Application of climbing robot RoSy II in the business of building conservation

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This paper intends to give a short overview about existing climbing robot systems and projects, the techniques of climbing robots and especially a description of the robots RoSy I and RoSy II. Furthermore it shows some aspects and arguments for the use of climbing robots and what climbing robots are able to do on construction sites regarding building conservation and maintenance today and tomorrow. RoSy II as an access equipment and a carrier for the none-destructive testing in civil engineering and for the building conservation. Finally, it will be stated what RoSy can already do today and tomorrow for the building industry.

1 Introduction

One of the fascinating new technologies in the field of robotics are the walking and climbing machines. Though, most of the realised vehicles are still walking and climbing in the labs of research institutes and are subject of investigation, some of them arises already on construction sites: the climbing robots. This kind of mobile systems have left the kindergarten and they are just going to learn different jobs to facilitate and improve the daily work on construction site.

The climbing and walking robots - also called CLAWAR-machines - are going to becomes an important member within the service robot community. However there is a lot to do regarding the commercialisation of service robots, that they come into the market, will be accepted and get an sincerely market penetration. CLAWAR is the abbreviation of Climbing and walking robots and additionally the acronym of a shortly established European thematic network [1]. The CLAWAR-network brings together the core research groups, industrial users and robot manufacturers who are engaged in work on climbing and walking robots and associated support technologies. The general aim of the network is to co-ordinate the future research and development activity. More specially the most important aims of the CLAWAR network are to establish and update regularly the state-of-the-art and disseminate this information, to pool information on user requirements in a variety of application areas, to identify synergies and overlaps between parties concerned, to define the user requirements as functionality modules, to advice EC and partners on future CLAWAR research priorities and to provide opportunities for sharing expertise.

One of the many tasks will also be to define common specification and safety rules for that kind of machines. Robotersysteme Yberle GmbH is a member of the network and I invite and encourage you to tell me and my colleagues your requirements on CLAWAR machines and I ask you for contribution to the first international CLAWAR symposium in Brussels, Belgium in November 26-28, 1998.

„The construction industry has identified wall-climbing robots as a priority, especially for inspection and refurbishment operations ..." wrote Robert Wing 1997 [2]. So it is not surprising to me, that climbing robots are one of the first CLAWAR machines that have left already the labs of European research institutes. Two companies already - Portech, UK and Robotersysteme Yberle, DE - try to commercialise them. Well known are also the Japanese devices which already do their jobs on high rising buildings [3, 4].

In deed, climbing robots fulfil the customer requirements and what is expected from construction automation as such as reduced costs, increased quality, better and safer work conditions for the human workers and also improved pollution control. Cost reduction by use of climbing robots is essential and not only because you save money on scaffolding. There is no doubt about that automated processing delivers a steady good quality. Climbing robots keep away the human worker from dangerous work places in great heights and aggressive environments.

I am sure I do not tell you of the construction automation community up to now something new. But, I will also address to some new participants of the „International Symposium of Automation and Robotics in Construction“ ISARC and most of all to the visitors of the BAUMA ´98. They are the users of our robots. They are our customers . So I will continue with some basically information about climbing robots.

2 Climbing robots

2.1 What is a climbing robot/ a climbing machine?

What are climbing machines or climbing robots? How do they work? And who on earth is „RoSy“? Is it a climbing assistance for overweight mountaineers or is it just the drivel of an individual, like the umpteenth patent for an „egg-beheading-machine“? This article will show you, that it surely does make sense to use climbing robots on construction sites and in the business of building conservation.

2.2 Motivation for the climbing technique

Imagine a high building, e.g. a silo has to be repainted. What has to be done for that? Your first thoughts will probably be, that you have to lease a scaffold, erect it, inspect its stability, there are safety precautions to take, look for the gas mask and so on and so on, until at last the painter can start using his paintbrush. There is a lot to consider until the actual task „Applying paint onto the surface“ can be fulfilled. What is really important is that the spray gun comes up and carries out its work. Feet should grow out of the spray gun so that it could climb up and apply the paint - we therefore do need a climbing robot! There is no universal definition of a climbing robot yet. My definition is the following: A climbing robot/ climbing machine is a device that can move independently on any inclined wall and carry out various jobs in that position. There is no need for external resources, like a hydraulic lift or rails, for the locomotion. The wall or surface can be made of different materials. Corresponding to the human mountaineer or free-climber the robot can climb with or without a safety rope.

2.3 How does a climbing robot work?

How can a machine climb up a wall? How do I climb up a wall? I have to hold on to wall, pull myself up with my arms and push myself up with my legs. Similarly, our closest relatives in nature follow this procedure; some of them even have a special trained climbing-tail. In nature, there are also completely different tricks being used to overcome the force of gravity. It is nothing more in the first moment. Whoever wants to go up the wall has to ensure that he would not fall down. There are animals that attach themselves with thousands of hairs to the surface like the gecko. Others secrete some sort of fluid and stick downright to the wall or use some kind of a sucker to hold on.

Climbing robots do nothing else. They use suction pumps and suckers to generate the required holding force, the suction for the robot. Therefore, the air is sucked out of the hollow between sucker and surface. A reduced airpressure, a partial vacuum is created, so that the outside normal air pressure pushes the sucker toward the wall.

2.3.1 Overcome the gravity

In the same different way as animals in the nature overcome the gravity it is possible to create the holding force for climbing robots, however, up to now an animal with magnetic foothold is not known (Table 1). On the other hand, in the robotics field there is still no climber designed or published, that uses sticky feet. For the construction site the climbing robots with vacuum suckers are the best choice for mainly two reasons:

- The normally used flexible materials of the suckers avoid damages of the structures surfaces.
- The vacuum feet can be used for a great variety of materials like concrete, brickwork, glass and also metals.

It must be considered that different materials and surface texture requires different elastic material and shapes for the design of the suction cups. The porosity of the surface material influences quality and performance of the vacuum generation devices.

Well, how do you suck the air out of the suckers? There are vacuum pumps and suction pumps, some are more or less an inverse air pump like the one you need for bicycles and other techniques. Another technical solution are so-called „ejectors". In these ejectors, compressed air - e.g. deriving from a compressor for a pneumatic pick, is blown through a chamber. Because of that, air particles are accelerated to a high speed that also sweeps away the air particles inside the sucker. The required vacuum to hold on is created.

Now we have got the force that presses the climbing robot to the wall. It still would fall down, though, if another basic physical principle, namely the friction, did not react to hold the robot in place. The sucker has to lay tight on the surface to create enough friction and with it the real holding force. The friction is dependent on the material of the sucker and surface. Then, this also leads to the surprising effect that, assuming an equal vacuum, the holding forces are higher on a rough concrete wall than on a smooth glass surface.

Table 1: Classification of (existing) climbing robots

Locomotion / kinematics — holding force	walking articulated limbs	continuous crawler, wheels	stepwise sliding frames	stepwise shape changing
magnetic	X	X	X	0
gripper / clamp	X	0	0	0
suction /vacuum	X	X	X	X
glue / stick	0	0	0	0

2.3.2 Locomotion of climbing robots

When the problem of how to retain the robot on the wall is solved, it has now to be set in motion. Arms and legs are required so the robot can push itself up. The second distinguishing mark of climbing robots is there method of locomotion and the kind of kinematics they use (Table 1). Therefore, research on tracked vehicles with suckers has been performed at the Fachhochschule in Aalen [5]. Researchers at the University of Hannover have done investigations with sliding frames [6, 7]. The most complex kinematics comprises of multi-limbed climbers with articulated legs. They are looking like crabs or spiders. With great efforts in research projects scientists all over the world are on the way to transfer the behaviour, the gait of animals to achieve floor-to-wall and wall-to-roof transfers of their robots [8]. This robots have the advantage that each leg can be separately attached to the surface and is so capable to equalise uneven surface and to clamber over obstacles. This is much more difficult for vehicles with tracks and not so easy for movable sliding frames. It depends on the user requirements and the structure of a building which kinematics will be the best solution. The easy kinematics of sliding frames and the special shape-changing design of RoSy are sufficient for a lot of large and even surfaces of buildings such as facades, bridges and dams. Additionally an easier kinematics requests easier control techniques and is easier to understand and to handle for the customer and service personnel.

3 Climbing robot RoSy

3.1 Who is RoSy?

RoSy is the name of our climbing robot concept [9]. The relation to the company name „Roboter Systeme Yberle“ is absolutely wanted, but the concept and RoSy I were borne before the company was founded in 1996. In this case you get a definitely answer to the old question „was the egg or the hen at first?“: The egg was the first. The project RoSy begun 1993. RoSy I is our prototype with whom we proved the feasibility of the climbing technique and could convince at first our venture capitalist. We developed RoSy II in the last two years, based on the experiences of RoSy I, as a carrier system for the non-destructive testing in civil engineering. RoSy II climbs since the mid of 1997 in our laboratory on a vertical chipboard wall. Until the end of spring 1998, the field test series on bridges will be completed. Then RoSy II is ready for professional application; for specification data see Table 2. The climbing robots RoSy I and RoSy II are reality. RoSy accomplishes its work as a carrier system, that can climb on vertical to horizontal surfaces made of different materials. Equipped with any tools RoSy is suitable for a wide variety of tasks. RoSy holds on to the wall with vacuum suction cups and moves on the surface to any direction with an easy patented kinematics. Manually controlled RoSy climbs to its operational area. Here RoSy is able to scan given regions automatically, e. g. in meander form. RoSy can move automatically and in a manual mode stepwise under the control of the operator. Some sensors and software algorithm monitor continuously the equipment and take care to hold the climber on the surface.

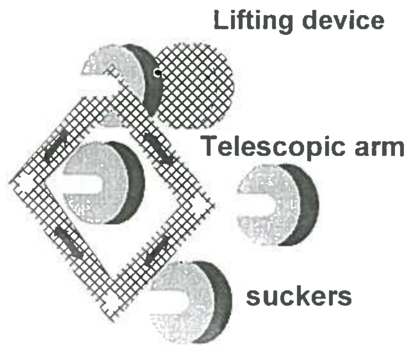


Figure 1: Assembly groups of RoSy

For safety reasons each robot foot has its own vacuum sensor. Safe vacuum and surface conditions provided only one foot of the robot will be lifted from the surface and searches for a new safe position.

Table 2: Basic specification of RoSy I and II

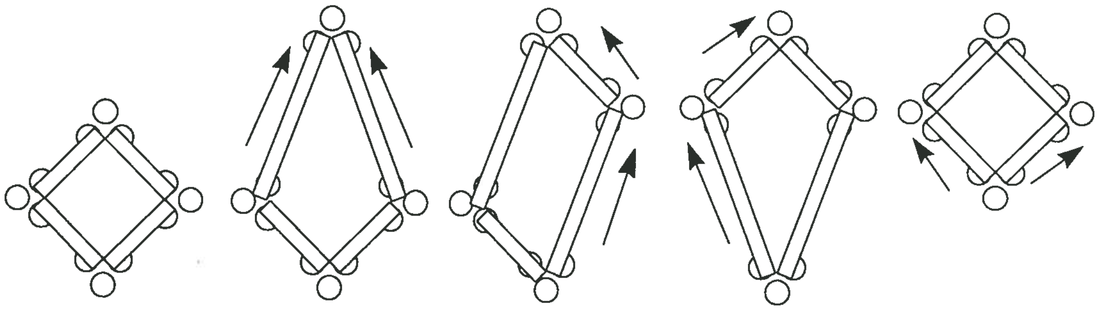
Item	RoSy I	RoSy II
Length	500 mm	1200 mm
Width	500 mm	960 mm
Height	170 mm	410 - 580 mm
Weight	25 kg	80 kg
Stride	33 mm	1 to 300 mm
Rotation	± 360°	± 360°
Step over height	5 mm	25 mm, 100 mm under test
Speed max *	500 mm / min	1000 mm /min
Foot holding force **	290 N	660 N
Payload	25 kg	25 kg
Air consumption *	180 - 1200 lpm	180 - 1200 lpm
Umbilical cord	40 m	50 m
Operating surface	Concrete and better surfaces	Concrete and better surfaces
Maneuverability	up, down, left, right, turn	up, down, left, right, turn
Drives	pneumatic cylinder	servo controlled DC motors

3.1.1 Concept and components of RoSy

The idea of RoSy was to design a simple kinematics that can move over a large surfaces. The robot has four legs comprising of the suckers and the lifting device. Each leg has three suckers that are jointly lifted and lowered through a lifting device. The four legs are linked to a rectangle through telescopic arms. The latter can change their length and so perform the movement of the robot. All eight axes of RoSy I are pneumatically driven controlled from an external control unit and operated from a personal computer. The movement is simply done by extending and retracting the cylinders. This is a sufficient method for very even surfaces. RoSy II uses servo-controlled electrical cylinders in all axes. Therefor she is more flexible to react on rough surfaces. Each leg of RoSy II has its own controller and two additional controller for the workpackages and sensors and one for administrative functions. The controllers are linked via CAN-Bus. The movement and monitoring of the gait is autonomiously done by the on-board controllers. From the operating station on the floor only the command are transfered via an serial link to the robot.

3.1.2 Gait of RoSy

The locomotion of RoSy shall now be described in a more detailed way.If the robot gets the command „make one step forward", the following is taken place: The vacuum at the foremost leg is turned off and the leg is lifted. If the vacuum were not turned off, the leg would have to be torn off against the strong pressing forces. After the leg was lifted, it is pushed ahead by two arms. The lifting device is pushing the suckers to the wall and the leg tries to stick to the wall again. Only after there is enough vacuum created and thereby enough *holding force* existing, the control of the robot is detaching the right leg, dragging it behind with the foremost arm and at the same time pushing it ahead with the rearmost arm. After the „touch down“ of the leg the game is starting over again with the left leg. Finally, the robot is dragging the last leg behind with the two lower arms (Figure 2).



a) Startposition b) Leg 1 forward c) Leg 2 forward d) Leg 4 forward e) Leg 3 forward next Startposition

Figure 2: Gait control of RoSy

The climbing robot is acting like a climber: There are always three legs fixed to the ground and the fourth leg is looking for a new hold further up. The advantage of the described kinematics - defined as the arrangement of several driving axes to a robot - is that it can immediately move from the standing position in any direction.

3.2 What can RoSy accomplish today?

RoSy II is prepared for the adaptation of various measurement systems. Together with inspection companies or institutes we as a service company will offer visual inspections, radar measurement, ultrasonic testing, impact-echo inspection and similar things at first. We are planning the adaptation of all common and new inspection techniques in the construction industry. Beneath them are inspection techniques which are only applicable because of the comprehensive testing capacity of the climbing robots. The first identified application areas for RoSy are large and tall structures such as bridges, dams and silos made of concrete. The advantages of RoSy are bipartite. First for present conventional works RoSy can ...

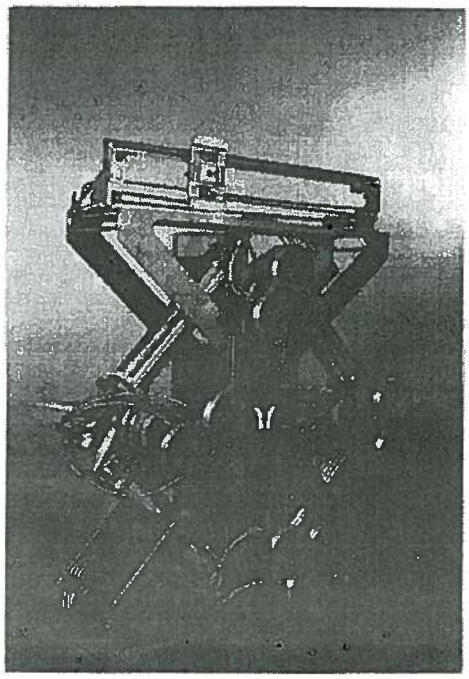


Figure 3: RoSy II

- ❑ keep away the worker from dangerous environment
- ❑ decrease the costs for scaffolding or access techniques
- ❑ execute automatically or remotely sequences of operations

Second RoSy enables absolute new solutions by technical developments and cost reductions e.g. examinations of buildings:

- ❑ Inspection of whole surfaces will be enabled
- ❑ Quality of the inspection rises by whole surface testing
- ❑ New sensors for inspection techniques could be used
- ❑ Intensive and repeated inspections save costs for reconstruction by an early detection of damages
- ❑ The inspection process, i.e. collecting the measuring data, can be done by a skilled worker. The analysis and valuation of the data makes the expert in his office.
- ❑ The qualified test engineer must be appropriate only in exceptions
- ❑ The mechanical inspection allows an automatic documentation and storing of the measuring results

4 Aspects of climbing robots regarding building conservation

4.1 What is a climbing robot supposed to do?

Like the name already indicates, a climbing robot shall climb. It shall move upwards on various surfaces and performs different jobs. The surfaces could be facades or slabs made of metal, brickwork, plaster, concrete, glass, wood, or other materials. On principle, all kinds of jobs which are necessary on the surface of a building, on a wall and, in the near future, on a ceiling are possible fields for using the robots (Table 3).

Table 3: Application of climbing robots

Application	Examples
Material testing	– quality inspection, testing – regular building tests (e.g. bridges) – assessment, tests before renovation, redevelopment, purchase, sale – visual surface inspection (video camera) – layer thickness testing – moisture testing – permeability test (porosity) – reinforcement in concrete structures: rebar detection, coverage – new none-destructive testing methods
Removal of layers	– cleaning – de-rusting – removing of varnish – decontaminate
Applying of layers	– protective coating – insulating layer – advertising
Repair and Mounting	– joint repairing – fissure pointing – doweling – preparing the safeguarding of scaffolds – anchoring

Why should climbing robots be used? What means building conservation? Building conservation is not only the renovation of venerable, historical buildings that shall be rescued shortly before the collapse. Building conservation is a continuous process of observation, maintenance and servicing of a building of any kind right from the beginning. Ideally, it starts immediately with the completion of works and together with the acceptance test a first analysis of the actual condition is made. To check the dimensional accuracy and obvious defects thereby is the easier practice. It becomes difficult to detect invisible defects - defects that are hidden in the material underneath the surfacc. Climbing robots are going to accompany all life cycles of a building from planning to construction, acceptance, service, maintenance, redevelopment and if need be demolition. There is work for climbing robots in all phases of a buildings life:

- accompanying quality control
- acceptance test
- decision on redevelopment/renovation
- planning of redevelopment/renovation
- carrying out repair and mounting works
- regular inspections and tests
- regular cleaning and servicing
- demolition

Building conservation concerns all of us. Every year more money is spent on redevelopment compared to the construction of new buildings (some 60-80 billion DM in Germany only)! It is a prejudice that demolition is cheaper than the construction of a new building. Even if this statement is not true yet, we are all challenged to make it come true.

4.2 Get actual building condition

For the planning of redevelopment or renovation processes it is absolutely necessary to have a comprehensive knowledge of a building. Only a complete testing delivers secured information to decide whether to refurbish, redevelop or to demolish. The present manual testing of large structures is mostly limited to random samples or requires an great expenditure of equipment. A visual inspection from below usually is not enough and a comprehensive testing already requires scaffolding. The climbing technique enables a thorough testing of large structures made of concrete, steel and other materials. An analysis of the building condition is possible without a costly scaffolding. The combination of conventional and new non-destructive testing methods with climbing robots is yielding a simplified execution and documentation of the results, as they are recorded automatically. The testing procedure can be managed without greater preparations easing the decision for a testing procedure.

4.3 Planning of redevelopment/renovation

Sample inspections for the tendering and offering procedures are often responsible for a multiple rising redevelopment budget while works are still in progress. With the climbing technique and a comprehensive testing this will not be a problem any longer. The planning and therefore the cost security for redevelopment is greatly increased. The redevelopment budget can be precisely planned: The owner can decide on the time of redevelopment and earmark the required financial resources. The result is minimised uncalculated costs.

4.4 Carrying out repair and mounting works

If you have a look at a building site nowadays and you see the workers in protective clothing and a gas mask it becomes obvious again that there are many jobs where a considerable amount of increased danger of health is inherent. It does not have to be the handling of toxic and aggressive materials, the dust or paint mist is sufficient to affect the health of a man. Hence, to ease that work for a man and to avoid the health risk is a further argument for using climbing robots. For works with extremely dangerous tools, like high pressure water spray guns the use of machines is already compulsory.

4.5 Work accompanying quality control

Not only since ISO 9000 was introduced, quality assurance is a well-known term in the German construction industry. But the recording and documentation of quantitative criteria is much easier with an automated processing and measuring technique. For example, while applying and removing surface layers, the layer thickness can be monitored. Wastes are reduced and the layer thickness is optimised. The workflow can be optimised and corrected while in progress.

4.6 Quality inspection

Many defects of buildings remain unnoticed, leading to building damage after the period of warranty and to an irritation of the owners. In the final inspection, a comprehensive and full-scale inspection of the performed works also saves costs. If the defects are discovered in time, even before the building site is cleared, then the remedy is much cheaper, as for example, all building machines are still at the site. The construction company and the owner have their advantage in form of saving marks and pennies.

4.7 Regular cleaning and servicing

Regular cleaning enables gentle procedures without chemical additives. The environment is treated with care. Furthermore, regular maintenance of facades does not only improve their appearance but also increase their service life. With climbing robots cleaning and servicing cycles can be reduced. The repair of smaller damages in time can postpone large redevelopment measures for several years. Today, such measures are remain undone due to the high effort for preparing the building site is deterring. These maintenance works might be the biggest opportunity for climbing robots besides the building inspection.

4.8 Automation

Although the term „Automation in the construction industry“ is on everyone’s lips today, the technology is still lagging behind the high demands. Moreover, the builders and those really concerned, the owners, who finally have to pay for every piece of work, have to make friends with the possibilities of automation. It is proved daily in industry that automation is an essential factor to cut down costs. The construction industry and the building owners still have to understand this opportunity - and to grasp it. As a matter of fact, the advantages of automation are well-known. Just the constant performance lasting for hours, which you can not demand from a human being, cuts down costs with the same quality of work achieved. Working on a building or facade comprises hard work which should rather be done by machines.

4.9 Safety for the human worker

The safety of the human worker has the highest priority regarding the list of arguments for a usage of climbing robots on large and high buildings. The expenditure for safety technology for the robot is essentially lower than for a human worker. They can be insured and are easier to be repaired - in contrast to a human worker. Additionally: If a worker does not have to climb the high scaffold he can not fall down, too.

4.10 Building conservation is active environmental protection

Do not forget the environmental aspect of the climbing technology. If you reduce nature and environmental protection to a simple denominator, to spare raw material supplies and not to pollute or to spoil our countryside excessively with our human creations, then building conservation is an active contribution to the conversation of nature. We save building material - our resources - if we preserve an old building and at the same time relieve our refuse dumps of builder's rubbish. Nowadays, builder's rubbish is the biggest part of wastes in Germany. Climbing robots offer the opportunity to make building maintenance affordable and with it make a valuable contribution to the conservation of nature.

5 The future

Several of the aforementioned possibilities of the climbing robots are lying in the future, even if its the nearer future. In the nearer future, we will adapt suitable work-packages for totally different applications, together with partners, for the discussed possibilities in the construction industry. First, these tools will be inspection and measurement devices and smaller tools. The development will continue until our goal for the next millennium is accomplished: The household-„RoSy", the climbing robot rented from the building market which can be used for such tasks as wallpaper removal, to knock slots in the a house or to paint the facade of a house while sitting comfortable in a deck-chair and guiding „RoSy" on the wall with a joystick.

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