Integration of the virtual 3D model of a control system with the virtual controller

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Abstract. Nowadays the design process includes simulation analysis of different components of a constructed object. It involves the need for integration of different virtual objects to simulate the whole investigated technical system. The paper presents the issues related to the integration of a virtual 3D model of a chosen control system with a virtual controller. The goal of integration is to verify the operation of an adopted object in accordance with the established control program. The object of the simulation work is the drive system of a tunneling machine for trenchless work. In the first stage of work was created an interactive visualization of functioning of the 3D virtual model of a tunneling machine. For this purpose, the software of the VR (Virtual Reality) class was applied. In the elaborated interactive application were created adequate procedures allowing controlling the drive system of a translatory motion, a rotary motion and the drive system of a manipulator. Additionally was created the procedure of turning on and off the output crushing head, mounted on the last element of the manipulator. In the elaborated interactive application have been established procedures for receiving input data from external software, on the basis of the dynamic data exchange (DDE), which allow controlling actuators of particular control systems of the considered machine. In the next stage of work, the program on a virtual driver, in the ladder diagram (LD) language, was created. The control program was developed on the basis of the adopted work cycle of the tunneling machine. The element integrating the virtual model of the tunneling machine for trenchless work with the virtual controller is the application written in a high level language (Visual Basic). In the developed application was created procedures responsible for collecting data from the running, in a simulation mode, virtual controller and transferring them to the interactive application, in which is verified the operation of the adopted research object. The carried out work allowed foot the integration of the virtual model of the control system of the tunneling machine with the virtual controller, enabling the verification of its operation.

1. Introduction
The dynamic growth of simulation capabilities, offered by modern engineering software of the CAE class, action allows conducting a simulation of a virtual 3D model of the given control system [7,12-14,16,18]. In the mentioned class of software the process of operation simulation is always preceded by a process of creating the concept, using different methods of designing and modeling [1,2,6,8,10-11,15,17]. While the integral part accompanying the verification process of operation of a system is the process associated with creating the control application using the software for programming the
PLC controllers, by means of which it could be, in a rational way, verified the correctness of a signal flow, with respect to the proposed drive system. The solution consisting in verification the operation of the given control system, in the form of the 3D model basing on control signals from the virtual controller, requires the use of an integrator [4,5,9]. The integrator has the task receiving output signals from the software of a virtual controller and transferring them to the system with the 3D model of the analyzed system, where on their basis is performed the simulation of its operation. The presented procedure is of particular importance in the case of designing specialized machines, manufactured in the regime of the piece production, which is especially important in the case of specific operating conditions of this device. The machine, of this type, is the tunneling machine for trenchless work. The mentioned machine allows drilling a tunnel in accordance with the micro-tunneling technology, without the necessity of digging up roadways, pavements or other elements of the urban infrastructure. Wherein micro-tunneling consists in drilling a horizontal tunnel between the two previously realized chambers: start one and closing one, using a tunneling machine (TM - tunneling machine). Due to the use in this technology machines with their own independent drive, the diameters of drilled tunnels are in the range from 1000 to 4000 [mm], wherein due to technological development the upper value of the diameter range is constantly increasing. The presented micro-tunneling technology is used in: realization of sewage and water pipelines, construction of pipelines for energetic media (gas, oil, etc.), installing casing pipes on other conduits (gas piping, telecommunication cables, heating conduits, etc.), drilling multi-conduits tunnels [3].

The paper presents the conceptual design of a tunneling machine for trenchless work, in relation to which was conducted the verification process of previously adopted operation cycle. The main subsystems of the conceptual design of the tunneling machine for trenchless work (figure 1) are:

- The outer jacket, which is the base element in relation to the other components of the tunneling machine;
- The set of four hydraulic cylinders of a linear motion, which allows for the movement of the whole tunneling machine. The cylinders, included in that set, are mounted within the outer jacket of a tunneling machine and influence on a support of the tunneling machine;
- The support of the tunneling machine, which props on the tubing system;
- The set of four hydraulic cylinders of a rotary motion, which drives the mining jacket;
- The mining jacket, which is the base element in the mining process of a ground;
- The system of the manipulator together with crushing head, which is used for output crushing;
- The system of power transmission from the engines of a rotary motion on the mining jacket;
- The system of output transporting.

In the phase of conceptual work it was assumed that in order to drill a tunnel, the tunneling machine should realize the following tasks:

- Running the system of output transporting;
- Running the mining jacket by the set of hydraulic cylinder of a rotary motion using the power transmission system;
- Running the drive system of the manipulator together with the crushing head;
- Running the system of the set of hydraulic cylinders of a translatory motion.
1.1. Preparing the model of the tunneling machine for operation simulation

Preparation of the 3D model of the control system of the tunneling machine for trenchless work for motion simulation was realized in software of the VR (Virtual Reality) class, EONStudio. In the first stage of the work was created an interactive visualization of operation of the 3D model of the tunneling machine. In the elaborated interactive application were created procedures allowing controlling the translatory motion system, rotary motion one and the drive system of the manipulator. It was also created the procedure enabling turning on and off the output crushing head, mounted on the last element of the manipulator. Actuators in particular control sub-systems (figure 2) are: four hydraulic cylinders of linear motion (drive system of translatory motion of the whole tunneling machine), four hydraulic motors of a rotary motion (drive system of the cutting ring), five hydraulic cylinders of a linear motion (drive system of the manipulator), and one hydraulic motor of a rotary motion (drive system of the output crushing head). Due to the scope of conducted researches, concerning the verification of operation system of the tunneling machine for trenchless work, in the 3D model of the tunneling machine, from elements of control systems, it was mapped drives and power transmission systems.

The mentioned drives operate, in the created interactive simulation, in accordance with the accepted characteristics of their operation (figure 2), where in:

- piston\(_1^+\), piston\(_1^-\), piston\(_2^+\), piston\(_2^-\), piston\(_3^+\), piston\(_3^-\), piston\(_4^+\), piston\(_4^-\), piston\(_5^+\), piston\(_5^-\), means the procedure related with the characteristic of moving out and in of the piston rod of the \(i\)-th linear drive, where \(i=1,\ldots,5\);
- shaft\(_1\)\_on\_off, shaft\(_2\)\_on\_off, shaft\(_3\)\_on\_off, shaft\(_4\)\_on\_off, shaft\(_5\)\_on\_off, means the procedure related with the characteristic of turning on and off of a rotary motion of a shaft of a rotary motor with the assumed rotational speed;

**Figure 1.** Conceptual design of the tunnelling machine for trenchless work.
In the adopted model were also created interactive components performing the functions of virtual distribution valves, logically mapping the function of the real two-position distribution valve (latch1, latch2, latch3, latch4, latch5, latch6, latch7). The described model could be manually controlled using the keyboard buttons (Q, A, W, S, E, D, R, F, T, G, Y, H, J, U), or using the integration with the virtual controller. In the created interactive application it has been established procedures for receiving input data from an external application, on the basis of dynamic data exchange (DDE), and assigning them to the components OS1, OS2, OS3, OS4, OS5, OS6, OS7, what allows controlling actuators of particular control systems of the considered machine. It is assumed that the control is based on a digital two-state signal of 0 or 1 (true or false).

1.2. Creating the program controlling the system in a virtual controller

The stage of the work, associated with the creation of the control program, was carried out in the CoDeSys program. The control program for the virtual controller is elaborated on the basis of the Ladder Diagram (LD) language. The control program (figure 3) was developed on the basis of the adopted operation cycle of the tunneling machine, and namely, the first must be turned on the hydraulic motors of a rotary motion which, by the power transmission system should start the mining ring. Then should be activated actuators of a linear motion moving the whole tunneling machine and, at the same time, should be activated work of the manipulator and output crushing head. The whole machine is moving, in one cycle, by a distance equal to the width of the tubing, used to reinforce the drilled part of the tunnel and to prevent the phenomenon of ground sliding.

In the created control program it was assumed that all actuators of a linear motion are in the start position, in which piston rods are in its extreme, rear position. The created visualization component allows applying excitations on the particular drives realizing the movement of the whole tunneling machine, by transferring the signal to the elements performing the role of virtual two-position valves.
1.3. Integration of the VR system with the virtual controller

The element integrating the virtual model of the tunneling machine for trenchless work with the virtual controller is the application (figure 4) written in a high level language (Visual Basic). In the developed application were created procedures responsible for receiving data from the controller, operating in the simulation mode, where the results of their actions are presented in the fields marked with the names of the signals: OS1, OS2, OS3, OS4, OS5, OS6, OS7. Then they are transferred to the interactive application, in which is verified the operation of adopted object of researches.

While iSJ signals, where i=1,…,5, j=1,2, reflect the states of virtual sensors indicating the position of the piston of cylinders in their extreme positions.

2. Conclusions

The important problem, related with the integration process of a model of the control system with the virtual controller, is correct mapping of operation of the analyzed system, on which allows software of the VR class, EONStudio. This mapping must include the operation characteristics of the particular drives of the control system.

The conducted works enabled the integration of the virtual model of the control system of the tunneling machine with the virtual controller, what allows verifying its operation.
The virtual analysis of the systems, basing on the integration of the virtual 3D model with the virtual controller, allows step by step eliminating errors without fear of material losses.

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