Expanding the Remote Experiment Set with the 3Axis Portal Physical Model

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Abstract—The problem of insufficient variety of experiments with physical models in laboratory workshops for distance learning in the design of control systems is posed. It is caused by the limited operations with the physical model when using the interface at the level of electromechanics control. The way of solving the problem is substantiated: the transition from electromechanics control of physical models of devices to control systems for the processes of using these devices. The proposed way to increase the number of types of experiments is illustrated with examples of systems for using popular physical models of an elevator, storage warehouse and production cell. However, the main focus is on expanding the functionality of the physical model 3-Axis Portal. These possibilities are realized by equipping the portal head of the base model with new sensors and actuators, improving the loads with which the portal works and using new types of active surfaces in the working field of the portal. Based on the aggregation of the proposed nodes with the basic portal model, sixteen types of systems for setting up remote experiments are described. The structures of these systems, elements of implementation and variants of experiments are described, which relate to the design of digital control systems, visualization of sorting algorithms, technical diagnostics of electronic assemblies, pattern recognition and other relevant topics for teaching students of engineering specialties.

Keywords—remote laboratories, physical models, 3-Axis Portal, nomenclature of experiments

1 Introduction

Remote experiments with physical models of control objects are an important element of distance and hybrid learning in the design of control systems [1]. Remote laboratories use modern methods of implementing remote experiments, technologies and learning scenarios [2]. As a rule, a remote experiment is accompanied by an animation and a live-stream of the control object on the screen of a remote student, which reflect changes in the object or its environment.

As a teaching tool in engineering education, remote laboratories are in transition to mainstream use [3]. In the field of teaching the design of control systems, this requires providing each student with an individual design experiment with a physical model of an object. In order for a student to focus on management in the process of preparing an experiment and not waste time studying the principle of the model's operation, he must meet the objects of the experiment in everyday life. In remote laboratories, vehicles, traffic lights, elevators, conveyors, robots and others are widely represented.

3Axis Portal is a popular model for studying the principles of controlling gantry cranes, 3D printers, CNC machines, industrial robots and other devices. Some devices of this type are designed to increase the visibility of experiments in the process of engineering university education. For example, 3-Axis Portal [4] is a model that is used to create Learning factories [5] and to conduct remote experiments with control systems in a remote laboratory GOLDi [6].

A general view of the 3Axis Portal model is shown in Figure 1.

Fig. 1. General view of the 3-Axis Portal model

The portal simulates a stationary control robot with an orthogonal workspace, which is used to transfer workpieces to a processing or sorting unit, as happens, for example, in factories with a high degree of automation.

The model consists of a gantry robot capable of moving in three linear directions and an electromagnetic gripper mounted on an actuator for movement in the Z-direction. This grip will be called an actuator of the robot mounted on its head. The available sensors serve only the model movement subsystem.

2 State of art

The range of experiments with the 3Axis Portal model is currently limited and does not allow providing a student with an individual task for educational design of a control system. If the student's control program differs only in the coordinates of the points to which it should be moved, then it cannot be considered original. A certain variety of experiments is introduced by the requirement of a certain order of the arrangement of the cargo. For example, it is solving the problem of placing cargo in the form of "Towers of Hanoi" [4] in the working field of the portal.

Another direction of expanding the nomenclature of experiments with the 3Axis Portal model is the study by the “FSM in Black Box” method [7], in accordance with which the student, based on the analysis of observations of the experiment, must restore the logic of the control system. The variety of experiments can be increased by using cyber-physical models instead of physical ones [8].

A promising method that provides an expansion of the set of experiments is the transition in educational projects from the problems of controlling the electromechanics of a physical model to the problems of programming algorithms for applying this model under certain conditions. The types of popular physical models, conditions of use and the range of tasks solved in educational design are given in Table 1.

Table 1. Models, conditions of use, and learning objectives

Physical model	Terms of use	Solved educational tasks
Elevator	Call flow from floors.	Optimization of passenger boarding along the route of the elevator in order to reduce the waiting time [9].
Warehouse	The flow of incoming and outgoing goods, requirements for their placement.	Sorting of goods according to a given criterion. For example, according to the rules of the game "15". Placement in order to minimize the length of movement of goods in the warehouse [8].
Production Cell	The sequence of operations for moving and processing parts. Parts flow through the system.	Synthesis of the structure of the production system and coordinated control of parallel operating devices.

At the same time, for the 3Axis Portal model, there are currently no conditions of use that can be used to increase the variety of experiments, which reduces the possibility of using the model in the educational process.

The aim of the work is to expand the set of remote experiments and the physical model of the 3Axis Portal by expanding the functionality of the vertically moving head, moving loads along the portal and improving the working surface of the portal.

3 Remote experiments with improved 3-Axis Portal model

As already noted, the design improvement of the 3Axis Portal model consists in the installation of new sensors and actuators on the head; changes in the physical and functional characteristics of the goods with which the portal works and the working field over which the working head of the portal moves. Table 2 gives a summary of the sensors and actuators, proposed to install on the portal head.

Table 2. Sensors and activators on the portal head

Name	Type	Function	Designation
Electromagnet	Activator	Holds the cargo while moving	HA1
Rotary mechanism	Activator	Rotates the cargo around the portal Z-axis in multiples of 90 degrees.	HA2
Pencil	Activator	Draws a line on the work area	HA3
Light-emitting diode	Activator	Illuminates a section of the working field	HA4

Contact probe with logic level generator	Activator	Injects a short current pulse into the internal circuit of the logic node	HA5
Vacuum Gripper	Activator	Holds the cargo while moving	HA6
Scales	Sensor	Measures the weight of the cargo attached to the head of the portal	HS1
Light sensor	Sensor	Photodiode with level driver	HS2
Color sensor	Sensor	Three photodiodes with different sensitivity ranges	HS3
Non-contact current pulse sensor	Sensor	Determines the presence of current pulses in the conductors on the working surface of the portal	HS4
Contact probe with voltage sensor	Sensor	Measures DC voltage in circuit nodes on the working surface of the portal	HS5
Contact probe with temperature sensor	Sensor	Measures temperature at points on the working surface of the portal	HS6
Distance sensor	Sensor	Ultrasonic sensor of distance to the working surface	HS7
Contact probe with Z-axis force sensor	Sensor	Fixes the excess of the permissible axial force when the head comes into contact with a load or surface	HS8
Contact probe with lateral force sensor	Sensor	Fixes the excess of the permissible lateral force when the head comes into contact with a load or surface	HS9
Web camera	Sensor	Forms an image of the portal working surface area	HS10
Thermal imager	Sensor	Non-contact temperature measurement of the point of the portal working surface	HS11
Barcode reader	Sensor	Recognizer of digital identifier of cargo on the working surface	HS12

Table 3 lists the characteristics of the cargo, changeable to increase the variety of experiments.

Table 3. Variable cargo characteristics

Name	Sensor / activator used for interaction	Designation
Magnetic properties	Electromagnet	B1
The weight	Scales	B2
Thickness	Distance sensors, axial force	B3
Color	Color sensor	B4
The form	Photo sensor, axial and lateral force sensors, Web camera	B5
Electrical conductivity	Contact voltage sensor	B6
ID, number	Barcode reader	B7
Emitted light	Light sensors, colors	B8

The magnetic properties of the cargo material and the traction force of the electromagnet must ensure that a certain weight is retained on the load. Weight, thickness, color, ID and cargo number can be used to sort them. As for the shape, in this case, the weights must have the same height (z), and their upper plane must be parallel to the working surface (plane (XY) of the portal and represent such geometric shapes as a square, triangle, circle, figures for playing Tetris, etc. When using a photo sensor to identify the type of figure, a contrasting contour line should be drawn on the upper surface of the figure. Electric circuits can be placed inside the cargo, which must be recognized by the system being designed by the student by their electrical conductivity, released heat, electrical voltage or logic level. When light is detected that is emitting from the cargo, a user-programmed action can be performed.

Table 4 gives a summary of the name and characteristics of the options for the working surface of the portal.

Table 4. Suggested working surfaces of the portal

Name	Description of functions	Designation
Base surface	Additional elements and functions are missing	S0
Drawing surface	Stores the trajectory of the portal tool (head) relative to the coordinate table	S1
Surface with contrasting contour lines	Sets the trajectory of the portal head movement along the contour line	S2
Head obstructed surface / labyrinth	Vertical partitions restrict the route of movement of the portal head	S3
Embossed surface	Forms extreme points, which must be detected by the portal control algorithm and the relief in order to find the optimal routes of the portal head between the given points.	S4
Surface with hot zones	Sets the temperature field of the experiment	S5
Surface with controlled light sources	Sets the light field of the experiment	S6
Surface with electrical circuits in which currents flow	Forms conditions for finding the place of electrical circuits closure	S7
Digital node PCB surface	Forms conditions for studying algorithms of in-circuit functional control and diagnostics of a digital node	S8
Surface for learning game algorithms	Forms conditions for studying the algorithms of the games "Minesweeper", "Tic-tac-toe", "Tetris", dominoes, checkers and others	S9
Touch screen surface	Forms images that are recognized by the Web camera installed on the portal head; performs the action programmed when the portal probe touches the area of the control element on the display screen	S10

The assignment of surfaces S0 – S3 does not require any special comments. Using the surface S4, an algorithm for finding an extreme point of the relief can be visualized by means of genetic algorithms. To study the algorithms for detecting and localizing the fuel elements of a diagnosed unit, surface S5 can be used. Surface S6 can change the light relief from experiment to experiment or depending on the nature of the portal head movements. Surface S7 defines the topology of electrical circuits, directions and moments of current impulses flowing in them. Surface S8 contains a digital node, to the inputs of which functional tests are applied, the values of the outputs are compared with reference reactions, and the internal points of the node are available for connecting a contact probe mounted on the portal head. The functions of the surface of the S9 are determined by the characteristics of the game. So for studying the game "Minesweeper" the surface stores the coordinates of the location of mines and forms two variants of the light response of the surface cell to finding the portal head above it: "Checked no mines" "Explosion".

An applied problem that is solved during the experiment requires the creation of a system that includes the following elements: 3Axis Portal, a set of sensors and actuators of the head, a set of weights with certain characteristics and a working surface of the corresponding type of task. The experiment system can include, as additional elements, a control system for the portal illumination and an angle control system for the Web camera. Examples of the tasks to be solved and the structure of the experimental systems are given in Table 5.

Table 5. Variants of the tasks to be solved and the experiment systems structure

Designation. Name	Feature / Description	Structure
A0. Warehouse	Placement of goods from the input buffer according to a given algorithm with return to the bunker at the end of the experiment	HA1+B1+S0
A1. Sorter in the XY plane	Moving loads within the working area according to a given placement algorithm	HA1, B7+S0, HS12+B1,
A2. Sorter in the Z plane	Changing the order of storage of goods depending on their size ("Towers of Hanoi")	HA1, HS1+B1, B2+S0
A3. Color sorter	Arrangement of goods in the working area of the portal, depending on their color	HA1, HS3+B1, B4+S0
A4. Sorter by number in conditions of limited free positions	Moving loads according to the logic of the game "15"	HA1, B7+S0, HS12+B1
A5. Plotter	Estimation of the accuracy of movement along a given trajectory	HA3+S1
A6. Choosing a path in a maze	Algorithm efficiency check	HS9, HA3+S3, S1
A7. Movement along the line	The efficiency of the algorithm for changing the direction of movement at a bend in the line	HS2(or HS3) +S2
A8. Choosing a path along the relief	Evaluating the quality of the extreme search algorithm	HS7+S4
A9. Diagnostics of heat-loaded elements	Construction of the thermal relief of the working surface	HS6 (HS11)+S5
A10. Diagnostics of places of short circuit of electric circuits	Assessment of the quality of the algorithm for finding a short circuit location	HS4+S7
A11. In-circuit diagnostics of logical nodes	Assessment of the quality of algorithms for functional testing and (or) diagnostics of a logical node	HS5, HA5+S8
A12. Identification of resistor circuits with "Black box" structure	Assessment of the quality of algorithms for identifying electrical circuits and calculating resistor parameters	HA1, HS5+B1, B6+S7
A13. Minesweeper game	Evaluating the effectiveness of a player's strategy	HA4+S6, S9
A14. The game "Tic Tac Toe" on the working field of the portal	Evaluating the effectiveness of various game strategies	HA1+B1, B4+S9
A15. The game "Tetris" on the working field of the portal	Evaluating the effectiveness of various game strategies	HA1, HA2+B1, B5+S9
A16. Recognition of images on the surface using a moving web camera, image control from the portal side	Evaluation of recognition efficiency	HS10+S10

The designations of the elements of the structure of the experiment system correspond to the designations that are given in Tables 2–4. (Namely HA, HS there is an activator, a sensor on the portal head; B is the characteristic of the cargo; S is the type of surface of the working field; and there is a designation for the experiment system).

System A0 has a basic structure. Before the start of the experiment, the goods to be stored are located at the edge of the working field of the portal in the place of the receiving hopper. The essence of the problem is to program them to move to a given zone of the working field and then return to the starting position to prepare for the next experiment.

The A1 system differs in that the goods have a number and the head of the portal is a reader of this number. This configuration of the system allows you to determine the place of storage of the cargo, taking into account its number and sorting criterion.

The A2 system determines the size of the load by its weight. In the initial state, the weights are placed on top of each other in random order. The system sorts the goods in order of decreasing weight, using the restrictions of the Tower of Hanoi game: goods can only be put in one pile.

The A3 system is similar in functionality to the A1 system, but differs in that the color of the load is recognized.

The A4 system differs from A1 in the weight permutation algorithm, which corresponds to the rules of the game "15".

The A5 system documents on paper the route of movement of the portal head, with which it is possible to evaluate the quality of algorithms for linear and circular interpolation, the total length of movements.

The A6 system is based on a four-way lateral contact sensor, which is triggered when the walls of the labyrinth are touched. In order to document the route of movement of the portal head through the maze, the system can additionally include a surface S1 and a drawing tool HA3.

The A7 system simulates the algorithms for moving the in-house transport along the markings.

The A8 system simulates the process of searching for an extremum, for example, using genetic algorithms.

The A9 system equipment allows you to measure the temperature at various points of the thermal model of the object. This is relevant in the process of diagnostics of equipment fuel elements. By switching electrical circuits in the surface of S5, it is possible to change the studied thermal relief, which makes it possible to increase the variety of experiments with A9.

The process of diagnostics of places of short circuit of electrical circuits on the printed circuit board of the electronic unit is simulated by the A10 system. The shorting conductors are located on the S7 surface and are covered by a screen. The essence of the method is that the student designs a system of currents, the set of which is different for different sections of the closing circuits. The probe with the HS4 probe moves over this surface and registers currents. Based on the results of the analysis of the currents, the direction of movement of the probe to the point of short circuit is selected.

The process of testing the correct functioning of the digital node and diagnosing the fault location is simulated by the A11 system. Surface S8 is a logical node, to the inputs of which test influences are applied, and the logic levels at the outputs are compared with a reference. If the reactions do not coincide with the standards, the point on the board is determined, where the probe on the portal head moves. The logical level measured by the probe specifies the location of the fault or is used to determine a new monitoring point. The HA5 shaper allows you to simplify verification tests.

The A12 system is used to identify resistor circuits by measuring voltages at the external outputs of these circuits. Structurally, these chains are weights transported by the portal in the working field. The lower and upper sides of the cargo have contacts that are connected to electrical circuits inside the cargo. The lower contacts are connected to the power supplies via the S7 surface circuits.

In the A13 system for simulating the Minesweeper game, the minefield is a surface S6 divided into cells. Each cage contains a light sensor and two indicators: "Tested" and "Mine". The sensor outputs are connected to a logic circuit that generates a variant of the location of mines in the current experiment. The sensor is triggered when the LED illuminates the HA4 head.

In the A14 system, the head of the portal builds a game situation by placing loads in the cells of the working field from the zones of the receiving bunkers on this field. Loads are color-coded "X" and "O" and are alternately laid out for each player.

Simulation by the A15 system of the Tetris game process requires the following operations with the load: shape recognition, rotation by an angle multiple of 90 degrees, and movement to the selected position.

Many opportunities appear in the A16 system, which contains a display as a working surface and a Web camera that moves on the portal head. For example, the image on the display may change because of head movement and recognition of data from a Web camera.

The implementation of the proposed systems requires additional sensors, actuators and electronic components that operate under the control of microprocessor boards. Figure 2 shows the generalized block diagram of the system.

When building specific systems, individual nodes and devices may be absent.

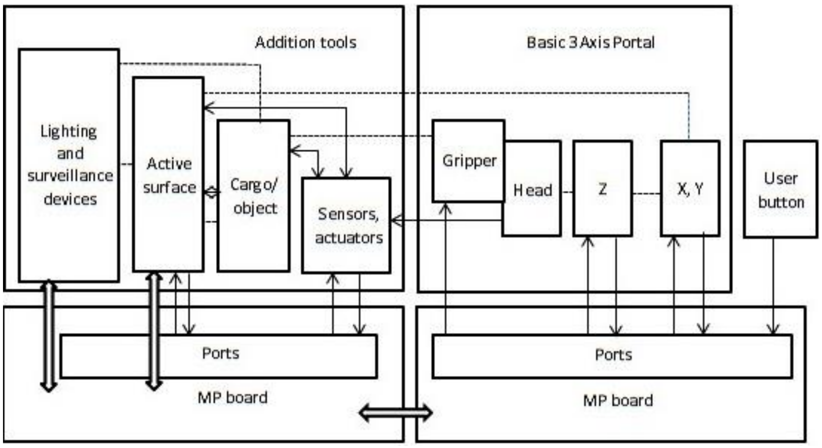

Fig. 2. Generalized block diagram of a system based on 3 Axis Portal

The basic physical model 3 Axis Portal contains XY-, Z-displacement nodes and a head with a single actuator - an electromagnetic part gripper and a sensor - a user button.

Additional experimental tools are placed on the head of the portal, inside parts, active surfaces, lighting and video surveillance. In this case, the mechanical connections of the nodes are shown with a dotted line, and the information-control ones - with a solid line. The control part of the system contains microcontroller nodes, both for the physical model 3 Axis Portal and for additional equipment. In some cases (for example, surface S10) the control unit is built-in.

The examples listed are by no means exhaustive of the possibilities for using the described robot with an orthogonal workspace, which serves as a backbone element for the interaction of intelligent loads / parts / objects with an active environment (including a game environment) and means of measurement, control, diagnostics, analysis, recognition, sorting, management and processing.

4 Conclusions

At the stage of transition to the massive use of remote laboratories in the process of distance engineering education, the role of such a characteristic of a remote laboratory as the number of original experiments with physical models of learning objects increases.

The construction of control systems for objects at the level of control of the electromechanics of the physical model does not provide the required variety of experiments.

The method of increasing the number of original remote experiments by including a physical model in the process of imitating the use of the original object proved to be effective in the practice of using remote laboratories.

This method is considered on the example of the physical model 3Axis Portal, which simulates the work of a stationary robot with three degrees of freedom and electromagnetic gripping of parts.

Additional sensors and activators that can be installed on the movable head of the portal are considered. The additional characteristics of the cargo are described, with the help of which they interact with the rest of the system elements. The proposed "active surfaces", which are electronic units interacting with the head of the portal and weights during the experiment. The ways of creating systems based on the combination of the physical model of the portal and the proposed additional equipment are shown. Sixteen types of measuring, diagnostic, sorting, gaming and other systems are described as examples.

The results obtained can be used in the processes of designing physical models and setting up educational experiments for the design of information and control systems for various purposes.

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