CLIMBING ROBOTS WITH ADAPTIVE GRIPPERS FOR CONSTRUCTION

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ABSTRACT
Climbing robots are intended to move over vertical and slope surfaces to fulfill different technological operation by means on-board equipment. Vertical surfaces of buildings can be porous and rough so the robot should perform adaptation to such kinds of surfaces. The paper presents a new climbing robot for construction tasks that has adaptive possibility to move over various surfaces by means of a vacuum adaptive gripper system. It includes pressure, flow and force sensors, sealing gripper design and feedback control system of pedipulators. The control system ensures a sealing mode of adaptive pedipulator motion. The robot has two platforms and a light skeleton structure with nine degrees of freedom including two flexible technological manipulators. The climbing robot design allows adaptation to vertical surfaces of different quality. The design of the robot, its technical characteristics and experimental results are discussed.

INTRODUCTION
An essential limitation of climbing robots is low reliability in application on porous and rough motion surfaces. However, such kind of surfaces is usual in many applications, especially in construction [1]. There are some designs of climbing robots that are intended to improve this characteristic. For example, usage of multiple grippers [2] or intelligent control system [3]. However, a combination of surface porosity and roughness makes such designs not reliable in applications. An interesting solution of the problem can be using propulsive force of a propeller [4] but such a design is rather complex and can not be used for applications inside restricted working space.

In such conditions Wall Climbing Robot (WCR) sensory system performs important role as adapted to surfaces with various quality and produced from different ferromagnetic and non-ferromagnetic materials, along which robot has to move. To increase the WCR load capacity up to 120 kg and more, a special gripper system was developed with pressure, force, and proximity sensors. At the same time it was needed to study some changing environments not predicted in advance such wind, rain, frost especially for such application as building construction, gas or oil detection of reservoirs [7-10]. The more complicated new potential technologies aroused the more complex

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sensory system development required [10-12]. One of the important requirements was the necessity for WCR to cross from one surface to other arbitrarily arranged displacement in the space. The fulfillment of this task was possible to solve using sensory fusion method and fuzzy control necessary for decision making under motion processes. The problem like above solved by various ways, including application of artificial intelligent. The elements of artificial intelligent behavior are necessary also to satisfy WCR motion on unstructured or dynamically changing environment, such as some special situations, for example, firefighting, or decontamination of the wall surfaces [13-24], or for inspection of underwater constructions [25-28].

ADAPTIVE ROBOT DESIGN

The design of the transport module of the robot is shown in Figure 1. The transport module consists of a translation part 1 and a rotation part 2. These parts are connected by means of a junction bracket. The translation part has two pneumatic cylinders. Translation pedipulators are fixed at the ends of cylinder piston rods. They have concentric grippers 4 and sealing grippers 5 that are actuated by means of lifting cylinders 6. The rotation part has a pneumatic rotary actuator with the same combination of the described grippers and lifting cylinders 7. Positions of the translation part grippers and the rotation part grippers are separated by a circle line 8. The robot has nine degrees of freedom.

Robot motion is carried out by alternate vacuum fixation of the translation part grippers and rotation part grippers to motion surface and step by step motion of the cylinder piston rods and cylinder bodies.

The robot pedipulator system is presented in Figure 2. The translation and rotation actuators 6 are coupled to the lifting cylinders 5. Cylinders piston rods 4 have flexible in a direction of lifting cylinders action connections 3 to concentric grippers 1 and sealing
grippers 2. This design gives a possibility for all grippers to be in contact to uneven parts of motion surfaces.

![Figure 2: Robot pedipulator system](image)

A functional principle of concentric gripper is shown in Figure 3. The gripper has a body 1 with two concentric vacuum working zones. A central zone 2 produces the main gripping force. A circular zone 3 plays a supporting role in case of porous motion surfaces. It forms a vacuum cone circle 4 around the main central vacuum cone 5. Airflow 6 goes through the porous surface mainly to the circular zone so the vacuum inside porous surfaces has a stepped configuration. It provides the lower pressure difference between two vacuum zones and, as result, allows keeping high vacuum level in the main working zone.

![Figure 3: Concentric gripper](image)

Sealing grippers serve for attachment of the pedipulators to rough parts the surface. Its diagram is presented in Figure 4. The sealing gripper has a hard body 1 with elastic thin circular perimeter 3. This perimeter permits to seal roughness 4 of motion surfaces while pressing the body to the surface and to keep working vacuum level in the vacuum zone 2 of the gripper.
Light weight and small size of the robot are provided due to using of pneumatic rotary actuator in skeleton design of the robot. The rotary actuator has a compact twin-piston design [5] that is shown in Figure 5.

Twin-piston principle allows backlash-free and rigid dynamic characteristics. Pistons 1 have the flexible end-position cushioning 2. The design has a contact-less end-position sensing 2 and a precision end-position adjustment unit 3. A body 4 has an adaptable tubing through-feed.

Compressed air supply 5 is placed at the end cap. A drive pinion variants has an output flanged shaft 6 for connection to the external robot platform. Variable mounting options can be done direct via centering sleeves 7.

Rotation moment characteristics for different diameters of twin-piston cylinders are given in Figure 6.
Necessary diameter can be chosen according to on-board technological equipment.

The robot without technological equipment demand minimum rotation moment due to the symmetrical design about the center of rotation.

**CONTROL SYSTEM OF THE ROBOT**

Control system of the robot is presented in Figure 7. It consists of an on-board computer that is connected to a central computer and by means of an interface to a translation cylinders valve VT, rotary actuator valves VR1 and VR2, a lifting cylinder valve of the translation pedipulators VLT, a lifting cylinder valve of the rotary pedipulators VLR, a vacuum valve of translation grippers VVT, and a vacuum valve of rotary grippers VVR. All translation pressure valves are 5/3-way type valves that have a closed neutral position and two flow positions. It allows positioning of the pneumatic cylinders at any point inside their working stroke.
The valve VT controls two translation cylinders CT1 and CT2 at the same time. Lifting cylinder valves of the translation and rotary pedipulators control corresponding cylinders LT and LR.

There are two independent vacuum lines in a supply system of the robot. The first line controls vacuum in the grippers of the translation part of the robot. The second line serves for the grippers of the rotary part. It allows acting any combination of the grippers simultaneously according to motion algorithm. Each gripper has an autonomous vacuum ejector. Vacuum valves VVT and VVR of the translation and rotary grippers GT and GR connect air pressure to the ejector inputs. Ejector vacuum line is jointed to the gripper internal volume. If valves VVT and VVR are closed, the gripper internal volumes are connected to atmosphere. All internal volumes are checked by means of vacuum sensors VST and VSR. The sensors give signal about actual state of vacuum inside all grippers to the on-board computer. The computer analyzes information from the grippers to be used at the next step and uses it for a decision reliability of robot fixation on the actual part of motion surface. If vacuum level is not high enough, the control algorithm changes position of the grippers to another place of the surface.

The view of the robot on a wall is shown in Figure 8. The photo illustrates opportunities of the robot on transportation of a payload, equal to its body weight, along a porous site of a surface with roughness and cracks. At movement on equal and dense sites of a surface the payload weight can be trebled.
SENSORY AND INTELLIGENT CONTROL

The possibility for remote sensory and intelligent control was investigated for different mechanical structures of climbing robot – WCR with on-board manipulator having two flexible arms, the length of arm is about two meters (Figure 9), and for rather simple prototype with one on-board manipulator (Figure 10).

Satisfaction of intelligent control is produced by using co-ordination between local and global control loops by means of feedback information from sensors.

Control system for mechatronic drives under consideration includes translation displacement and rotation angles sensors, accelerometers, and pressure sensor and transducer valve in feedback local loops. Main attention allocates on fuzzy approach to control system development. The problem of information real time processing by using special suggested algorithm based on fuzzy logic and Weight Associative Rule Processor (WARP) intended for mobile WCR is developed [24-26]. Some results are discussed concerning with intelligent control system development as well motion planning system in the unstructured environments with sudden moving and fixed obstacles. Experimental data illustrate results of evaluation such main parameters for high precision mechatronic drive as response time, vibration characteristics, error estimation and accuracy improvement of WCR drive motion by means of a fuzzy controller.

Necessity of Autonomous Wall Climbing Robot (AWCR) development can dictate by expediency of some applications in extreme environments, such as inspection, underwater WCR for shallow water, or fire-fighting WCR [15-21, 25-26].
Structure of AWCR remote control system includes mechatronic drives, sensors and transducers, intelligent interface and fuzzy software.

Another problem concerns with reliability improvement of robot in particular if surface quality can change very fast on the robot way (different size cracks, variable roughness, cavities), but feedback vacuum valve productive capacity is insufficient or reaction system delay is too much. The intelligent system could help to solve this problem using modern identification algorithms.

CONCLUSION

The examples were illustrated an artificial intelligent and decision making applications for climbing robots for construction. The describes the autonomous wall climbing robot which is heavier comparing to vehicle intended for the motion over horizontal surfaces with obstacles not predicted in advance. The important problem to be solved is on-board light-weight electrical and pneumatic supply units. Reliable WCR motion for transition from one surface to another is also a significant problem solved by means of intelligent robot behavior. Sensory fusion fuzzy control system could be applied for implementation of decision making algorithms that are needed for motion in unstructured environments such as surface roughness, random obstacles, edges or margins of the walls, ceilings, and roofs.
REFERENCES