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MODELLING OF TERRAIN SURFACE

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In this contribution, we deal with the methodology of visualisation of terrain surface, on which experimental measurements of driving manoeuvres of an agricultural technological vehicle MT8-222 were performed. The introduced methodology uses a defined approach when determining the dynamic stability of agricultural vehicles following the standard STN 47 017. Records of the centre of gravity accelerations were obtained from driving manoeuvres at every instance of time during the drive. From records of accelerations and by using Euler's parameters with respect to the inertial system, there were evaluated contact points of the wheel with the terrain. Performed driving manoeuvres consisted of movement in the direction of down grade slope as well as in the direction of tractive movement on the slope. We created a model of terrain surface in the Surfer® program from obtained experimental data. Next, by using supporting commands in Matlab®, we created an algorithm for visualisation of terrain surface. Following this algorithm, there was created another model of terrain surface. Both visualisations of terrain surface are depicted in Figs 4 and 5.

Keywords: mathematical modelling, terrain modelling, vehicle manoeuvre

Algorithms of surface models are used in many technical applications and form an essential part in constructional applications of CAD/CAM programs. Basically, technologies such as OpenGL or DirectX are mostly used for visualisation of a given curve surface area, as introduced by Rédl (2006). A special case of application is the field of terramechanics and vehicle dynamics. The knowledge of terrain surface can also be utilised in the detection of soil penetration resistance by means of a GPS device, as introduced by Jobágy et al. (2006). Hutchinson and Gallant (1999) demonstrate and discuss the representations of terrain in environmental modelling and landscape visualisation as well as digital terrain modelling. For listed reasons, models of terrain surfaces are usable not only in geographical applications but also in vehicle dynamics, mainly in predicting the safety of operation of agricultural mobile machinery, as presented by Rédl et al. (2012). At present, there are many computer applications which enable us to model and visualise different types of surfaces. They encompass for example the Surfer® program the modules of which can be used when programming an application in a Visual Basic language, as published by Zheng et al. (2010). Surfer® is a full-function 3D visualisation, contouring and surface modelling package by Golden Software, Inc. (2002) that runs under Microsoft Windows. It is a grid-based graphic program interpolating irregularly spaced XYZ data into a regularly spaced grid. Grids may also be imported from other sources and then the grid is used to produce various types of maps, including contour, vector, wireframe, image shaded relief and surface maps. Connecting the Surfer® program with the AutoCAD® program is discussed by Marschallinger (1991). He states that by connecting the gridding-contouring software (Surfer®) and 3D CAD system (AutoCAD®) it is possible to create a true 3D model in a standard MS-DOS environment. Hahmann (1999) deals with visualisation techniques usable in surface

analysis. The usage of mathematical parameters of spatial curve surface is however unavailable in these applications. Considering the listed fact, it is therefore appropriate to create an own computer model and use the graphical 3D technologies for visualisation only. For visualisation of terrain surface, it is also possible to use the Matlab® program by MathWorks, Inc. (2013); however, it is necessary to create an own algorithm for visualisation of terrain surface using supporting commands. Matlab®, known as the language of technical computing, is a high-level language and interactive environment for numerical computation, visualisation, and programming. Using Matlab®, it is possible to analyse data, develop algorithms, and create models and applications. The language, tools, and built-in math functions enable us to explore multiple approaches and reach a solution faster than with spreadsheets or traditional programming languages. Matlab® can be used for a range of applications, including signal processing and communications, image and video processing, control systems, test and measurement, etc.

Material and methods

Definition of surface area

As stated by Ivan (1989), a surface area is created by a continuous deformation of some coherent part of the plane. We can imagine this surface as a bent sheet (of paper, metal plate...) or as a surface (boundary) of some body (or its part). Sometimes, we can imagine the surface area as a set of positions of a moving point, which – visually said – has two degrees of freedom.

By the term surface area we will denote a hodograph S of vectorial function $\vec{r}$ of two variables u, v , having the following properties:

1. its definition scope is a coherent set $G \subset E_2$;

Figure 1 Function from the set $G \subset E_2$ into E_3

2. it is continuous on the set G ;
3. there exists such partition $\{G_k\}$ of the set G that it is one-to-one on the set $U_k \subset G_k$.

Especially, if the function $\bar{r}$ is one-to-one on the whole set G , it is a simple surface area.

From the definition of surface area and from the definition of vectorial function $\bar{r}$ of two variables follows that exactly one point P from the surface S appertains to every point $[u, v] \in G$, namely the end point of the position vector $\bar{r}(u, v)$ in respect of the pole of the hodograph (Fig. 1). Using the vectorial function $\bar{r}$, there is defined a function from the set $G \subset E_2$ into E_3 . We say that this function, which is usually called a dot function of two variables, is generated (induced) by the vectorial function $\bar{r}$. We denote it with the letter R . Therefore, $P = R(u, v)$ will stand for the point of the surface area S which is an image of the point $[u, v] \in G$ in the function R (Fig. 1). The surface area itself is then the image of the set G in the function $R: S = R(G)$.

The vectorial function $\bar{r}$, the hodograph of which is the surface area S , is called an (admissible) parametric expression of the surface area S or shortly an (admissible) parameterisation of the surface area S .

Equation:

$$\bar{r} = \bar{r}(u, v), [u, v] \in G \quad (1)$$

by which the function $\bar{r}$ is defined, is called a vectorial or parametric equation of the surface area S . If in the coordinate system $(O, \bar{i}, \bar{j}, \bar{k})$ it holds that $\bar{r} = x\bar{i} + y\bar{j} + z\bar{k}$, $\bar{r}(u, v) = x(u, v)\bar{i} + y(u, v)\bar{j} + z(u, v)\bar{k}$, then vectorial equation (1) is equivalent to this system of equations:

$$\begin{aligned} x &= x(u, v), \\ y &= y(u, v) \quad [u, v] \in G \\ z &= z(u, v) \end{aligned} \quad (2)$$

Equations (2) are called parametric equations of the surface area S in respect of the given coordinate system. The numbers (variables) are called the parameters of the surface area S . The set G is called the domain of parameters of the surface area S .

Model of terrain surface

When creating a digital visualisation of terrain surface, we followed the diagram depicted in Fig. 2.

An experiment was performed using the agricultural technological vehicle MT8-222 on which the accelerometers were placed. There were carried out driving manoeuvres during which

the vehicle performed the movement along down grade slope and tractive movement on the slope. After driving manoeuvres, we obtained the records of acceleration of the centre of gravity at every instance of time. Obtained records were processed according to the methodology that uses a defined approach for determination of dynamic stability of the vehicle following the standard STN 47 0170. We formed the system of motion equations, which were subsequently solved by numerical integration, where Runge – Kutta numerical methods were utilised. In this way, we obtained angular velocities. By consequent processing, we obtained Euler's parameters with respect to the inertial coordinate system. By using the Euler's parameters, we evaluated the corresponding velocities and coordinates of the contact points of tyres with the terrain in the direction of down grade slope as well as in the direction of tractive movement on the slope.

Obtained coordinates were subsequently utilised for modelling the terrain surface on which the agricultural technological vehicle was moving during the manoeuvre. Surfer® and Matlab® were used for visualisation of the terrain surface.

Results and discussion

The experiment was performed with chosen manoeuvres like movement

Figure 2 Modelling of terrain surface

Figure 3 Dislocation of contact points of the tyres with the terrain

along the down grade slope and tractive movement on the slope. The manoeuvres were performed by the agricultural technological vehicle MT8-222. There were no overturns of the vehicle during the manoeuvre. Fig. 3 shows a schematic model of the vehicle with demarcated tipping axes and contact points A, B, C, D of the tyre with the terrain. The inertial coordinate system is labelled as $X_s Y_s Z_s$. The coordinate system of the vehicle is $G_x G_y G_z$. There are also shown external tipping axes, namely the rear, front, left side, right side and also internal tipping axes. There is also depicted the plane of the centre of gravity ρ_k , the normal vector of which is $\bar{n}_T^0$. The normal vector $\bar{n}_k^0$ of the plane ρ_k is perpendicular to the normal vector of the plane of the centre of gravity $\bar{n}_T^0$.

Also the corresponding accelerations are shown in Fig. 3. After the experiment, we obtained the coordinates of contact points of the wheel with the terrain from obtained records of accelerations by progressive processing following the diagram in Fig. 3. Dislocations for the point B are then obtained by solving the following equation:

$$\begin{bmatrix} X_B \\ Y_B \\ Z_B \end{bmatrix} = \prod_{i=1}^n \begin{bmatrix} \lambda_0^2 + \lambda_1^2 - \lambda_2^2 - \lambda_3^2 & 2 \cdot (\lambda_1 \cdot \lambda_2 - \lambda_0 \cdot \lambda_3) \\ 2 \cdot (\lambda_1 \cdot \lambda_2 - \lambda_0 \cdot \lambda_3) & \lambda_0^2 + \lambda_2^2 - \lambda_3^2 - \lambda_1^2 \\ 2 \cdot (\lambda_3 \cdot \lambda_1 - \lambda_0 \cdot \lambda_2) & 2 \cdot (\lambda_2 \cdot \lambda_3 - \lambda_0 \cdot \lambda_1) \end{bmatrix} \begin{bmatrix} B5 \\ -B6 \\ B7 \end{bmatrix} + \begin{bmatrix} X_T \\ Y_T \\ Z_B \end{bmatrix} \quad (3)$$

where:

$B5 = 0.657$ m, $B6 = 0.81$ m and $B7 = 0.62$ m are the placements of sensors, whereby the sign over the matrix $\begin{bmatrix} & \\ & \end{bmatrix}^T$ means that it is transposed at every i -th step. For other points is the procedure similar

Obtained coordinates of contact points of the wheels with the terrain were subsequently implemented into the two computer programs, i.e. Surfer® and Matlab®.

Surfer® has inbuilt algorithms which are used to create various types of maps (e.g. contour, vector, wireframe, surface maps...). For creating the model of the terrain surface on which the vehicle was moving during the experiment, we used the obtained coordinates of the contact point with the terrain. These coordinates corresponded to the manoeuvre when the vehicle was moving along the down grade slope. We imported them into Surfer®, and consequently, we created a 'GridFile' with the given coordinates. Finally, we used the function 'Map/Surface' and created a surface map of the terrain which is shown in Fig. 4.

In Matlab®, it is not possible to directly create a model of the terrain surface. That is why we created an own algorithm for implementation of obtained coordinates:

```
clear all, clc
load ('vstup.mat')
figure(2), gcf
plot3 (dat(:,2), dat(:,3), dat(:,4)), hold on
plot3 (dat(:,5), dat(:,6), dat(:,7)), hold on
plot3 (dat1(:,2), dat1(:,3), dat1(:,4)), hold on
plot3 (dat1(:,5), dat1(:,6), dat1(:,7)), hold on
o = [dat(3:421,2), 1*(dat(3:421,3)), -1*(dat(3:421,4))]
d = [dat1(420:838,2), dat1(420:838,3), -1*(dat1(420:838,4))]
figure (2)
plot3 (o(:,1), o(:,2), o(:,3)), 'r', hold on
plot3 (d(:,1), d(:,2), d(:,3)), 'r'
x = ((o(:,1))-5)
y = (0:3/length(x):3-length(x))
y = y'
for i = 1:419
z(:,i) = (o(:,3)+(o(1,3)-d(i,3)))+1.3;
end
figure (3)
surf (x, y, z)
```

Following this algorithm, there was created the terrain surface shown in Fig. 5 which is a linear combination of

Figure 4 Model of the terrain surface created in Surfer®

Figure 5 Model of the terrain surface created in Matlab®

coordinates of two manoeuvres depicted on the whole length of manoeuvre duration.

As can be seen in Figs 4 and 5, the model of the terrain surface created in Surfer® is more realistic than the model obtained in Matlab®. It is a result of the fact that Surfer® uses its own algorithm which uses more exact approximations by various statistical methods and curves, whereas in Matlab®, all steps of algorithms are programmed by user and created surface is just a linear combination of coordinates.

Conclusion

In this contribution, we have dealt with visualisation of the terrain surface on which the agricultural technological vehicle MT8-222 was moving during the experiment. The goal of this contribution was to model the terrain surface following the coordinates obtained from the records of accelerations of the vehicle's centre of gravity during the experiment. Manoeuvres in the experiment consisted of movement in the direction of down grade slope and in the direction of tractive movement on the slope. Accelerations of the centre of gravity were recorded while performing the manoeuvres. Measured records of accelerations were processed by using the numerical integration of Runge–

Kutta methods and Euler's parameters with respect to the inertial system so that by using Equation (3) we obtained the coordinates of contact points of the wheel with the terrain. Obtained coordinates were subsequently implemented into Surfer®. For visualisation in Matlab®, at first we created the algorithm which uses supporting commands of this system, and consequently, we created the model of terrain surface. The obtained visualisations are shown in Fig. 4 for the model of terrain surface from Surfer® and in Fig. 5 for the model of terrain surface from Matlab®. In Surfer®, it is not possible to directly influence the algorithm of surface creation, whereby in Matlab®, it is possible to use sophisticated methods of modelling which use Beziér curves and Beziér surfaces.

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