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Pre-Forming Inspection System to Detect Deep Drawing Defect Due to Punch-Die Misalignment using Image Processing Technique

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Abstract. Deep drawing processes are extensively used in the industry for the fabrication of a wide range of sheet metal products from household appliances to automotive parts. In a deep drawing process, the alignment of the punch and die is extremely important to avoid defects such as variation of thickness and intolerable thinning condition of the drawn part. In this paper, a computer vision system is proposed that is able to identify the degree of misalignment in the punch-die configuration. The apparatus consists of an image capture and analysis system that can be used as a tool for pre-forming inspection setup. The image analysis implements the centroid recognition approach using the Image Processing Toolbox function in MATLAB. The offset value between centre of the punch and the centre of die indicates the severity of misalignment between punch and die. The system was successfully tested for a square profile, with more accurate results obtained for a colored punch as compared to the punch with the original metallic surface. Verification of the system was then conducted to align the centroids of a punch and die, and the results show that a good alignment of the centroids was achieved within two alignment attempts.

1. Introduction

Deep drawing is defined as the forming of a flat stretched sheet metal through a die into various shapes by using a compression force. Four basic components are required to perform a drawing process, namely, the punch, die, blank and blank holder. The drawing process can be conducted in a single step, although for greater depths, multiple drawings are usually needed. The total number of redrawing depends on many factors such as the material used (the blank), the dimensions required, and the final shape of parts. As compared to other production methods, the deep drawing process is able to produce high quality and complex shaped parts with minimal costs [1].

Some of the defects that can occur in deep drawing process are earing, wrinkling (either on the flange or wall of part), tearing and surface scratches [2]. Earing defects occur due to variations in properties because of the anisotropy of the material used as the blank. Anisotropy is a phenomena that is difficult to avoid when working with sheet metals [3]. Wrinkling is another type of defect that usually occur in a deep drawing process, its severity increases by insufficient blank holder force. Wrinkling usually occurs on the flange of the part, although it can also appear on the wall of the part. Tearing defects can occur due to severe thinning of the blank, caused by incorrect geometrical dimension of the die such as die radius, punch nose radius and punch-die clearance. Excessive thinning at the wall of the part is one the major contributing factor in the failure of the draw process. As mentioned by Colgan and Monaghan

[4], a decrease in the die radius would increase the drawing force. This increase in drawing force creates uneven thickness distribution at the wall of the part and thinning of the part structure. Severe thinning would result in tearing of the part.

Uneven wall thickness would result in thinning of the part. To minimize uneven wall thickness of the drawn part, the alignment between the punch and die should be controlled. Severe misalignment between the punch and die would result in undesired thinning of the part and failure initiation by tearing. This misalignment could be caused by incorrect tolerances used during die fabrication or alignment inaccuracies in the assembly of the die. Such misalignment and dimensional inaccuracies can be reduced by precision workmanship during those stages. Vairavan and Abdullah [5], in their studies on deep drawing of square cups without blank holders, have remarked that that alignment between punch and die is important for obtaining high quality parts. Slavič et al. [6] have found that misalignment between punch and die will increase the drawing force, although their study was limited to circular blanking process only. In contrast to cylindrical cup shape where the pressure is uniform on all area, rectangular shell requires increased force due to additional corners on the shape. This was the conclusion of Tamaoki et al. [7] whom have stated that stress concentration in a drawing process for a rectangular shaped part is higher than a cylindrical cup shape. Younis and Jabber [8] found that thinning of a square cup deep drawing usually appear in the corners of a part due to excessive stretching in those regions. Behrens et al. [9] also concluded that the degree of punch force has a more pronounced influence in a rectangular cup profile as compared to cylindrical cup shape when die radius variation was studied.

In recent years, integration of computer-aided technology in the stamping industry has opened up a new era in the production of high quality stamped components [10]. These technologies are commonly implemented in pre-production as a predictive tool, such as in the use of computer simulation software for deep drawing processes. For examples, Ogawa et al. [11] have utilized LS-DYNA, a finite element analysis (FEA) simulation software, to acquire early knowledge on the formability of square cup deep-drawing of pure titanium, which was then verified by experimentations. Yang et al. [12] were able to propose an optimal blank shape on deep drawing process of trapezoidal and square cups with the use of DEFORM-3D, another commercial FE package. Similarly, Reddy [13] used FEA to determine the formability of warm deep drawing for AA1050-H18 rectangular cup while Zein et al. [14] also used FEA to predict thinning and spring back conditions of sheet metal in a deep drawing process. Results of FEA simulation enable early prediction of the forming process which improves the overall production flow in term of reduced costs, decreased fabrication time and increased part quality. Computer-aided technology can also be used in supervision and surveillance of product quality control. These are usually packaged as a smart automation technology, in which various sensors and computer-aided monitoring equipment are used to detect part quality automatically. In a forming operation, the technology can be implemented before the drawing process (pre-forming), during process (in-situ) or after a process (post-forming). Past researchers have proposed vision and non-visual methods of evaluation which can be integrated in the forming production process. For example, Garcia [15] has used an artificial intelligent method to detect wrinkles and crack formation during a drawing process. In addition, Zoech et al. [16] have used electromagnetic and micromagnetic NDE technique to detect online crack and thinning while Kibe et al. [17] have used a commercial vision system to detect alignment between the punch and die before performing a shearing process. Similarly, Berger and Zussman [18] have used a novel measurement technique based on noncontact ultrasonic-based gauge to detect online wall thickness distribution of circular part during deep drawing processes. Among these methods, the computer-aided vision system is deemed to be the most suitable for integration into a deep drawing process. The vision system can be used as a pre-forming inspection of the alignment between punch and die in deep drawing process to detect the severity of misalignment of the components.

This paper proposes a pre-forming inspection system to detect the misalignment between the punch and the die for a square cup deep drawing process. This inspection procedure would be performed before the actual drawing process takes place. The inspection system consists of a vision system and a computer algorithm developed in MATLAB. The captured images of the punch and die is analyzed using

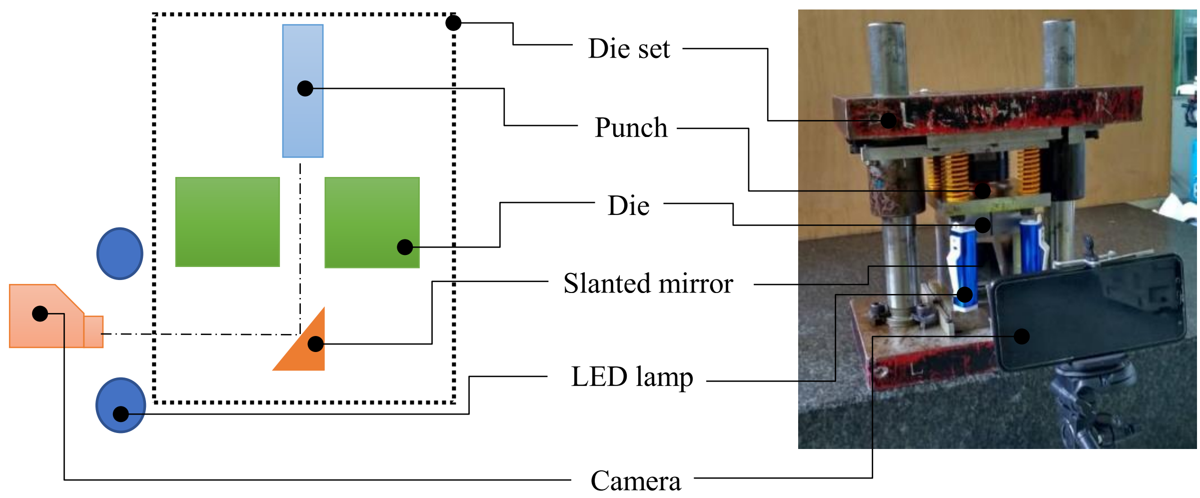
MATLAB based algorithm for centroid recognition. The offset values between centre of the punch and the centre of die indicate the severity of misalignment between the punch and die.

2. Model Development

2.1 Equipment Setup

Figure 1(a) shows the schematic diagram of the system developed in this study. The system consists of a digital camera, a back-lighting system, an anti-glare mirror and the die set. A push-through draw dies type with a blank holder was selected for use in this system. This type of die has a blind slot in the die block that enables the blank to be drawn into it via a die insert, as shown in Figure 3. Each component of the die is mounted on a center-post die set type having two guideposts on the right and left of the die shoes. The punch is mounted on the upper die shoe using a punch holder and the die insert is mounted on the lower die shoe by using a die block. The flat surface of the punch was aligned to be parallel with the surface of the die insert using the blank holder. The shape of punch is square with the dimensions of 13.6mm x13.6mm, while the punch nose radius, R_{PN} and the punch corner radius, R_{PC}, are both 2.5mm. For the die insert, the dimensions of square opening size are 15.74mm x 15.74mm, the die radius, R_D, is 5mm and the die corner radius, R_{DC}, is 3.57mm. The clearance value, *C,* between the punch and the die is 1.07mm. Figure 2 shows the overall dimensions of the punch and die insert.

As shown in Figure 1(b), the digital camera is mounted on a tripod facing the front of the die set. The digital camera has a 13 Megapixels sensor with an aperture size of *f*/1.9. In this study, the camera resolution was set to 4128×3096 pixel (4:3, 12.78MP), with focus length of 0.15m, ISO 500 film setting and a shutter speed 1/100 second to ensure clear observation of the die set. The height of camera is adjustable to ensure that the center of focusing lens is always straight and parallel with the center of image reflected off the mirror. The anti-glare mirror, tilted at a 45° angle, provides a clear image of punch and die insert. A mirror holder is mounted below the die block and located at the center of the die block opening. The back lighting increases the ambient illumination, reducing undesired image noise in the image captured. The lighting system consists of two 15 Lumens LED white light is, arranged to illuminate the image capture area. The auto focusing and auto exposure modes were disabled to ensure a consistent image setting was used for all image captures. The captured images are then uploaded into MATLAB software for subsequent image processing.



(a) Schematic diagram arrangement of system (b) Actual setup of the system

Figure 1. Arrangement of the system

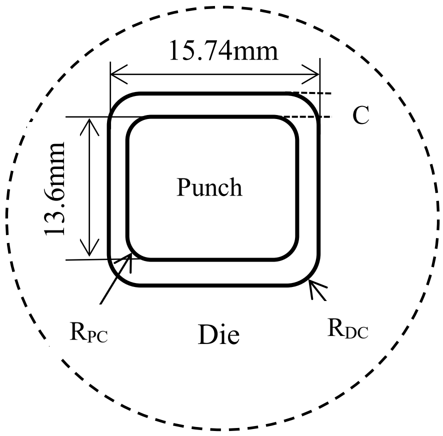


Figure 2. Dimension of punch and die

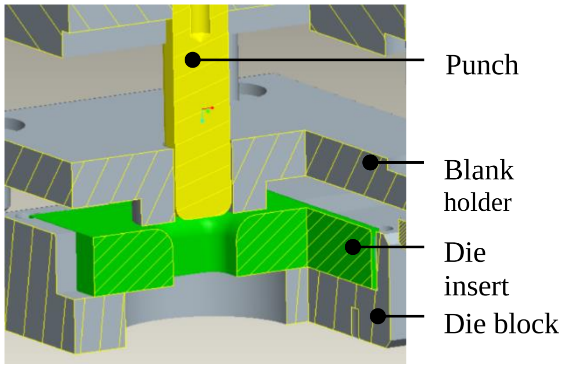


Figure 3. Cross-section view push through draws die

2.2 The Proposed Algorithm

In this study, a centroid recognition method was used to detect misalignments between the punch and die. The Image Processing Toolbox function in MATLAB was used to process the captured image (raw image) to obtain the centroids of the punch and die. Variations of the centroid values between the punch and die indicates the extend of misalignment between the two components. The raw image needs to undergo several image analysis processes prior to the centroid detection procedure. Firstly, the raw image is calibrated and transformed appropriately. Then, image noises are removed through an image restoration process. Color segment detection function is then used to detect the surface of punch while the edge detection function is used to detect the edges of die. The punch is painted red for the color segmentation process. For the die, the canny method of edge detection was used to define the edges of the die. The image is then converted to into a binary image and morphological filtering is performed to remove unwanted pixels and to obtain an improved binary image of the punch and die. The centroid of the punch and die can then be obtained by using image region properties function. Figure 4 shows the process of image processing and analysis to obtain the centroids of the punch and die.

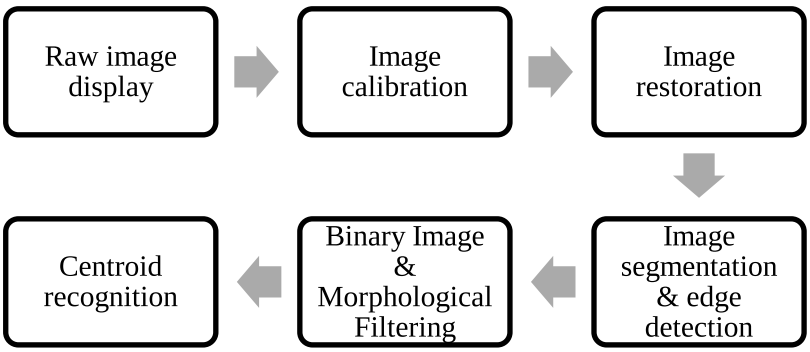
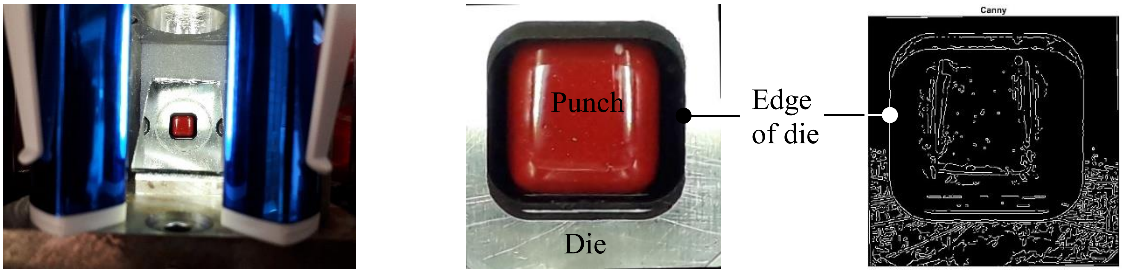


Figure 4. Image processing procedure flow chart to determine centroid

3. Result and Discussion

The captured raw image needs to undergo appropriate cropping and transformation procedures before it can be further processed. Since the position of the camera is not parallel to the image appearing on the 45° tilted mirror, as shown in Figure 5(a), appropriate corrections needs to be conducted to correct the projection of the image. This can be achieved by simple geometrical transformation such as rotating and cropping to obtain an improved image, as shown in Figure 5(b).

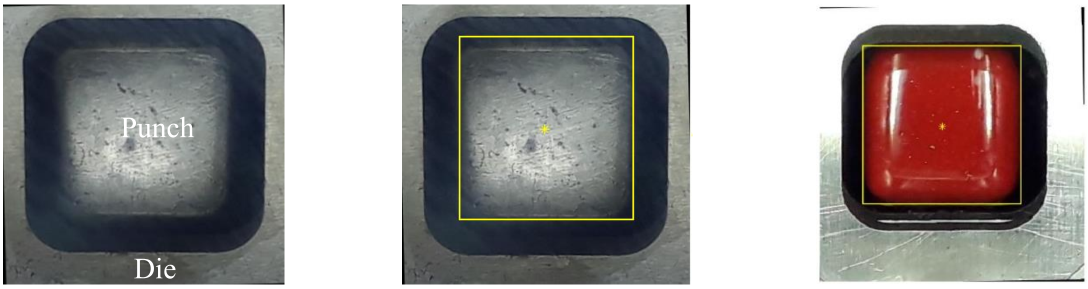


(a) (b) (c)

Figure 5. (a) Raw image (b) Image after geometrical transformation (c) Edge detection of die

Several edge detection methods, such as Sobel, Prewitt and Roberts can be used. However in this study, the more efficient Canny edge detection method is selected. Figure 5(c) shows result of Canny edge detection for the die. For comparison, the uncolored metal punch is shown in Figure 6(a). It was seen that an uncolored punch located deep inside the die was very difficult to be observed clearly and the metallic surface was very reflective. This reflectivity affected the visibility of the punch and edge, especially for the edge detection process, with increased image noise resulting in an inaccurate calculation of the centroid. This problem can be overcome by coloring the punch, and then using the color segmentation procedure to identify the punch surface area. Figure 6(b) shows an inaccurate centroid of punch (star mark) due to unclear punch edge identification. In comparison, the centroid of the colored punch is more precise due to distinct edge profile, as shown in Figure 6(c).

The resolution of the raw image also plays a role in the accuracy of centroid detection. Low resolution image also resulted in inaccurate centroid detection. As shown in Figure 7, a low image resolution of 480×640 pixels resulted in a blurry image of the punch edge, and the centroid detected was therefore inaccurate. Using a high-resolution raw image is therefore recommended for accurate centroid detection.



(a) Image of original punch (b) Inaccurate centroid of punch (c) Centroid of colored punch (red)

Figure 6. Comparison accuracy of centroid between original punch and a red colored punch

(a) Raw image of 480×640 pixels (b) Centroid detection of punch

Figure 7 Detection of punch centroid for raw image with 480×640 pixels

Figure 8 shows the centroid value for an image of a punch and die configuration. The difference between the centroid values of the punch and die were (4.0696, 2.248) pixels. Using a conversion factor, this correspond to a displacement of (0.015,0.05) mm, indicating the punch is slightly to the left and towards the top of the die.

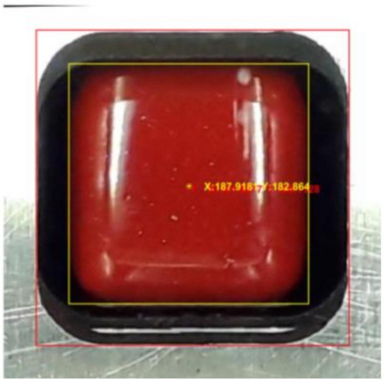


Figure 8. Centroid of punch and die

Table 1 shows the example of applicability of the proposed technique in determining the degree of misalignment of the punch and die for a deep drawing process. Three images were captured and analyzed in an attempt to firstly determine and then to align the centroid of the punch with the centroid of the die using the developed system. The initial offset is calculated from the original image. Once the offset was determined, the first attempt (Attempt 1) was made to align the centroids of the punch and die. The second attempt (Attempt 2) is to fine tune the alignment, based on the offset values calculated from Attempt 1. The results have shown that after the second attempt, the centroids of the punch and die were able to be aligned with minimal offset values.

Table 1. Result of offset values between original condition and after modification

Image Status	**Offset value centroid punch-die, mm**	
	X axis	Y axis
Original Condition 	0.411	-0.326
Attempt 1 	0.204	-0.047

Attempt 2 	-0.008	0.046

4. Conclusion

In this work, a computer vision based pre-forming inspection system to detect misalignments between punch and die for square shape cup has been developed successfully. Preliminary results showed that the proposed system has successfully detected the centroids of the punch and die of a deep drawing die set.

Future works would concentrate on the drawing process of the aligned punch and die using a Universal Tensile Machine (UTM). Result from experimental evaluations such as the punching loads and wall thickness distribution of the part would be compared with the results from FEA simulations.

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