Structure of wall climbing robot control system

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***Abstract*—Structure of control system is presented that intended for wall climbing robot with vacuum contact devices to realize motion along vertical, slope surfaces and ceilings. The principal schemes of vacuum contact devices are adapted to the surfaces by means of force, pressure and tactile sensors as so as feedback loops. Information is transmitted from sensors to microprocessors of control system. Suggested algorithms of discrete control are developed on the base of information parameters about dynamics of vacuum contact devices.**

Structure of control system permits producing automatic mood of motion, supervision principle of remote control with man-operator participation and combine mood when man-operator can possibilities to include in control in critical points of extreme conditions. Mechanical transport system consists of two platforms and drives intended for performing translation and rotation motions of robot with technological equipment.

Essential peculiarities of wall climbing control motion are analyzed, such as non-predicted in advance quality of surfaces, external disturbances, and some kinds of obstacles that is necessary to inspect by sensors of information system and to avoid by means of control and drives systems.

Keywords—control system, structure, wall climbing robot, vacuum contact devices, feedback loop, sensors, discrete system, extreme.

I. Introduction

The wall climbing robots (WCR) are intended for realization of the motion along various vertical and slope surfaces placed in air or in water environment and for fulfillment some kinds of technological operations.

In previous investigations main attention was centered on application of WCR in extreme conditions for achievement such technologies like cutting, welding, not destructive testing [1-4] using equipment of on-board manipulators. It was supposed that such working operations were developed with the help of man-operator mainly [5-8].

Control systems of such WCR were not analyzed in detail from view point of rational levels of automation. The structure and hierarchy of control systems for WCR were developed not sufficiently.

Elaborated control systems were intended for to support different operations in accordance with specific demands what is rather important for design machinery processes [9-11]. At the same time it was arise the necessity in correlation of access. Besides collaborative human-robot interaction [12] can be applied for WCR also. This is a reason in using generalized approaches for consideration of WCR control systems and indication the possibilities of human-robot cooperation in hierarchy structure. In our paper the following problems are under consideration:

- design of WCR mechanics;
- multisensory generalized conception for control system;
- structure of WCR control system;
- structure of the control system for man-operator collaboration with robot.

II. Design of WCR

Wall climbing robots for decontamination, inspection and repair in nuclear power station illustrates approach to design their main systems and modules.

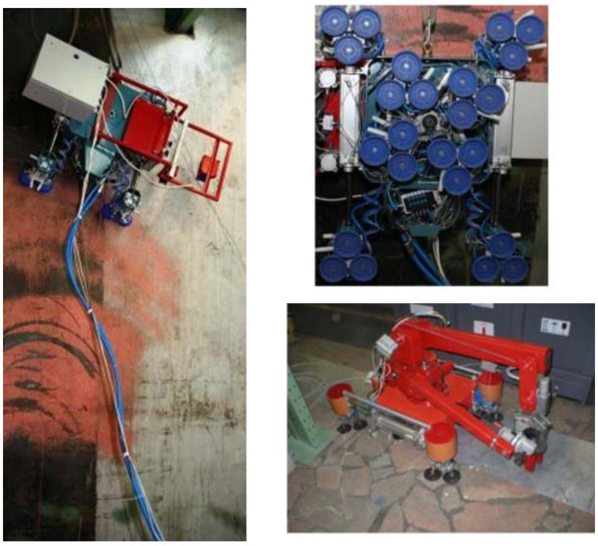

Fig. 1 Wall climbing robots for decontamination, inspection and repair in nuclear power station.

Wall climbing robot (WCR) consists of the following systems: mechanical transportation, sensory information, drive control, technology manipulator (Fig. 1). WCR in common case includes two platforms with linear pneumatic drives, two systems of vacuum grippers or vacuum contact devices (VCD), every of which is connected with platforms, on-board manipulator with technological equipment, on-board control and sensory systems.

The platforms realize translation motion and one of them can rotate relatively other. When one of the platforms is connected with the surface that may be wall by means VCD another can possibility to move along the surface.

III. MULTISENSOR GENERALIZED CONCEPTION FOR WCR CONTROL SYSTEM

One of the important problems is to choose minimum necessary information volume to have representative minimum quantities of necessary sensors that needed for realization required algorithms and smooth dynamic motion of the WCR. On the base of experimental experience [13] it was established and determined that WCR reliable motion and production of technological operations with on-board manipulator may be realized to take into consideration following sensory information parameters: position, pressure, vacuum, force, artificial vision, tactile, navigation (Fig. 2).

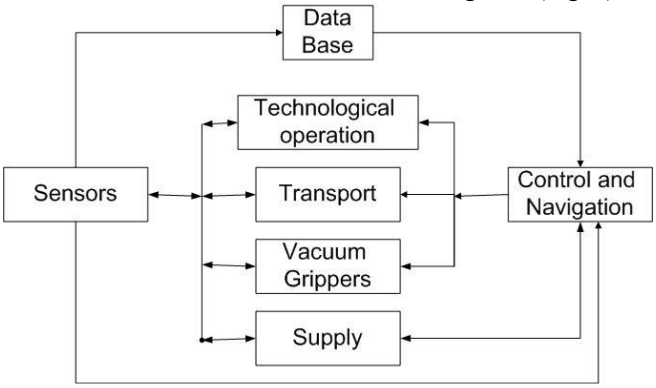

Fig. 2 Main modules connection.

The information concerning with transport system of the WCR, on-board manipulator, and coming to control and monitor systems through special interface. In this case the on-board manipulator during the first steps of the technology has to be rather simple.

IV. STRUCTURE OF WCR CONTROL SYSTEM

The structure of WCR control system includes information, navigation and estimation blocs (Fig. 3). Sensory information transmits from mechanical transport system to the control and image processor modules. Control output data transfers to transducers and drives for realize motion of translation and rotation transport modules, legs, TV-camera, vacuum grippers and technology manipulator.

The full system (Fig. 3) includes a navigation block, consists of path planning and run-time control modules and estimation block that includes situation analysis and motion analysis modules. Signals from the situation analysis modules come to the task planning module, connecting with prescribed tasks module, where program is generated.

Our conception supposes that three levels of WCR control exists;

- program or correction program control;
- intelligent automatic control;
- Supervision collaborative human-robot control.

Program and correction program controls are usually applied.

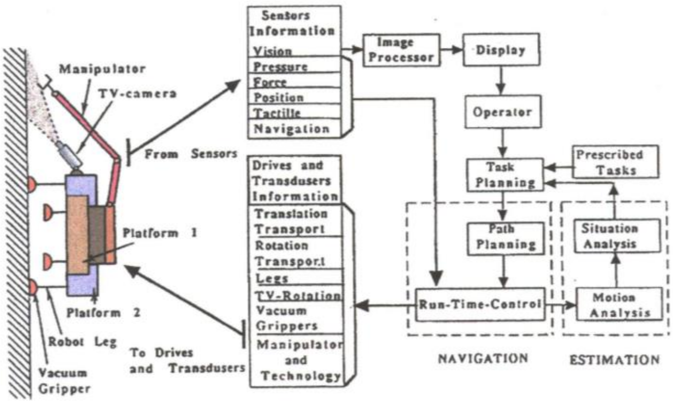

Fig. 3 Structure of WCR control system.

In correction program control WCR moves along the trajectory to be programming and the path planning system is on action. Sensory information about pressure, vacuum, force and position is intended to correct program trajectory.

An internal loop of the run-time control realizes the motion path planning techniques with cooperation with asymptotic methods intended for compensation of the deviations from the nominal programming motion is adjustable. To reduce the deviations from the nominal path $q^{\circ}(t)$ corresponding to the programming control law $U^{\circ}(t)$, feedback is introduced:

$$U = U^{\circ}(t) - J(q, \dot{q}, \Delta q, \Delta \dot{q}, \Delta \ddot{q})$$

Here q, Δq are vectors of WCR joint translations and rotation coordinates and their deviations.

Intelligent automatic control of the WCR is significantly different from the correction programming control, and it is working independently at all times. In this case all feedback loops are in action and sensory information about position, force, pressure, tactile, vision and navigation is collected into the data base. Full possible information permits to realize the next steps or to automatically produce a decision about the next action. For example, when it is possible to avoid some obstacles, to start or to produce technological operations depending on conditions or identification processes. In this case, two kinds of mode of operations may be realized: 1) Identification of obstacle and it avoidance with smooth dynamic robot motion, and 2) taking a decision and determining what is needed for the technology to be realized while maintaining a high production quality. Here, the robot is in action in unstructured environments, characterized by undetermined situations, so situation analysis procedures and representation of environments knowledge is producing in the correlations of the sensors information.

Intelligent multisensory control is implied that feedback coefficients may be automatically change depends on environmental situation in which WCR moves that reflects on sensory information and task planning modules.

The methods for operation of robot in unstructured environments base on representation of environments data and situation analysis procedures. Analysis of situation is considered as problem-oriented processes directed toward WCR motion and technology operations planning. The situation analyzer space includes all objects that are involved in planning, such as goals, failures, procedures, constrains, equipment, specific environment features, surface quality and surface attributes.

The path one trajectory planner module is considered as one of important for function allocation, reconfiguration and control problem solving. In common case structure of the trajectory planning with obstacle avoidance is presented in Fig. 4 and it includes five blocks: situation analyzer with prediction (1), trajectory correction and planning (2), control with obstacle avoidance (3), decision making and maneuver production (4), information link interface (5).

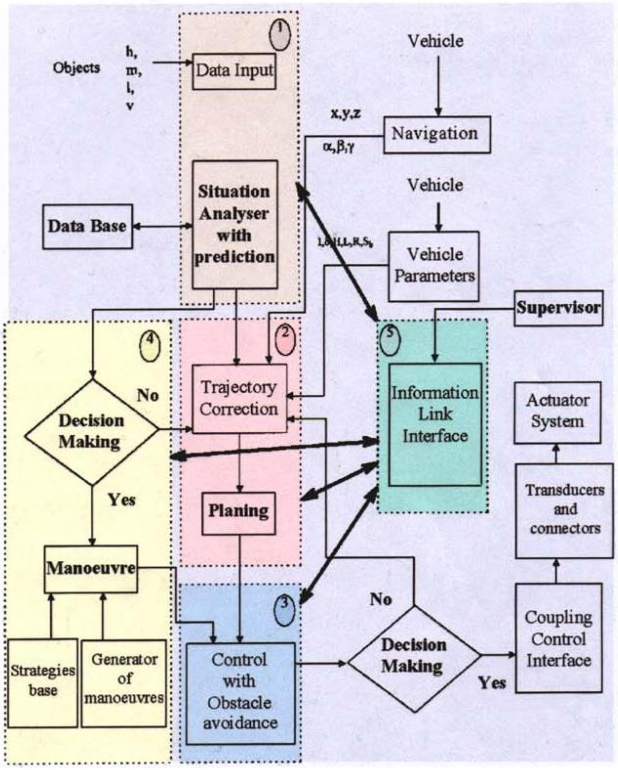

Fig.4 Structure of the trajectory planning with obstacle avoidance.

Decision making for obstacle avoidance may be based on fuzzy logic and fuzzy control.

V. Structure of the Control System for Man-Operator Collaboration with Robot

WCR control system provides for collaboration of man-operator with robot.

Block-diagram of hierarchy for control determines position of man-operator which connected with control desk and control system, and has possibility to receive information about working situation from sensors. Depends on situation, operator can includes in the control process during any time. Structure of control system (Fig. 5) includes five levels of control. Upper level is supervision one control with man-operator participation, then level intended for produce simple decision making with elements of artificial intelligence, after that levels for program and drive control.

Supervision control may be remote type when robot system is working in extreme conditions.

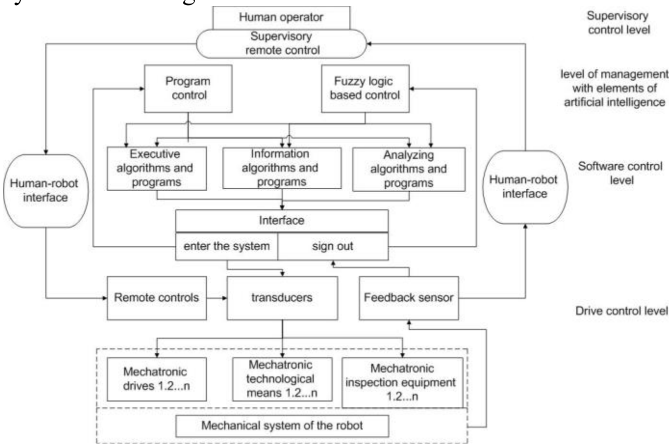

Fig. 5 Structure and levels of the control system for WCR.

Feedback interface between robot and man connects sensors, transducers and remote devices with supervision control of operator. Interface between man and robot organize direct participation of man in control system when it is necessary on critical situations or points of motion.

Program control is based on information, analyzer and drive algorithms and produces program motion of robot by means of transducers and mechatronic drives of robot translation and rotation motion and VCD drives to connect robot body to the wall.

Systems of WCR produces all types of automation mood and permits to include man-operator to produce supervision control in every step of motion and technology realization.

In this case a man is the only "intelligent" component along with the WCR, remote manipulator on its base, display, sensory hardware, communication system, control modules (Fig. 3). Information data from sensors is echoed back from the environment of the WCR and board manipulator in the suitable form for human perception and interpretation. One of the best solutions for this case may be a force reflecting joystick [14]. Control input device and man-machine interface have to be normally transparent to information flowing through the operator and the WCR. Control system requires a computational data base and a ful system has a man-machine interface with intelligence qualities to drive the WCR transport module and board manipulator. To compensate for external disturbances acting on the robot, friction effects, internal feedback is included in order to avoid manual operator confusion between signal and noise. Programmable joystick-to-end effector position mapping and end-effector-to joystick load state mapping may be recommended to be included in the control system.

Collaborative fulfillment is produced to solve assigned technological tasks such type for example as cutting, welding, inspection in the water pool or in decay tank.

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