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Research paper

Geometric characterization of moldboard plough using coupled close photography and surface fitting model

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ABSTRACT

Designing a moldboard plow is a complex task. In many cases, moldboard plows are manufactured mostly based on experience and empirical methods The objective of this study is to identify a way to use a mathematical approach for the design. Therefore, both the mathematical surface (multi variable equations, NURBS and Bezier) and the number of control points required for its adjustment (A, B, C, D), are examined to produce optimal modeling of the semi helical moldboard plough geometry. The 3D coordinates of 196 marked points on the plough surface were acquired using image processing techniques. The results obtained indicate that the surface of the moldboard plough can be shaped with $R^2 = 0.81$ and RMSE = 13.35, by the adjustment of a coupled fifth-order polynomial, exponential and sinus functions. Furthermore, the guide curve and angles of generatrix lines can be represented with a coupled first-order polynomial, exponential and sinus functions and fourth-order polynomial function, respectively, by high $R^2 = 0.9998$ and low RMSE = 8.5×10^{-5}. Overall the results confirmed that our method is suitable and effective for designing the moldboard plough.

1. Introduction

Geometric modeling and computer designing have recently been used in many industrial fields such as for aircraft, car, ship and agricultural implements emphasizing the importance of using the emerging technology and simultaneous intensive research in mathematical theory, representation and analysis of surfaces (Dimas and Briassoulis, 1999). Geometric modeling is a very useful tool in industrial designing and manufacturing as well as in implicit and parametric representations (Dimas and Briassoulis, 1999). According to researches, computer models can widely be used instead of physical methods. These computer models not only lead to better and cheaper products but also offer a simpler way to analyze and to apply possible changes than with former methods (Dimas and Briassoulis, 1999). The moldboard plough is one of the most important tillage implements. Although the decrease in the use of moldboard ploughs can reduce negative environmental effects, such as soil erosion, soil compaction or carbon release (Soane and Van Ouwerkerk, 1994), the moldboard plough would still be used in some cases regularly to enhance some soil properties (Ghanbarian, 2009). The main reason is that this tillage operation is efficient to manage soil structure, to bury fertilizers and residues of the preceding crop and to control weeds (Moss and Clarke, 1994). Moldboard design based on farmland properties is an essential challenge, while it is also important to describe and characterize the three dimensional shape of the plough, that leads to interesting studies such as analyzing the effect of soil interactions on the plough (Formato et al., 2005). Manual design of a plough is a time-consuming task with inadequate accuracy, while this challenge can effectively be overcome with the help of computer aided designs (White, 1917; Nichols and Kummer, 1932). Some primary studies of empirical methods and computer graphic techniques for plough designing have been conducted by Reed (1941) and Richey et al. (1989), respectively.

According to the different soil types and ploughing conditions, different shapes of moldboards including cylindrical, cylindroidal and helical have been developed. Ortiz-Canavate (1993) classified the moldboards in terms of their geometry (cylindrical, universal and warped) and with regard to their inclination (steep, semi-steep and distended). The geometrical heterogeneity in moldboard ploughs limits its inclusion in models which try to estimate the redistribution of soil particles and the force exerted on the working component.

Richey et al. (1989) used computer graphic techniques of the parametric models to represent the plough graphically which in turn permit the application of computational models on the variations in their shape. The employment of parametric modeling techniques like those developed by Bezier, B-splines and Non-Uniform Rational B-Splines (NURBS) can facilitate the design and analysis for both real and

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artificial models (Gutierrez de Rave et al., 2011). The determination of 3D coordinates of points on the surface of the moldboard plough is absolutely necessary for the parametric modeling of the geometric surface.

The purpose of this study is to explore geometric algorithms to improve the traditional moldboard plough design process. To meet this purpose, image processing techniques are used which can be employed in Reverse Engineering. Accordingly, an optical coordinate measuring technique is suggested in order to define marked points on the surface of a moldboard plough. In the exploration step, the different algorithms of NURBS, Bezier and analytical methods are compared to characterize the 3D geometry of the plough based on the quality of the obtained results. Then a new equation fits the points marked on the moldboard plough to model the plough surface and to find an index affecting the plough curvature. Finally, two new equations for modeling the guide curve and angles of generatrix lines are provided.

2. Material and methods

2.1. Description of the moldboard plough surface

The plough studied in this research was a semi-helical moldboard plough, manufactured by stamping with a central body (Fig. 1). It was limited by three spatial curves, a straight section in the lower part and a large curve in its upper lip. According to the researches, it is not possible to describe these curves with simple analytical functions (Ravonison and Destain, 1994). More recently, different algorithms of Bezier and NURBS that have the potential to represent curves and surfaces of freely formed complex models can be used to describe the plough surface (Dimas and Briassoulis, 1999). In this research, these two methods were compared with complex analytical functions for 3D surface modeling of the moldboard plough surface and its lip curves. To create a model for illustrating the plough surface, some points of the surface should be determined. To achieve this goal, 196 targets were marked on the surface of the moldboard plough using a black marker (Fig. 1). Then, their 3D coordinates were determined from the images of the moldboard plough by using new image processing techniques.

2.2. Photography

The marked moldboard plough was photographed from three vertical sides and saved for later reliability analysis. A digital color camera (Model G_7 Canon, Japan) with a resolution of 480 × 640 pixels was used to record the images. Some converging images from three vertical sides of the plough were taken at a distance of 1.5 m. Thus, the coordinates of each target were calculated by the intersection among the images. Many authors choose the design of a close-range photogrammetric network formed by three images (Fraser and Riedel, 2000; Mills et al., 2001).

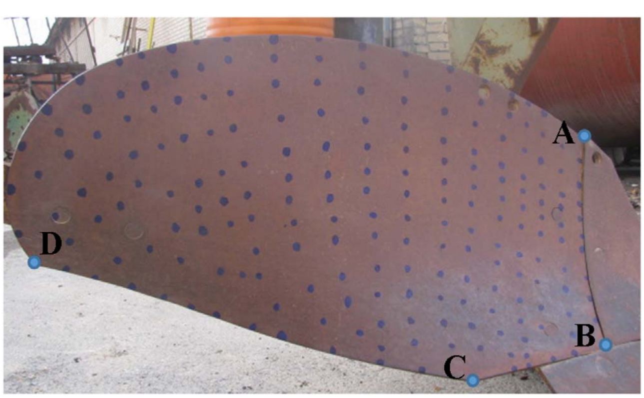

Fig. 1. Semi helical moldboard plough with marked points.

2.3. Image segmentation and filtration

Image segmentation, subdividing an image into different parts or objects, was used as the first step in image analysis. In segmentation algorithms, the thresholding was assayed as an important part in image segmentation. The threshold value was presented as a constant value for the same environmental conditions. In this study, the threshold was calculated using a mask which was determined by the covariance matrix of a part of each image (Mahmoodi-Eshkaftaki et al., 2008; Rahmani and Mahmoodi-Eshkaftaki, 2015).

For subtraction by standard segmentation routines, linear and Gaussian filtering were used due to the color contrast between the background and plough. The filtering improves the plough images with sharpening the edges of objects, reducing random noise, correcting the unequal illumination, and deconvoluting to correct for blur and motion (Gonzalez and Woods, 1992). These procedures were carried out by convolving the original image with an appropriate filter kernel and producing the filtered image. A serious problem with image convolution is the enormous number of necessary calculations to be performed, often resulting in unacceptably long execution times. For reducing the execution time, convolution by separability and FFT (Fast Fourier Transform) was used (Rahmani and Mahmoodi-Eshkaftaki, 2015). These filtered segmented images were then employed to determine the coordinates of marked points. Therefore, the filtered images were converted to gray scale images and the binary images were then obtained from the gray images using the calculated threshold according to Otsu's method. Next the images were labeled and the maximum area of the objects in the images was measured and all other objects with one tenth or less of the maximum object area were removed. The remaining white region, the largest detected object, was the moldboard plough area for each image (Fig. 2(b)). The final binary images were separately multiplied to R, G, and B color components of the filtered images and finally concatenated in an image (Fig. 2(c)). The images were again converted to binary images and after removing the outer lip, the marked points were retained (Fig. 2(d)). These stages are shown in Fig. 2 of a front side image. Finally, the coordinates of marked points were determined using MATLAB 7.12 software and its 3D surface design was built as illustrated in Fig. 3.

2.4. Bezier surface models

Bezier curves have several properties that are useful for surface design (Farina, 1999). In general, they can be adjusted by some curves with an unlimited number of checkpoints with polynomial grades preferred from second to fifth. For n + 1 control points ($P_i = (x_i, y_i, z_i)$), i varies from 0 to n, P(t) describes the trajectory of a polynomial function of the approximate Bezier curve among P_0 and P_n which can be calculated from Eq. (1) (Gutierrez de Rave et al., 2011).

$$P(t) = \sum_{i=0}^{n} \frac{n!}{i!(n-i)!}(1-t)^{n-i}t^{i}P_i,\ n = 0,1,2,3,... \tag{1}$$

where t varies in the interval [0,1] and P_i coefficients represent the coordinates of control points (Fig. 4). For instance a cubic Bezier function with four control points is:

$$P(t) = (1-t)^3P_0 + 3t(1-t)^2P_1 + 3t^2(1-t)P_2 + t^3P_3 \tag{2}$$

The control points are determined on the edges of the warped quadrilateral by which the surface of the plough is approximately defined. According to Ravonison and Destain (1994), this algorithm starts from the ends of these curved edges that are the control points P_0 and P_3 (Fig. 4(a)). The inner control points, i.e. P_1 and P_2 are determined by selecting proportional increments in distance over the tangents traced at the ends of these edges, in such a way that the resulting Bezier curve passes through an intermediate point of known coordinates (Gutierrez de Rave et al., 2011). By knowing the start and