part.

4. Results and Discussions

Table 3 enlists the comparison between the average electrodes length measured, after EDM process, using digital caliper, laser scan device, and proposed vision method respectively, and the absolute error values were computed between digital caliper results and laser scan device results, and between digital caliper results and the proposed vision method results respectively, and they both indicate there were no big deviations.

Table 3. Electrode's length measurement after EDM process and the absolute error.

No.	Average electrode length (mm) using digital caliper	Average electrode length (mm) using laser scan device	Error (mm)	Average electrode length (mm) using proposed vision method	Error (mm)
1	39.87	39.56	0.31	39.41	0.46
2	39.83	39.61	0.22	39.58	0.25
3	39.79	39.51	0.28	39.63	0.16
4	39.87	39.60	0.27	39.54	0.33
5	39.85	39.63	0.22	39.59	0.26
6	39.88	39.77	0.11	39.70	0.18
7	39.78	39.59	0.19	39.61	0.17
8	39.81	39.76	0.05	39.69	0.12
9	39.79	39.49	0.30	39.51	0.28
10	39.81	39.73	0.08	39.66	0.15
Average	39.83	39.63	0.20	39.59	0.236
Std. dev.	0.037	0.098	0.093	0.088	0.103

Using laser scan device, the maximum value for the error computed is found to be (0.31mm) for the electrode No. 1, while the minimum value for the error computed is found to be (0.05mm) for the electrode No. 8. While using the proposed vision method, the maximum value for the error computed is found to be (0.46mm) for the electrode No. 1, while the minimum value for the error computed is found to be (0.12mm) for the electrode No. 8 .Thus the experimental results show small deviation in the compared values obtained from both the laser scan device and the proposed vision method, thus concluding the acceptance of the results and it is considered to be accurate.

Figure 6 shows the comparison chart between the experimental values obtained from the digital caliper, laser scan device, and the proposed vision method values. From the observation, it is clear that there is a very little deviation between the experimental values obtained from the laser scan device and the proposed vision method values which validates the proposed method.

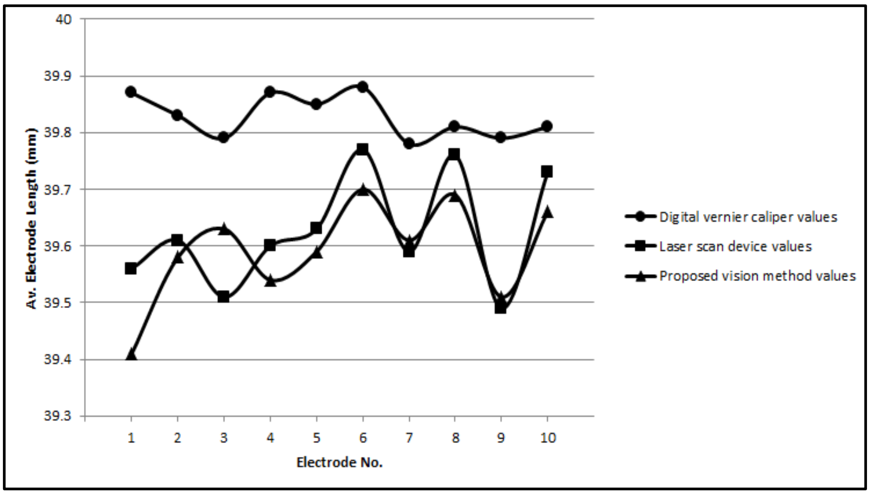
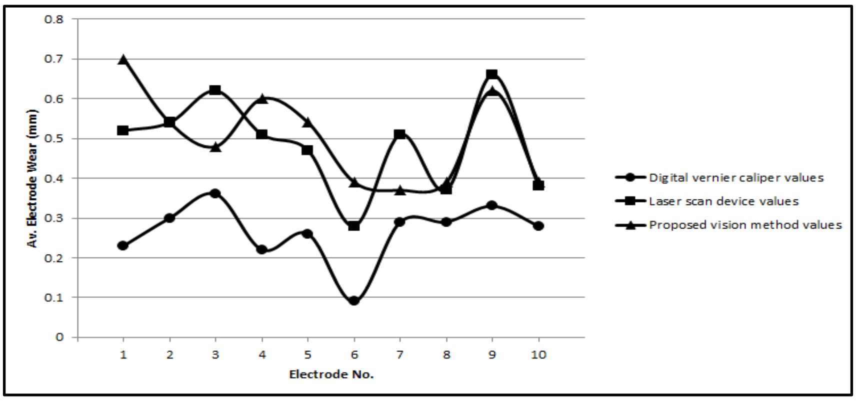


Fig. 6. The experimental comparison chart.

Table 4 and Fig. 7 show the estimated electrode wear values obtained experimentally using digital caliper, laser scan device, and using the proposed vision method. Using the conducted experiments, it could be observed from these experimental results that the laser scan device values and the values obtained from the proposed vision method are both successful in positively identifying electrode wear values.

Table 4. Estimated average electrode wear values (mm).

No.	Average electrode wear (mm) using digital caliper	using laser scan device	using proposed vision method
1	0.23	0.52	0.7
2	0.3	0.54	0.54
3	0.36	0.62	0.48
4	0.22	0.51	0.6
5	0.26	0.47	0.54
6	0.09	0.28	0.39
7	0.29	0.51	0.37
8	0.29	0.37	0.39
9	0.33	0.66	0.62
10	0.28	0.38	0.39
Average	0.265	0.486	0.502
Std. dev.	0.0744	0.1158	0.1160



5. Conclusions

The objective of this work is to propose a novel, inexpensive, and efficient method to estimate electrode wear in EDM, and although the goal of estimating electrode wear measurement from a captured image is a challenging task, the proposed vision method succeeded to estimate close to real measurements. These close to real measurements were gained due to the well arrangement and setting of the used camera, suitable selected image threshold value, and the careful setting of camera calibration process.

The results illustrated that there is a little deviation between experimental values obtained from the laser scan device and the proposed vision method values which validates the proposed method. Consequently, the proposed methodology is acceptable, within the accuracy limit of the proposed method and compared with the resulted data of reference [3], to estimate electrode wear measurement, using relatively inexpensive equipment. Future research will focus on studying more advanced approaches for extracting electrode features and information from the captured images.

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