Visualization of the Working Process of a Novel Manipulator for a Stone Protector of a Stony Soil Tillage Implement

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Abstract
The paper studies the motion of a novel manipulator that can be used in the structure of stone protectors of soil tillage implements. According to the virtual reality technology-based method, the composition technology of the virtual model of a manipulator and its positions in the working process are described in details. This virtual model is used for making a video clip, simulating the motion of the novel manipulator, three points of which are moving along two lines and one curve. The results obtained and the computer program which realizes the virtual reality technology–based study of the working process of the virtual manipulator for stone protectors can be used by designers of stone protectors for soil tillage implements.

Key words: Manipulator, virtual model, virtual reality technology, simulation of motion

1. Introduction

Stone protectors are designed to protect the working tools of stony soil tillage implements from damage by stones in the working process.

Fig. 1 shows a four bar based manipulator for a stone protector, where A, B, C, D are pivots and K, F, M – characteristic points. Point K is supposed to be connected to the axis of the copying wheel and M is the forward end of the working tool of a soil tillage implement. The link KBFCM is supposed to be rigid.

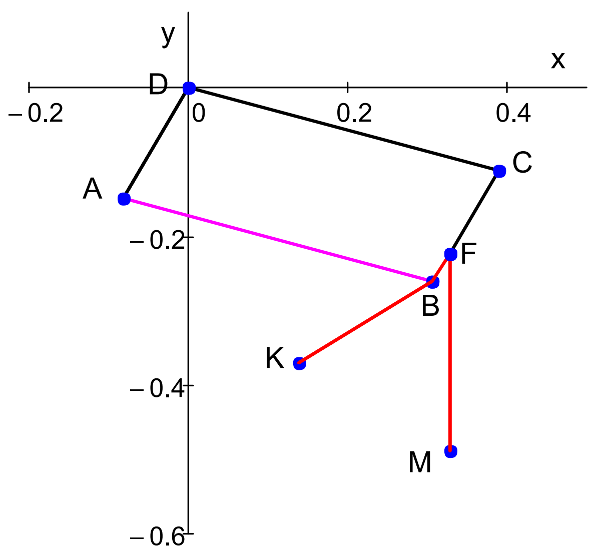

Fig 1: four bar based virtual manipulator.

The problem with the manipulator in Fig. 1 is that sometimes the link CD or the working tool of soil tillage implement gets damaged, when in the working process an obstacle stops the horizontal movement of point M of the working tool. To solve this problem, Olt, Heinloo (2009) have suggested a manipulator for stone protector, shown in Fig. 2, where the link CD in Fig. 1 is replaced by the safety device DEICLG, which consists of rigid links GDI, ECL and an elastic spring GL. The rigid links GDI and ECL are connected with the pivot E. A besieger, connected to point I, ensures that the initial positions of points D, E and C are not in line. The safety device DEICLG operates when point M meets an obstacle and can't move in Fig. 1 to the left and the tension of the spring GL exceeds the limit value. If the tension of the spring GL does not exceed the limit value, the manipulator in Fig. 2 works as the manipulator in Fig. 1. It is possible to adjust the required initial tension of the spring GL by a screw that can be installed to the pivot G or L.

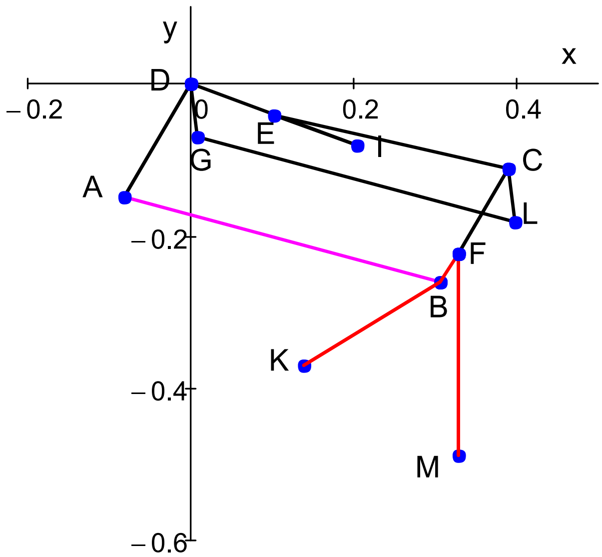

Fig 2: virtual manipulator with the safety device DEICLG.

This paper presents the results of studying the motion of a novel virtual manipulator for a Stone Protector of Stony Soil Tillage Implement by using a virtual reality technology–based method which was earlier used in the studies of the working processes of elements of agricultural machinery by Heinloo et al., (2005), Heinloo, Olt (2006), Heinloo (2006), Heinloo, Leola (2007), Heinloo, Leola (2008) and Olt, Heinloo (2009).

2. Creation of a Novel Virtual Manipulator

A novel virtual manipulator can be obtained from Fig. 1 by removing links AD, DC and CB and joining together points B and F. To image the novel virtual manipulator before beginning the motion (t = 0), let us suppose that its points A, B, K and M have the following co-ordinates:

$$A_{x0} = -0.082\,,\; B_{x0} = 0.299\,,\; K_{x0} = 0.118\,,\; M_{x0} = 0.299\,,$$

$$A_{y0} = -0.149\,,\; B_{y0} = -0.284\,,\; K_{y0} = -0.369\,,\; M_{y0} = -0.500\,.$$

The column vectors (http://en.wikipedia.org/wiki/Column_vector)

$$x_0 = \begin{pmatrix} A_{x0} \\ B_{x0} \end{pmatrix}, \qquad y_0 = \begin{pmatrix} A_{y0} \\ B_{y0} \end{pmatrix}, \qquad x'_0 = \begin{pmatrix} K_{x0} \\ B_{x0} \\ M_{x0} \end{pmatrix}, \qquad y'_0 = \begin{pmatrix} K_{y0} \\ B_{y0} \\ M_{y0} \end{pmatrix},$$

drawn on the worksheet of the Computer Package Mathcad novel virtual manipulator ABKBM (Fig. 3) for a Stone Protector of Stony Soil Tillage Implement.

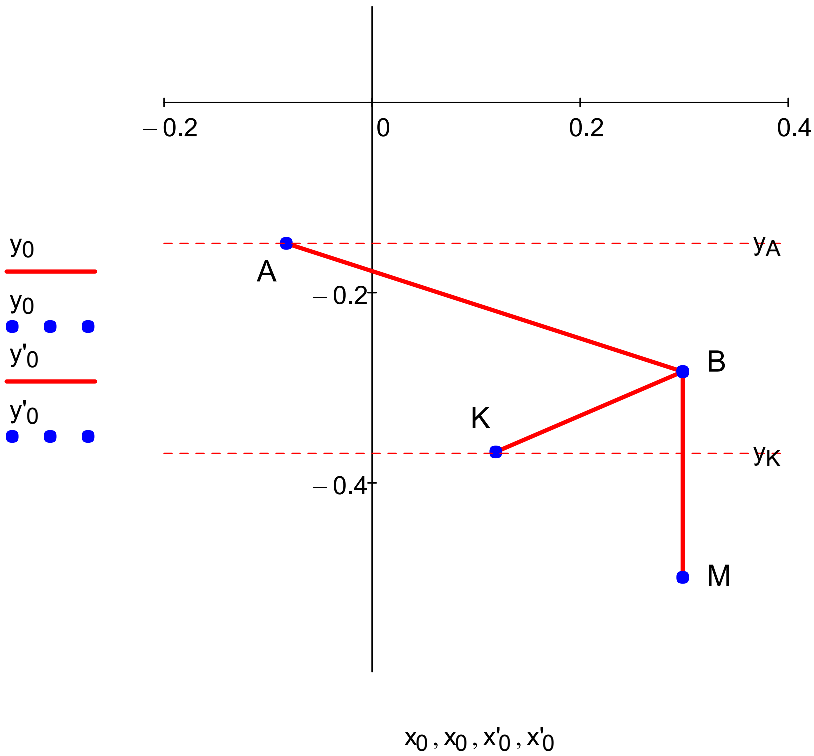

Fig 3: novel virtual manipulator.

3. Motion Simulation of Virtual Manipulator

Let us suppose that the trajectories of points A and K are moving by straight lines (Fig. 3) ($A_y = A_{y0}$, $K_y = K_{y0}$) and the trajectory of point M is given by the following parametric equations:

$$M_x(\tau_1) = M_{x0} - a\tau_1, \; g(\tau_1) = h\sin(10\,\tau_1 - 1) - b,$$
$$M_y(\tau_1) = g(\tau_1), \text{ if } g(\tau_1) \geq -b, \text{ else } g(\tau_1) = -b, \qquad (1)$$

where $M_x(\tau_1)$, $M_y(\tau_1)$ are the x- and y-co-ordinates of point M, τ_1 is the parameter and $a = 2$, $h = 0.12$, $b = 0.5$ are constants.

The co-ordinates B_x, K_x, B_y of points B, K and the parameter τ_1 were found out from the following system of equations:

$$
\begin{aligned}
&(B_x - A_x(t))^2 + (B_y - A_y)^2 = l_{AB}{}^2, \\
&(K_x - B_x)^2 + (K_y - B_y)^2 = l_{KB}{}^2, \\
&[K_x - M_x(\tau_1)]^2 + [K_y - M_y(\tau_1)]^2 = l_{KM}{}^2, \\
&[B_x - M_x(\tau_1)]^2 + [B_y - M_y(\tau_1)]^2 = l_{BM}{}^2,
\end{aligned}
\qquad (2)
$$

where l_{AB}, l_{KB}, l_{KM}, l_{BM} are the distances between points A, B; K, B; K, M; B, M; $A_x(t) = A_{x0} - vt$, t – the parameter and v = 2 is a constant. The system of equations (2) was solved by using the Mathcad (http://www.ptc.com/products/mathcad/) solve block "Given-Find" in dependence on values of the parameter t.

To image 6 positions of the virtual manipulator from the video clip showing the motion of this manipulator, let us define the column vectors (http://en.wikipedia.org/wiki/Column_vector)

$$
x_i = \begin{pmatrix} A_x(t_i) \\ B_x(t_i) \end{pmatrix}, \quad y_i = \begin{pmatrix} A_{y0} \\ B_y(t_i) \end{pmatrix}, \quad x_i' = \begin{pmatrix} B_x(t_i) \\ K_x(t_i) \\ B_x(t_i) \\ F_x(t_i) \\ M_x(t_i) \\ F_x(t_i) \end{pmatrix} - s(t), \quad y_i' = \begin{pmatrix} B_y(t_i) \\ K_{y0} \\ B_y(t_i) \\ F_y(t_i) \\ M_y(t_i) \\ F_y(t_i) \end{pmatrix}, \qquad (3)
$$

where $t_i = \dfrac{i}{2N}$, i = 0, 1, 2,…,N, N = 100 and matrices:

$$
\begin{aligned}
&X = augment(x_0, x_{20}, x_{40}, x_{60}, x_{80}, x_{100}), \\
&X' = augment(x'_0, x'_{20}, x'_{40}, x'_{60}, x'_{80}, x'_{100}), \\
&Y = augment(y_0, y_{20}, y_{40}, y_{60}, y_{80}, y_{100}), \\
&Y' = augment(y'_0, y'_{20}, y'_{40}, y'_{60}, y'_{80}, y'_{100})
\end{aligned}
\qquad (4)
$$

Here the Mathcad function augment (A, B, C...) returns the matrix, formed by placing vectors A, B, C... from left to right.

The derivatives

$$
v_{Ax}(t) = \frac{d}{dt}A_x(t), \quad v_{Bx}(t) = \frac{d}{dt}B_x(t), \quad v_{By}(t) = \frac{d}{dt}B_y(t), \qquad (5)
$$

$$
v_{Kx}(t) = \frac{d}{dt}K_x(t), \quad v_{Mx}(t) = \frac{d}{dt}M_x(\tau(t)), \quad v_{My}(t) = \frac{d}{dt}M_y(\tau(t))
$$

were found out by using the Mathcad algorithm of numerical differentiation and the speed of change on the x- and y-co-ordinates of points A, B, K, M was determined. The vectors $v_A(v_{Ax}(t), 0)$, $v_B(v_{Bx}(t), v_{Bx}(t))$, $v_K(v_{Kx}(t), 0)$, $v_M(v_{Mx}(t), v_{My}(t))$ determine the values and directions of the speed of change of the positions of points A, B, K M.

To image the vectors of speeds on the Mathcad worksheet we have used the following function, presented as Mathcad program Bertjajev, (2005):

$$F(x, y, v_x, v_y, m) = \left| \begin{array}{l} v_O \leftarrow \begin{pmatrix} x & x & x & x & x & x \\ y & y & y & y & y & y \end{pmatrix}^T \\ l \leftarrow \begin{pmatrix} 0 & 0.85 & 0.85 & 1 & 0.85 & 0.85 \\ 0 & 0 & 0.03 & 0 & -0.03 & 0 \end{pmatrix}^T \\ \Omega \leftarrow \begin{pmatrix} \frac{v_x}{\sqrt{v_x^2 + v_y^2}} & \frac{v_y}{\sqrt{v_x^2 + v_y^2}} \\ -\frac{v_y}{\sqrt{v_x^2 + v_y^2}} & \frac{v_x}{\sqrt{v_x^2 + v_y^2}} \end{pmatrix} \\ v_O + m \cdot \sqrt{v_x^2 + v_y^2} \cdot l \cdot \Omega \end{array} \right.,$$

where x and y are x- and y-co-ordinates of the origin of the arrows of speeds, v_x, v_y the speed of change of a point on the x- and y-co-ordinates and m – the coefficient of proportionality.

The values of the derivatives (5) at *i*-th position of the manipulator are:

$$v_{Ax_i} = v_{Ax}(t_i),\ v_{Bx_i} = v_{Bx}(t_i),\ v_{By_i} = v_{By}(t_i),$$

$$v_{Kx_i} = v_{Kx}(t_i),\ v_{Mx_i} = v_{Mx}(t_i),\ v_{My_i} = v_{My}(t_i).$$

The program returns the matrices

$$A_i = F(A_{x_i}, A_{y_i}, v_{Ax_i}, 0, 0.09),\ B_i = F(B_{x_i}, B_{y_i}, v_{Bx_i}, v_{By_i}, 0.09)$$

$$K_i = F(K_{x_i}, K_{y_i}, v_{Kx_i}, 0, 0.09),\ M_i = F(M_{x_i}, M_{y_i}, v_{Mx_i}, v_{My_i}, 0.09)$$

in two columns. Let us define the matrices:

$$v_{x_i} = augment\left(A_i^{\langle 1 \rangle}, B_i^{\langle 1 \rangle}, K_i^{\langle 1 \rangle}, M_i^{\langle 1 \rangle}\right),\ \ v_{y_i} = augment\left(A_i^{\langle 2 \rangle}, B_i^{\langle 2 \rangle}, K_i^{\langle 2 \rangle}, M_i^{\langle 2 \rangle}\right),$$

where the symbols $\langle 1 \rangle$ and $\langle 2 \rangle$ denote the first and the second column of matrices A_i, B_i, K_i and M_i, respectively.

To image the set of speed vectors at 6 positions of manipulator, let us define the matrices:

$$V_x = augment\left(v_{x_0}, v_{x_{20}}, v_{x_{40}}, v_{x_{60}}, v_{x_{80}}, v_{x_{100}}\right), \tag{6}$$

$$V_y = augment\left(v_{y_0}, v_{y_{20}}, v_{y_{40}}, v_{y_{60}}, v_{y_{80}}, v_{y_{100}}\right).$$

Fig. 4 was composed by using the matrices (4) and (6) and shows the set of speed vectors at 6 positions of the virtual manipulator and the trajectory (dotted curve) of point M (Fig. 3) in overcoming a virtual stone. (To simulate the motion of the virtual manipulator in Fig. 4, click on link http://www.youtube.com/watch?v=MNTztcBsBoA) in the online mode.)

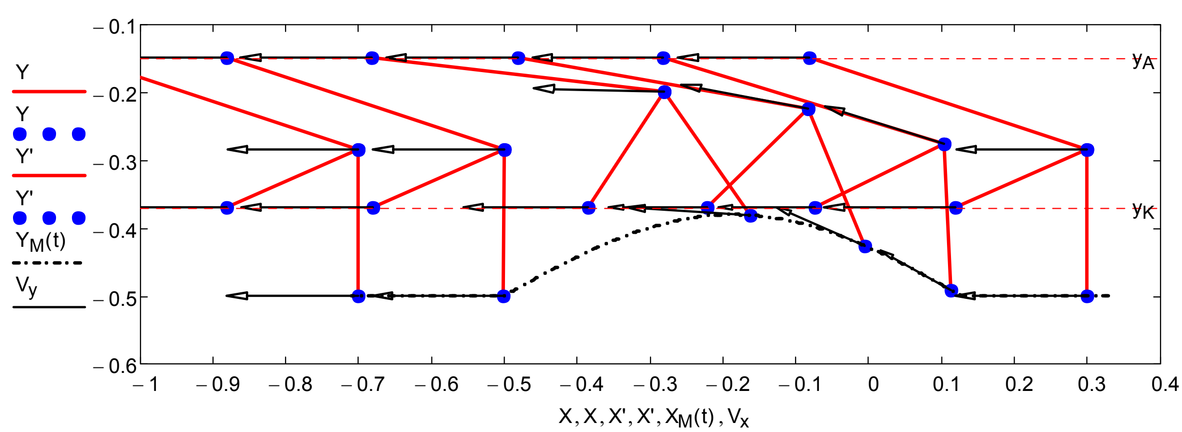

Fig 4: positions of the virtual manipulator in overcoming a virtual stone.

Let us suppose now that the trajectories of points A and K are straight lines (A_y = A_{y0}, K_y = K_{y0}) and the trajectory of point M (Fig. 3) is given by the following parametric equations:

$$M_x(\tau_2) = M_{x0} - A\tau_2\,,\quad M_y(\tau_2) = H\cos(20\,\tau_2) - B\,, \tag{7}$$

where τ_2 is the parameter and A = 2, H = 0.055, B = 0.45 are constants.

The co-ordinates B_x, K_x, B_y of points B, K and the parameter τ_2 were found out from the following system of equations:

$$\begin{aligned}
&(B_x - A_x(t))^2 + (B_y - A_y)^2 = l_{AB}{}^2\,,\\
&(K_x - B_x)^2 + (K_y - B_y)^2 = l_{KB}{}^2\,,\\
&[K_x - M_x(\tau_2)]^2 + [K_y - M_y(\tau_2)]^2 = l_{KM}{}^2\,,\\
&[B_x - M_x(\tau_2)]^2 + [B_y - M_y(\tau_2)]^2 = l_{BM}{}^2\,,
\end{aligned} \tag{8}$$

where $A_x(t)$ = A_{x0} – vt, t – the parameter and v = 2 is a constant. The system of equations (6) was solved by using the Mathcad solve block “Given-Find” in dependence with the values of parameter t. It was used to compose the set of speed vectors.

Fig. 5 was composed by using matrices (4) and (6) and shows a set of speed vectors at 6 positions of the virtual manipulator and the trajectory (dotted curve) of point M (Fig. 3) in motion in a virtual stony field, according to (7). (To simulate the motion of the virtual manipulator in Fig. 6, click on http://www.youtube.com/watch?v=UePHY7v7yEo in the online mode).

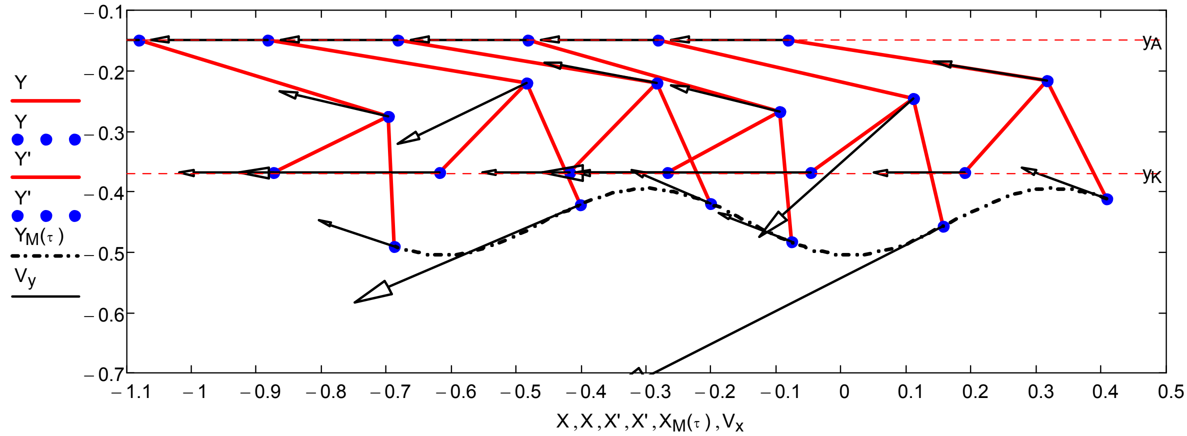

Fig 5: positions of the virtual manipulator in a virtual stony field.

Let us now consider a case, when points A and K are moving along a straight line: $A_y = A_{y0}$, $K_y = K_{y0}$ and point M (Fig. 3) can't move to the left: $M_x = M_{x0}$. In this case the co-ordinates B_x, K_x, B_y, M_y were found out from the following system of equations:

$$
\begin{aligned}
&(B_x - A_x(t))^2 + (B_y - A_y)^2 = l_{AB}^{\ 2}, \\
&(K_x - B_x)^2 + (K_y - B_y)^2 = l_{KB}^{\ 2}, \\
&[K_x - M_x]^2 + [K_y - M_y]^2 = l_{KM}^{\ 2} \\
&[B_x - M_x]^2 + [B_y - M_y]^2 = l_{BM}^{\ 2},
\end{aligned}
\tag{9}
$$

where $A_x(t) = A_{x0} - vt$, t – the parameter and v = 2 is a constant. The system of equations (9) was solved by using the Mathcad solve block "Given-Find" in dependence with values of parameter t.

Fig. 6 shows that in this case the manipulator lifts point M up (to simulate the motion of the manipulator in Fig. 6, click on link http://www.youtube.com/watch?v=7b9GsOX0oBM in the online mode).

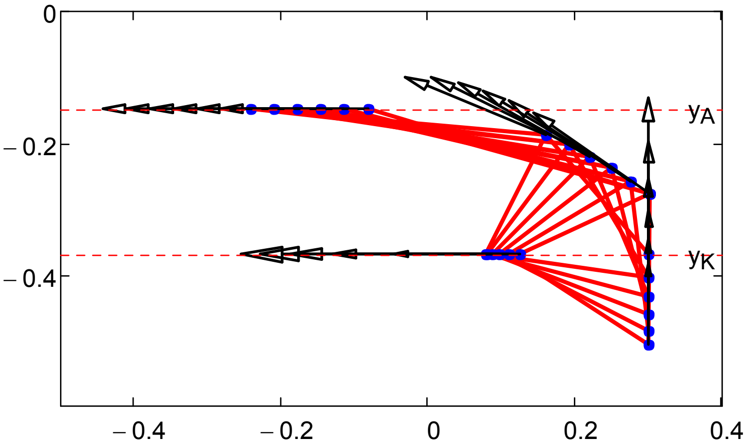

Fig 6: positions of the virtual manipulator, when point M (Fig. 3) can't move to the left.

Fig. 7 shows the dependence of the parameter τ_1 in the equations (1) and the parameter τ_2 in the equations (7) on parameter *t*.

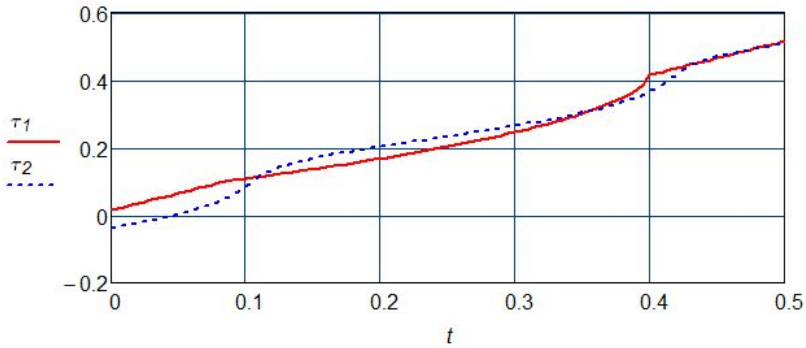

Fig 7: the dependence of parameters τ_1 and τ_2 on parameter *t*.

4. Conclusions

To solve the problems stated in this paper, it is necessary to solve numerically the nonlinear systems of equations (2), (8) and (9).

It is possible to treat the parametric equations for the trajectory of point M (Fig. 3) differently from equations (1) and (7).

The Computer Package Mathcad has all the necessary tools for solving the problems stated in this paper and for visualizing the results of computations by complex figures and video clips, showing the motion of the virtual manipulator (Fig. 3).

The paper has also demonstrated that it is possible to create a virtual manipulator, two points of which are moving along a straight line and one point along the prescribed curve given by parametric equations (1) and (7).

It follows from the paper that if point M cannot move horizontally, the virtual manipulator lifts it up.

It follows from the paper that a real manipulator, corresponding to the virtual manipulator in Fig. 3, can be used in the structure of a stone protector for a stony soil tillage implement.

The results obtained in this paper and the computer program realizing the virtual reality technology–based study of the working process of the virtual manipulators for stone protectors, can be used by designers of stone protectors for soil tillage implements.

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