Berg Huettenmaenn Monatsh (2022) Vol. 167 (9): 435–442
https://doi.org/10.1007/s00501-022-01268-6

BHM Berg- und Hüttenmännische Monatshefte

A Knowledge Based Framework to Design and Analyze Metal Working Die Using Image Processing Technique

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Received July 11, 2022; accepted August 2, 2022; published online August 20, 2022

Abstract: The present work focuses on the knowledge-based expert system to develop an automated die and punch tools design for the sheet metal forming process (deep drawing operation). The major limitation of the conventional forming process is the manufacturing of dies. As the attributes of the final component varies, the configuration of the tooling (punch and die) require to be modified. Hence, the tooling cost and inventory increases and results into higher production cost. Therefore, to address this issue, a hybrid intelligent system is proposed considering the concept of image processing and knowledge based architecture. A novel algorithm is proposed which consists of bunch of rules to construct the conventional forming tools design. Python and AUTOCAD-VBA tools are used to develop the intelligent model. Such, hybrid model is able to handle large variety of configurations with semi skilled operator. The benefits, like reduced trial and error method with minimum production cost, can be achieved.

Keywords: Artificial intelligence, Image processing technique, Expert system, Sheet metal forming, Deep drawing, Python, AUTOCAD-VBA, ABAQUS

Ein wissensbasierter Rahmen zur Konstruktion und Analyse von Metallbearbeitungswerkzeugen mit Hilfe von Bildverarbeitungstechniken

Zusammenfassung: Der vorliegende Beitrag konzentriert sich auf ein wissensbasiertes Expertensystem zur Entwicklung eines automatisierten Werkzeugs für die Blechumformung (Tiefziehen). Die größte Einschränkung des konventionellen Umformprozesses ist die Herstellung von Werkzeugen. Da die Eigenschaften des endgültigen Bauteils variieren, muss die Konfiguration des Werkzeugs (Stempel und Matrize) geändert werden. Dadurch steigen die Werkzeugkosten und der Lagerbestand, was wiederum zu höheren Produktionskosten führt. Um dieses Problem zu lösen, wird ein hybrides intelligentes System vorgeschlagen, das das Konzept der Bildverarbeitung und der wissensbasierten Architektur berücksichtigt. Es wird ein neuartiger Algorithmus vorgeschlagen, der aus einem Bündel von Regeln besteht, um die konventionellen Umformwerkzeuge zu entwerfen. Für die Entwicklung des intelligenten Modells werden Python und AUTOCAD-VBA-Tools verwendet. Ein solches hybrides Modell ist in der Lage, eine große Vielfalt von Konfigurationen mit einem halbwegs erfahrenen Bediener zu handhaben. Die Vorteile, wie z. B. eine reduzierte Versuchs- und Fehlermethode mit minimalen Produktionskosten, können erzielt werden.

Schlüsselwörter: Künstliche Intelligenz, Bildverarbeitungstechnik, Expertensystem, Blechbearbeitung, Tiefziehen, Python, AUTOCAD-VBA, ABAQUS

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1. Introduction

Artificial intelligence (AI) is an interdisciplinary field which includes various applications where algorithm, methods, and techniques are used for automated decision making. It is a part of software engineering where others' conscious insight is re-enacted with a machine. The utilization of AI is in genuine assuming a main job in the innovation advancement of clever frameworks. The framework can be described by their ability to deal with the problems.

TABLE 1
Literature review

Authors	Methodology	Outcome
Sabzi et al. [2]	Meta-heuristic algorithm	The study includes the identification of weed in the crop of potatoes based on the expert system. The emphasis is on the accuracy of identification of precision on spraying on crop and the algorithm is based on minimization of color and texture properties
Kleemann et al. [3]	Bayesian Belief network	The work emphasized on the development of model considering the three important parameters of high and low rainfall and food insecurity
Stewart et al. [4]	Probabilistic Bayesian belief network	A model was developed to quantify risk factor of rice-shrimp in the region of Vietnam
Menekay M [5]	Knowledge based	Considered the studies pertaining to the banking and financial sectors
Del Mar Roldán-García et al. [6]	Ontology-driven approach	They performed on anti-fraud detection, detection enhancement for use of a card in e-commerce sites
Albusac et al. [7]	Knowledge based	For enhancing and improving the pedestrian crossing based on obtained knowledge database of visual feedback
Zhang et al. [8]	Linear regression, power regression, stepwise MLR and SVM methods	Developed algorithm for sheep body dimensions measurement. MLR = multiple linear regression SVM = support vector machine
Sunoj et al. [9]	Image processing	They have recognized sunflower's head, disc, and ray florets. They have used ImageJ's inbuilt thresholding method with basic image processing concept and technique
Hernández et al. [10]	Segmentation	They have used pseudo color based segmentation for water level identifications
Zhao et al. [11]	Image processing	They have proposed a model to grinding damage depth recognition on optical glass K9 material
Wei et al. [12]	Knowledge based	Summarized various situation awareness in intelligent human-machine interaction of decision making. It was reported in various AI technologies like CNN, Fuzzy logic etc. can be effectively used
Reed and Gillies [13]	Image processing	Developed a chair maker program in which a new design of chair is automatically generated from a set of existing objects of the same class. They have combined the properties of each object for decision making

These problems do not require unambiguous calculations, scientific relationships, and more. Thus it can be used for a deterministic and novel response. AI is the investigation of how to influence PCs to find and apply structured solutions to complex issues by using unstructured dispersed data. According to Aguilar et al. [1], AI has problem-solving techniques like Problem Solving and Planning (PSP), Expert Systems (ES), Natural Language Processing (NLP), Robotics, Computer Vision (CV)—Image Processing, Machine Learning (ML), Genetic Algorithms (GA), Artificial Neural Networks (ANN), and more. Out of these topics, expert systems provided the much-needed capability to automate decision making in a problem-solving environment. The brief state of the art related to the present research is shown in Table 1.

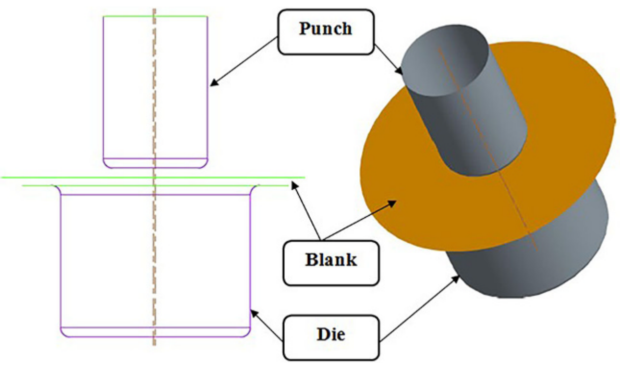

Fig. 1: Schematic of deep drawing operation

Sheet metal forming (one of the manufacturing processes) is the shape change operation where the volume of the raw material remains constant. In this process, a metal sheet (usually up to 6 mm) is placed over the die. Later the clamping pressure is applied by the blank holder and travelling punch is deforming sheet under the contact zone (Fig. 1). In such a way, the final product is obtained.

There are several operations involved in the sheet metal forming viz. deep drawing, punching, blanking, etc. Among them, deep drawing is widely implemented to produce the components with large variety, i.e. ranging from household utensils to the defense and aviation components. The major issue with deep drawing is the tooling design with the variation in the attributes of the final component. There is a need to manufacture separate tooling (punch, die, and blank holder) with the specification of the final component. Thus, every time Micro Small and Medium Scale enterprises (MSME) are required to produce product specific tooling. Such practice ends up with a huge raw material requirement for tooling, larger inventory to handle, increased lead time, lesser adaptability to respond the market demand, and more. Thus, an attempt is made to develop a hybrid intelligent system wherein the die designing rules are gathered from the design data book

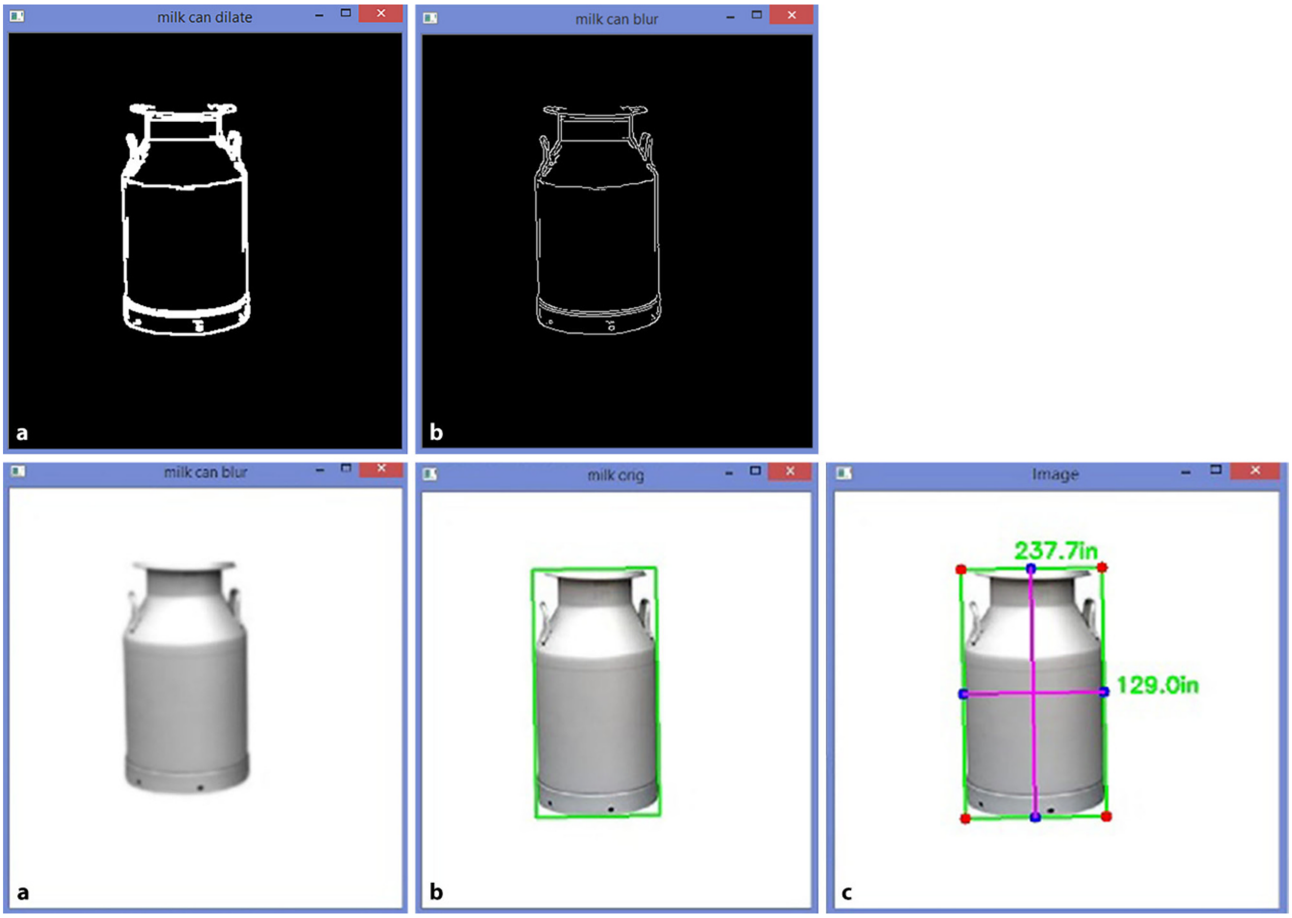

Fig. 2: **a** Blur operation on grey image **b** dilation operation **c** edge detection **d** box on found contours, and **e** height calculation

and the industry experts. The bunches of collected data are set as rules. These rules are being operated through the AUTOCAD-VBA environment through the image processing concept. This practice requires the final product geometry. By using the digital image processing, the dimensions like height and width are calculated and later the manufacturing drawing of all components for all stages are generated. The enterprise would be able to operate the proposed intelligent model with a semi skilled operator. Also, by implementation of the proposed model the direct and indirect costs can be saved.

2. Materials and Methods

2.1 Development of Intelligent Model Framework for SMC (Sheet Metal Component) Die

To develop an expert system, an intelligent model framework is formatted and applied. Development steps include requirement gathering, framing of production rules, Verification and Sequencing of Rules, Identification of dimensions from the 2D image, Construction of Knowledge-based Module, User interface, Validation and verification of the module, Identification of analysis tools, Module Testing, Industrial Testing, Validatation using the simulation results, and more.

2.2 Model Architecture Configuration

The calculation parts of the physical attributes for the forming operations are defined by the height and width of the desired product. Therefore this task is segmented in two parts. The first part contains the calculation of product measurement (height/width) from the digital image. Basic image processing operations are used for pre-processing (Fig. 2a–c). The developed novel algorithm is applied for height/width (in inches) calculation (Fig. 2d,e).

2.2.1 Height Determination of Target Object from the Image

A novel algorithm is developed to measure a target object's height/width from a digital image. In this regard, the following steps are followed:

1. Take a 2D image of the product from the camera. It is required that the background color should be different from the object. (In the present case, the glass color is considered as orange and background color as brown in order to provide sufficient contrast).

2. Apply grayscale operations to an image and blur it lightly. The Gaussian Blur effect is employed in the present case.
3. Perform edge detection (to detect edges in the image, canny edge detection technique is used in present work).
4. Perform a dilation and erosion to close gaps in between object edges. It is desired to maintain continuity between pixels. Hence dilation and erosion technique is used to count close gap between pixels.
5. Find contours in an image from edge map.
6. Pass width and arrange the contours from left-to-right and initialize the base for counting. The procedure is initializing "pixels per metric" calibration variable to count ration from an image. In present work, 150 pixels are considered per known width. By doing this, the pixel per matrix ration variable can be determined. This technique is the same as graph paperwork.
7. Loop over the contours individually. If the contour is not large and the gap is there, then ignore it. If there is no gap and counter is large enough, then bound this area with a box on x-y coordinates and make a mid-point.
8. Compute the Euclidean distance between midpoints sets for height and width (x-y coordinates).
9. Utilize "pixels per metric" variable. The division of counted width in the pixel with provided known width is performed. By doing so, approximate pixels per inch can be determined. Use it with top-left, top-right, bottom-right, and bottom-left co-ordinates so that dimensions height and width can be obtained.
10. Draw these dimensions, height and width of the target object on the required image.

By following this procedure, one can arrive at the height of an image form width and vice versa. The image processing mechanism is required to be understood because a proper understanding will only provide the quality improvement in terms of accuracy of dimensions obtained. The basic image processing concept and novel algorithm is applied on input image. ES is capable to measures height/width (inches) in an appropriate manner. The sample images (pre processing of image) are shown in Fig. 2.

It can be seen from Fig. 2 that the system is capable to calculate axi-symmetric large objects height/width. Afterwards these product attributes (height/width) are used as an input for a further process. The accurate dimensions of die and punch tools with respect to the original product is calculated in subsequent processing.

2.2.2 Blank Diameter, Clearance (Gap), Punch and Die Profile, Number of Draws, Punch Diameter, Die Diameter and Load Calculation (Using Rules and Knowledge-based Concept)

The input variables are calculated using the standard equations from Ghosh and Malik [14], Hosford and Caddell [15], and ASM handbook [16]. Also the inputs gathered from the industries are incorporated with the empirical equations. These inputs are utilized with regulations using VB.NET and AUTOCAD to derive the outputs. The output phase comprises the determination of the quantities, like the ini-

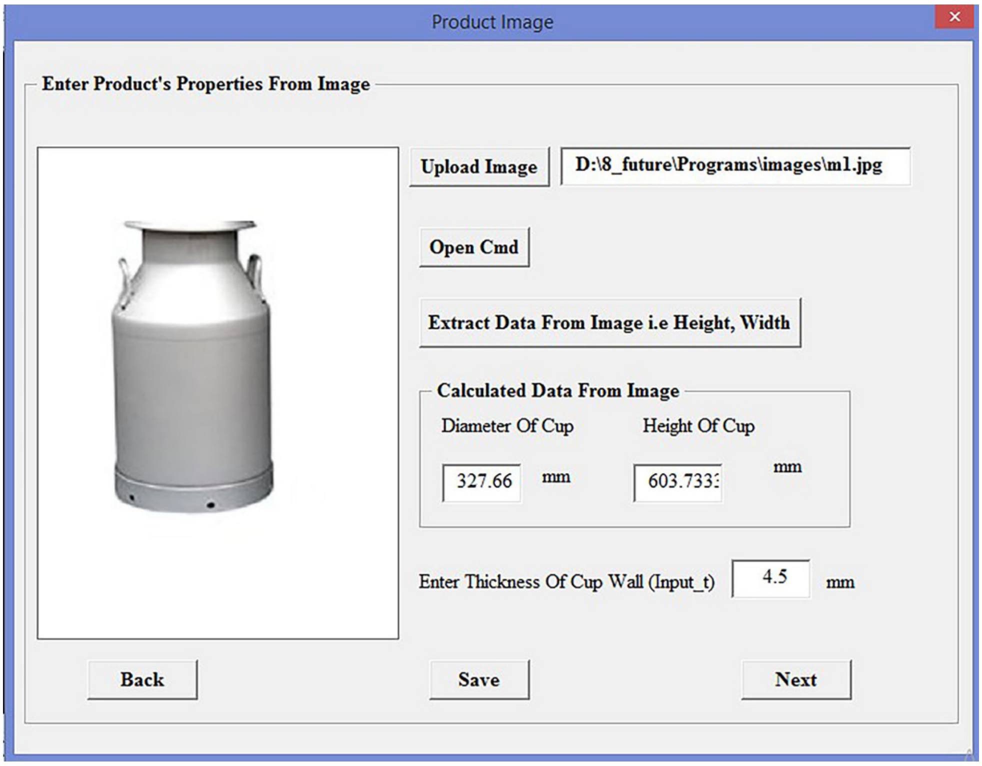

Fig. 3: Input definition: product configuration

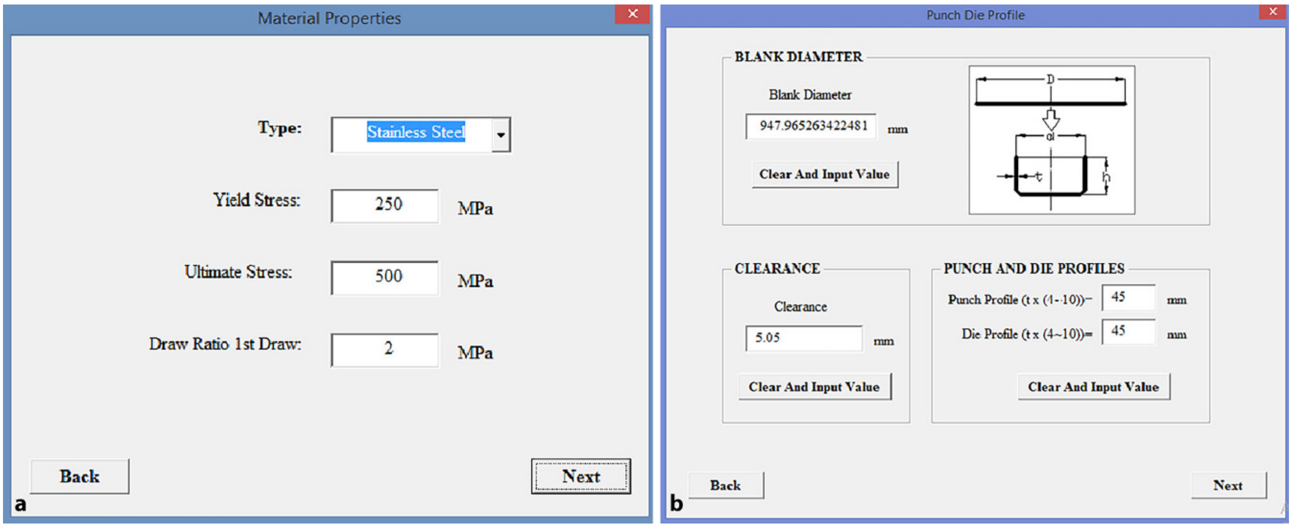

Fig. 4: **a** Material definition and **b** determination of tools profile

tial blank diameter required for the given configuration, the clearance required between the punch and the die, and the forces encountered on the punch and the die reaction forces. Finally, the manufacturing drawings are plotted in AUTOCAD.

2.3 Prototype Execution

A Graphic User Interface (GUI) makes the framework user-friendly. For execution, the image of the end product must be uploaded. Then the fetching of the data, i.e. height and width, are done as shown in Fig. 3. Based on that, the diameter, width, and height (in inches) are calculated. The original height and width of this product (large milk container) were 328 mm and 604 mm. which are matched with the expert system result (here the dimensions are in mm). Further, the workpiece thickness must be inserted manually. In order to run the prototype, presently stainless steel is selected as material type input (as can be seen in Fig. 4a). The image represents the indicative image of the milk cane because the milk cane manufacturing includes deep drawing along with spinning and welding. As the present work is emphasized on the deep drawing process, this image is considered as indicative. The cup thickness is considered with 4.5 mm and the remaining information is described in Fig. 3.

This framework is limited to mild steel, stainless steel, and aluminum, since they are the major material types used in domestic household appliances.

The required material properties are the yield and ultimate stresses (as shown in Fig. 4). Corresponding other material properties (i.e. density, poisons ratio, elastic limit, and others) are already used during the programming. Hence, very few data are required for initiation.

Later, during the execution stage, the blank diameter is first calculated (Fig. 4b). The blank diameter is very important because it has to be cut from large metal coils. Thus, the accurate blank diameter will reduce the material wastage in the long run. Further, the clearance is calculated as shown in Fig. 4b. The accuracy of the clearance reduces the risks of defects like wrinkling in the wall, scratches, excessive thinning, and more. The punch and die profiles are also being calculated (Fig. 4b). Some amount of fillet on the corners of punch and tool must be provided to avoid cutting action during the process. The number of draws can be obtained based on Fig. 5. It shows the determination of the number of draws which includes required tooling configuration, i.e. punch and die diameters. In the forming process, sheet metal for large container cannot be formed in shape using single draw. A large deep drawing product may require a number of drawing operations to be performed on sheet metal. So it is advisable to calculate the number of draws required based on the input material and dimension for an error-free result. The developed system is

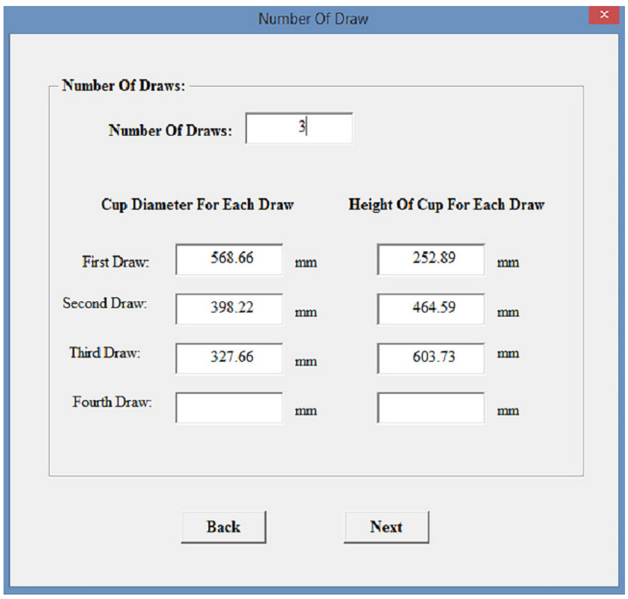

Fig. 5: Determination of the number of draws

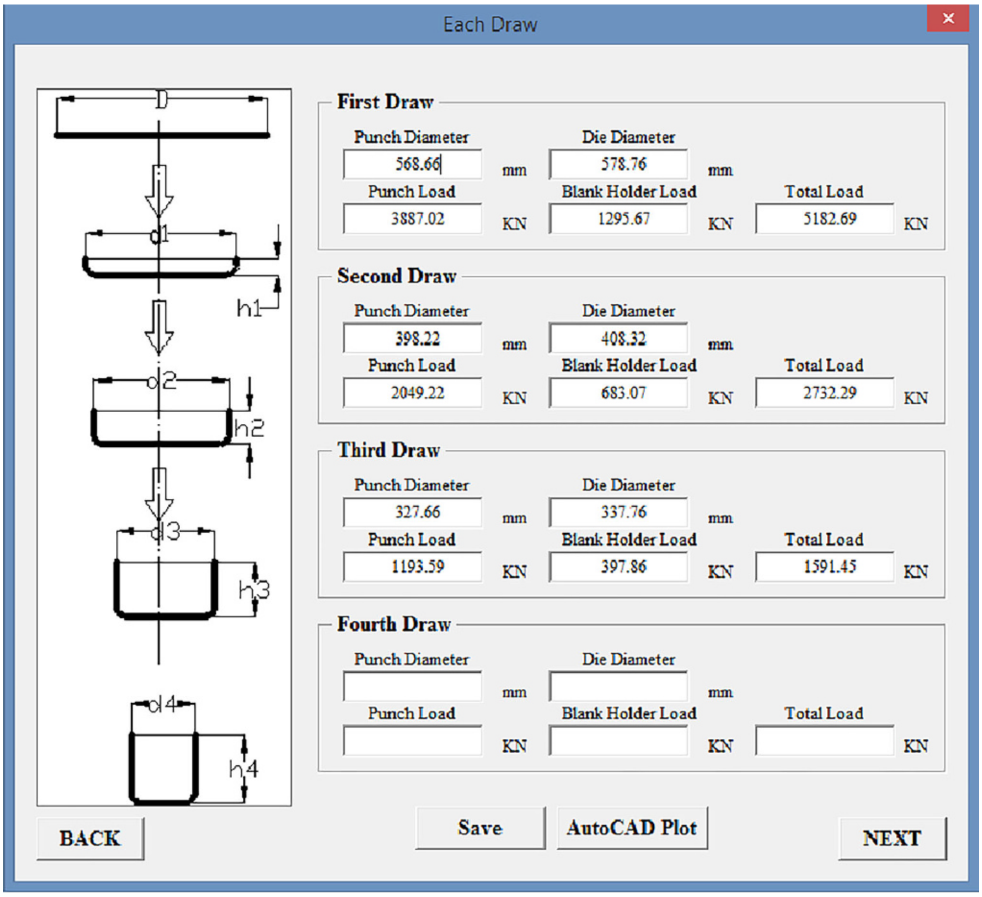

Fig. 6: Estimation of punch diameter, die diameter, punch load, blank holder load, and total load

capable of calculating the number of draws and each draw configuration (product diameter and height) automatically based on the raw material (Fig. 5). Manufacturing rules and standards are applied in an if-then fashion.

The intelligent system is capable of calculating punch die meter, die diameter, punch force, blank holder load, and total load for each and every draw. Based on the requirements, total draws (punch) are calculated three times. Therefore, the tooling configuration for each three drawing operations is calculated. The data are verified and validated with the industrial practices and are found to be satisfactory. The calculated data are transferred to the AUTOCAD system to generate a die and punch design automatically. Finally, the detailed manufacturing drawing of the punch and die for all draws are generated into AUTOCAD (Fig. 6). These drawings can be directly used for manufacturing of tooling. In such a way, indirect costs for inventory carrying can be reduced. Also the enterprise can react promptly to a floating market demand. Fig. 7 shows the manufacturing drawing of the deep drawing die with other components along with their dimensions during each draw.

It can be seen that the initial blank is flat, and, later for successive draws, the component obtained from first draw functions as the blank for the second draw and similarly for the third draw. In this way, the final dimensions of the desired product are obtained through several stages of operation. Thus, one can obtain the manufacturing drawing from the proposed intelligent framework module for the sheet metal component die. This framework module is tested and validated with the experimentation in the industry and discussed in subsequent subsection. Apart from that, the simulation modeling of the deep drawing process is performed for another validation check. These checks are applied in the proposed intelligent module and found in reasonably good agreement.

3. Simulation Analysis

In the previous section, the knowledge-based system (KBS) was demonstrated with the AUTOCAD plot of manufacturing drawing. In this section, the synchronization of the KBS with ABAQUS is illustrated to find out the punch and die forces during processing (shown in Fig. 8). There are mainly two forces, i.e. axial and radial, acting on the punch. The die forces are nothing but the reaction forces of the punch forces.

It was proposed in the KBS to evaluate the forces directly via a finite element analysis (FEA) using the ABAQUS software. The KBS data are fed in the ABAQUS through a PYTHON scripting. This file has been analyzed by the software solver and the results are generated. The forces encountered on the punch and die are given in Fig. 9. To determine forces, two separate reference points are provided to the punch and the die. Thus to determine the forces, these reference points are required to be selected individu-

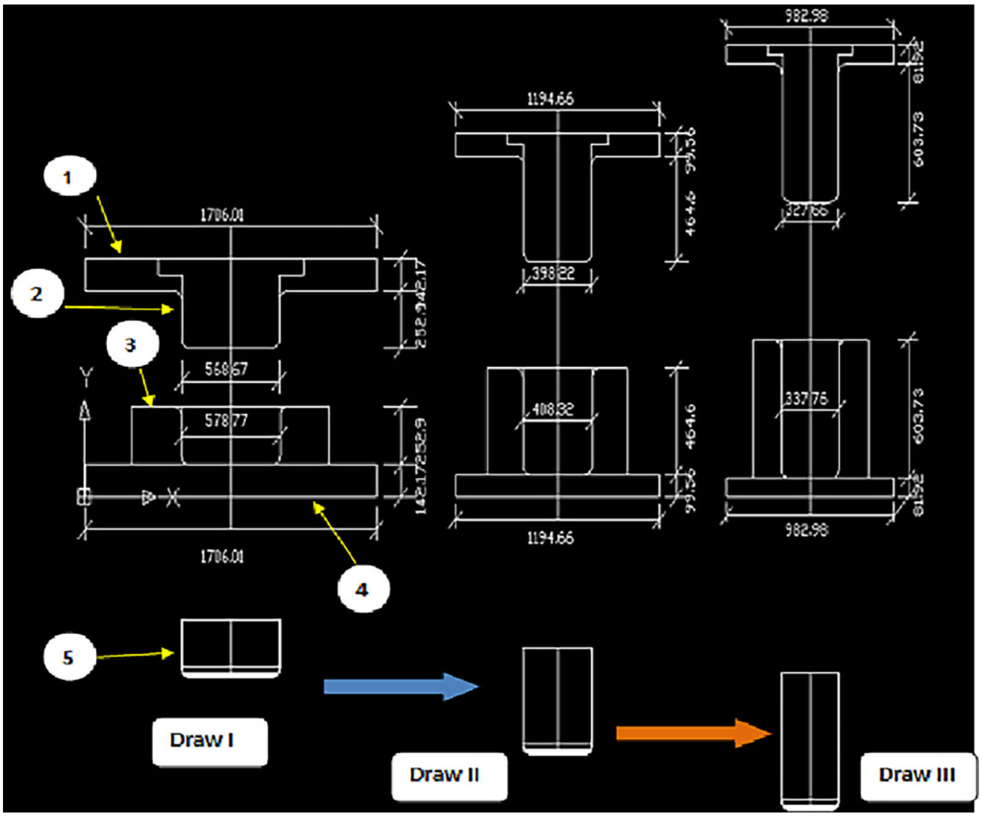

Fig. 7: Manufacturing drawing of the tooling (die and punch) for each draw (1) punch block, (2) punch, (3) die, (4) die block, and (5) product of first

ally. It can be seen that the radial punch force is positive in trend because the punch exerts force on the die wall in positive x-direction. Also the punch travel is the main force responsible for the axial force which is having negative trend due to its downward motion during processing. Simultaneously, the die is exerting reaction forces in both directions. Hence, the nature of these forces is opposite to each other.

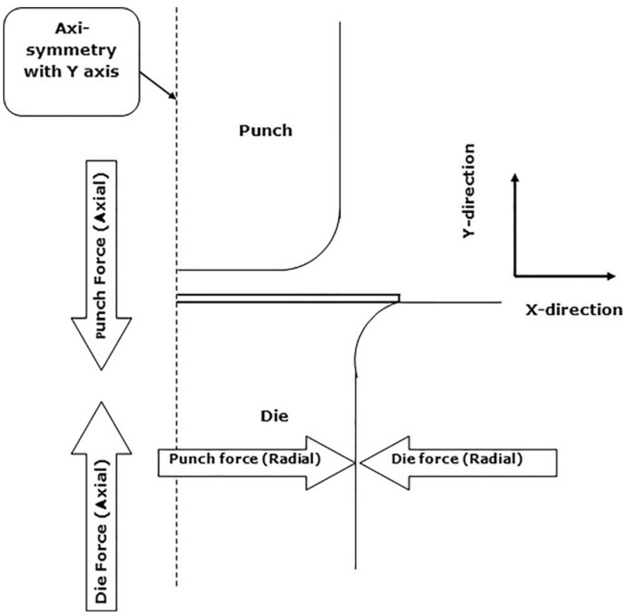

Fig. 8: Forces acting on punch and die

If the axial force is too high, it will thin the workpiece in the wall, which leads to excessive thinning and fracturing. On the other hand, if the radial force is too high, it

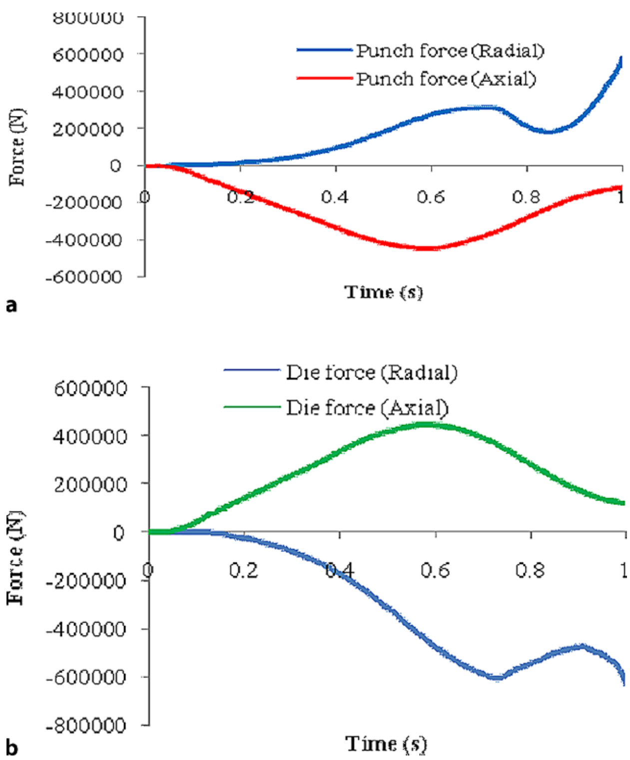

Fig. 9: Forces encountered **a** punch **b** die

will generate a rubbing action and in turn heat due to more friction. That generates scratches on the finished component. Hence, it is required to optimize the forces. That can be done based on the configuration changes, like adequate clearance, punch diameter, punch and die profile radii, and more.

4. Conclusions

In the present research work, an intelligent model system is proposed to determine the die size and configuration. Also the validation of the prototype configuration is done with the industrial testing and finite element analysis. The expert architecture is developed considering the 2D image initially. The systematic steps are followed from dimensions extraction from a 2D image. The image processing concepts are used considering the Python and OpenCV environment.

Later, these data are used as the input for the expert architecture to determine the manufacturing attributes of deep drawing process. The system is synchronized with VBA of AUTOCAD. The industrial testing is done based on the prototype model. Based on the proposed model, the forces are analyzed which are encountered on the punch and die during the process. The results of forces are compared with the FEM results of the published work and are found in good agreement.

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