
Computer aided design of moldboard plough surface

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Mouldboard plough is an important agricultural implement and is widely used in primary tillage. An accurate design of plough bottom based on farmland soil properties is an essential problem. Therefore, computer aided design of mouldboard must be applied. An algorithm of plough design is presented and carried out in MATLAB software and 3D shape of plough was plotted.

Introduction

Geometric modeling and computer aided design (CAD) is recently used in many fields of industry. Design and manufacture of such diverse objects such as aircraft, cars and ship hulls harvest the benefits of the emerging technology and simultaneous intensive research in the mathematical theory, representation and analysis of surfaces would be studied. As a result, physical objects have widely been replaced by computer models. This leads to better and cheaper products as the latter are simpler to analyze and easier to change than the former (Dimas and Briassoulis, 1999). Mouldboard plough is one of the most important tillage implements and is widely used in the world for many years. Designing of moldboard based on characteristics of farmland is an important problem, also it is important to describe and characterize the three dimensional shape of the plough, that facilitate more interesting studies such as analyzing the effect of the soil interactions on the plough (Formato *et al.*, 2005). For these studies a computer model of plough is needed. Manual designing of a plough is a time-consuming method and has not adequate accuracy, but these problems do not happen in computer aided design.

Traditionally, plough design and manufacture have been based on empirical methods and experiments (Shrestha *et al.*, 2001). A new CAD method is necessary to describe and design of plough surface based on soil properties of farmland. Several methods were developed for designing of plough by

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computer. Ravonison and Destain (1999) developed a mathematical expression based on Bezier's form of cubic surfaces to describe an existing mouldboard and focused on an algorithm to improve the efficiency of approximation of a theoretical surface and the actual one. Their method was well suited to describing mouldboard designs. Formato *et al* (2005) studied on the plough mouldboard soil interaction phenomena. They used a detecting system that was able to determine the X, Y, Z spatial components. The detecting system had three bars located along the three Cartesian axes of the reference system. On each bar, there was a sliding pointer, axially adjustable by a micrometric screw, to measure displacements along the X, Y and Z axes, respectively (Fig. 1).

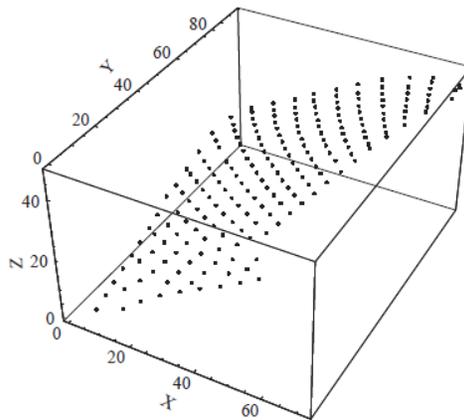


Fig. 1. Detected points of a plough surface (Formato *et al.*, 2005)

Gutiérrez de Ravé (2011) pose was exploration of the geometric algorithms based on the spline concept.

This paper aimed to develop a mathematical algorithm of mouldboard plough designing based on single directrix curve (Bernakci, 1972). The algorithm would be able to design the plough surface based on desired characteristics.

Material and methods

In designing of mouldboard, top view, front view and directrix curve must be drawn that are explained following. Furthermore the three dimensional shape of designed plough is made.

Front view

To plot the front view of plough, coordinates of P_0 to P_6 (Fig. 2) must be obtained and joined together. A quadratic line was used to join P_2 and P_3 . The coordinates of P_0 was assumed zero. P_1 and P_2 are obtained as following:

$$X_1 = \Delta s \quad (1)$$

Where Δs is the breast edge of mouldboard falls from the perpendicular.

$$Z_1 = H \quad (2)$$

$$X_2 = b \quad (3)$$

$$Z_2 = \sqrt{a^2 + b^2} \quad (4)$$

Where a and b is depth and width of furrow slice.

To obtain coordinates of P_3 the sine law was used (see Fig. 2):

$$v = \sin^{-1}\left(\frac{a}{b}\right) \quad (5)$$

$$\alpha = \sin^{-1}\left(a \times \sin\left(\frac{\pi}{2} + v\right) / a + 2.5\right) \quad (6)$$

$$\lambda = \frac{\pi}{2} - \alpha - v \quad (7)$$

$$Z_a = a \times \cos(v) \quad (8)$$

$$Z_b = \frac{b}{2} \sin(\lambda + v) \quad (9)$$

$$Z_3 = Z_a + Z_b \quad (10)$$

$$C = a \times \frac{\sin(\lambda)}{\sin(\alpha)} \quad (11)$$

$$\theta = \tan^{-1}\left(\frac{b}{2 \times (a + 2.5)}\right) \quad (12)$$

$$L = \sqrt{\left(\frac{b}{2}\right)^2 + (a + 2.5)^2} \quad (13)$$

$$C_1 = L \times \cos(\beta) \quad (14)$$

$$X_3 = 150 - (a + b + C - C_1) \quad (15)$$

The Z value of P_4 is obtained by following equation:

$$Z_4 = S \times \sin(\delta_2) \quad (16)$$

Where δ_2 is cutting angle and S is width of share blade.

The slope of line P_3P_4 is $\tan(v)$ and the coordinates of P_3 are known, so:

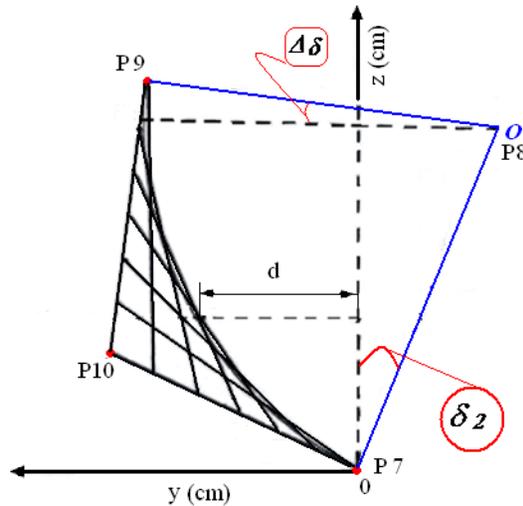


Fig. 3. The directrix curve of mouldboard.

The Z and X values of arc center that makes directrix curve is obtained by Eq. 23:

$$Z_o = R \times \cos(\delta_2) \quad (23)$$

$$X_o = -R \times \sin(\delta_2) \quad (24)$$

To calculate coordinates of P_9 following equations are used:

$$X_9 = R \times \cos(\Delta\delta) + X_o \quad (25)$$

Where $\Delta\delta$ depends on the type of moldboard (Bernakci, 1972).

$$Z_9 = Z_o + R \times \sin(\Delta\delta) \quad (26)$$

The lines P_7P_{10} and P_8P_9 are perpendicular to OP_7 and OP_9 , respectively. So the slope of P_7P_{10} and P_8P_9 are $\tan(\delta_2)$ and $-\cot(\Delta\delta_2)$, respectively. P_{10} is obtained by intersecting of P_7P_{10} and P_8P_9 .

$$X_{10} = \frac{Z_9 + \cot(\Delta\delta) \times X_9}{\cot(\Delta\delta) + \tan(\delta_2)} \quad (25)$$

$$Z_{10} = \tan(\delta_2) \times X_{10} \quad (26)$$

To complete the directrix curve, the lines P_7P_{10} and P_8P_9 must be divided into desired sections and obtained points must be jointed together as a certain order.

Top view

For designing of the plough the Shchuchkin formula (for cylindrical and helical plough) is used. The Shchuchkin equation calculates the value of ϕ_n as a function of contour line height. In this paper the directrix curve has been inserted in middle of $P_0 P_5$ and perpendicular to it.

$$X_a = \frac{X_0 + X_5}{2} \tag{27}$$

$$y_a = \frac{y_0 + y_5}{2} \tag{28}$$

The components of P_{i2} are obtained as:

$$X_{i2} = X_a - d \times \cos(\phi_0) \tag{29}$$

Where d_i is the distance between directrix curve and Z axis at contour line i (Fig.3).

$$y_{i2} = y_a + d \times \sin(\phi_0) \tag{30}$$

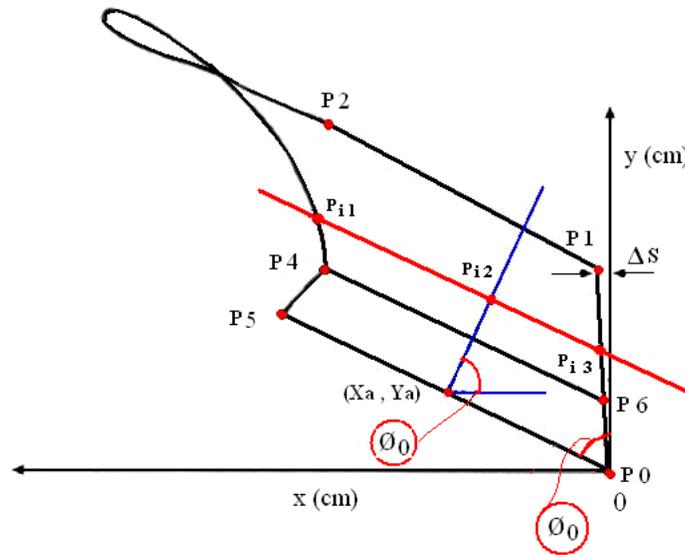


Fig. 4. The top view of plough.

By a point and the slop of a line, the equation of the line can be obtained, so the equation of $P_{i1}P_{i3}$ is obtained as:

$$y_{i1} = \cot(\phi_i) \times (X_{i1} - X_{i2}) + y_{i2}$$

Where ϕ_i is the setting angle at each contour line and X_{ij} is the X value of each point that is obtained in front view (Fig. 2).

This order is repeated from P_0P_5 to P_1P_2 . By jointing of obtained point, the top view is plotted.

Three dimensional model

The X and Z values of each peripheral point of plough surface are obtained in front view. By having the X value, the Y component of each point can be calculated by means of directrix curve and top view of mouldboard, so the all needed coordinates of each point can be obtained and thus the software can plot the 3D model of designed plough surface.

Results and discussions

The proposed algorithm of plough designing process was programmed in MATLAB software and was carried out. The needed parameters in this method for designing of plough surface are composed of the width of share blade (S), width (b) and depth (a) of furrow slice, cutting angle (δ_2), distance of plough edge from furrow wall (Δs), setting angle (ϕ_0), ϕ_{min} , ϕ_{max} and $\Delta\delta$. A typical designed plough by MATLAB is presented in Fig. 5 and Fig. 6.

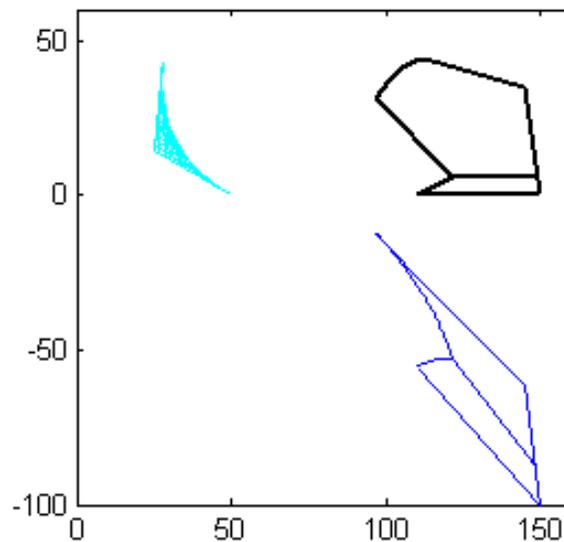


Fig. 5. Tuesday Map view of a typical designed plough surface.

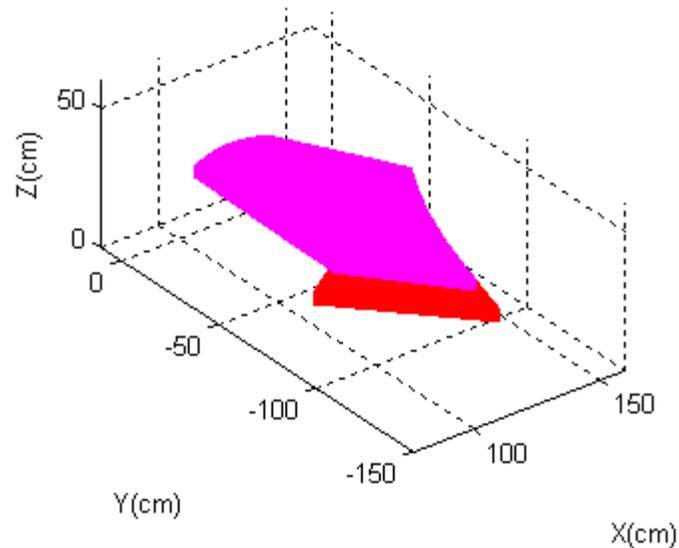


Fig. 6. Three dimensional shape of a typical designed plough surface

The reverse engineering of plough surface in traditional method needs determining the spatial coordinates of a finite number of points on the actual working surface. Determining of the 3D coordinates of points on the surface of a moldboard plough also needs a high accuracy detecting system. To perform the 3D model, obtained points must be imported into modeling software as stated by Formato *et al.* (2005). In traditional method of moldboard modeling, because of manual detecting of coordinates, a few points can be obtained. Also the accuracy of modeled surface decreased. By proposed method in this research, we can enhance the accuracy of plough modeling. By this method we can perform the 3D model of plough surface only by measuring of a few characteristics of moldboard. In designing of plough surface, the proposed method allows the designer to change plough surface, soil properties, and operating conditions. With this, Massah and Alimardani (2008) also designed and modified an automatic mouldboard profilograph based on the reverse engineering of plough design. The designed expensive apparatus was able to draw the profilograms of a 3-D object as a 2-D drawing in the same contour lines of mouldboard plough bottom. In this study, the presented algorithm can design and model a mouldboard based on necessary conditions reliably.

Conclusion

This paper presented mathematical expressions of plough surface based on single directrix curve to design plough as a function of desired

characteristics. The plough surface is represented three dimensionally that can be exported to other analytical software to investigate interaction between the soil and the plough bottom or predict the needed draught force. This method gives a high accuracy of mouldboard designing and eliminates the human error that occurs in manual designing of plough.

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