

# Climbing Robots for Commercial Applications – a Survey

**K. Berns, C. Hillenbrand, T. Luksch**

University of Kaiserslautern, 67653 Kaiserslautern, Germany

Email: berns@informatik.uni-kl.de

## SYNOPSIS

In this paper a short survey on the research of climbing machine is given with a strong focus on industrial applications. Based on a classification of different types of climbing machines examples of robots are presented, which are prototypically developed for industrial and commercial use. Considering the application environment the system requirements of climbing machines will be presented. At the end of the paper a climbing machine used for the inspection of concrete bridges is presented as an example with a huge commercial potential.

## 1. INTRODUCTION AND OVERVIEW

Since the end of the 80ties climbing robots are examined for different types of application scenarios all over the world. E.g at the end of the 80ties and the begin of the 90ties in Japan several national projects concerning climbing robots for specific application scenarios have been developed. These include cleaning robots for glass walls, ship hull cleaning robots, rescue robots for fire brigades, inspection robots for steel tanks and wall. Most of the developments were stopped because there still exists adhesion problems. Also the cost for the development of such machines were to high. At the end of the 90ties mainly in Europe several different prototype machine have been developed for different types of applications like the inspection of pipes and ducts in the petrochemical industry, maintenance and inspection work in the construction and nuclear industry or cleaning robots for huge class walls.

In the following first a classification for climbing robots is given. Based on the classification some prototype machines for special applications are introduced. At the end of the paper our Climbing robots for the inspection of huge concrete walls is presented.

## 2. CLASSIFICATION OF CLIMBING ROBOTS BASED ON ITS LOCOMOTION ABILITY

In literature one can find different types of climbing machines which are developed in the last year. For this paper climbing machines are defined as robots able to move on vertical surfaces of upside down. Based on this definition a very flexible walking machine, which can walk on very rough and steep terrain should not belong to the class of climbing robots. In the following climbing robots will be distinguished into 3 classes based on their locomotion ability:

- (1) wheeled-driven or chain-driven machines,
- (2) legged locomotion,
- (3) locomotion based on arms and grippers.

Type (1) is mainly adequate for even terrain like glass walls, concrete or brick wall, steel walls while type (2) and (3) can be used for real complex surfaces. Concerning the 3<sup>rd</sup> type one can find a few machines built for applications because the control of locomotion is very complex.

The adhesion in class one and two is done in 3 different ways:

- (1) pressing to the inner wall of the construction
- (2) using magnetic adhesions
- (3) using under pressure
- (4) grasping

Additional to that molecular force can be used for adhesion (Gecko principle). Up to now this kind of adhesion can only be found in micro or nano machines. Therefore this kind of adhesion is at the moment not interesting for inspection robots. Fig. 1 shows 3 examples of climbers belonging to different locomotion and adhesion classes.



**Fig. 1 Examples of the 3 types of climbing robots – from left to right Max V[1] a chain-driven climber with vacuum chambers of the University Aalen, Germany, Rest [2] six-legged welding robot with magnetic feet (CSIC Madrid, Spain), and Roma [3] a grasping robot for steel bridge inspection (University of Madrid, Spain)**

## 3. APPLICATIONS OF CLIMBING ROBOTS

In the following a table some climbing machines are classified according to the above mentioned classes.

A complete list of machines and references to literature can be ordered by the authors.

Application	Robot	Developer	Class of climbing robot	Adhesion principle
Pipe inspection in chemical systems		Inspector Systems, Germany	1	1
Ship cleaning/inspection	Octopus	Cybernetics, France	1	2
Welding robot	Rest	CSIC, Spain	2	2
Airplane cleaning and inspection		British Aerospace	1	3
Oil tank inspection		IQS, Portugal	1	3
Nuclear plant inspection	Nero	Uni. Portsmouth, UK		
Steel bridge inspection	Roma	Uni. Madrid, Spain	3	1
Cleaning and Inspection of glass wall	Cleanbot	University of Solothurn, Switzerland	3	3

## 4. CLIMBING ROBOT FOR BRIDGE INSPECTION

A very interesting application area is the inspection of concrete bridges like those of motorways which are up to 200m high. By law regular inspections of the pier and the underside of bridges must be performed. At the moment visual inspections by humans are done with the help of special lift systems.

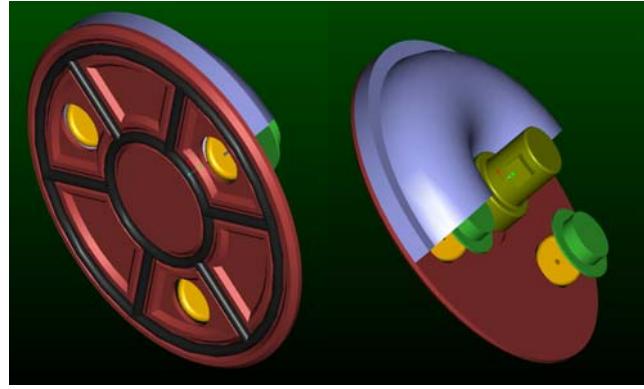
The use of a climbing robot for this application is useful because of the following reasons:

- to reduce costs of the inspection,
- to improve the objectivity and reproducibility of results of the inspection,
- to be able to use different types of inspection sensors due to the surface conditions,
- to decrease the total inspection time,
- to reduce the risk for human inspectors and improve their working conditions.

In our lab a climbing robot for the bridge inspection is under developments able to move horizontal, vertical and over side at low bended surfaces (radius 5 m) [4]. With the machine it should be possible to overcome steps up to high of 2cm and width of 2 cm. It should carry a maximum load of 10kg and reach a speed of 10 m/min. A robot equipped with inspection sensors [5] should be fixed on the robot to allow scans of the surface or to perform manipulation tasks.

### 4.1 The concept for a climbing robot

The robot type which is build belongs to class 1 and use the adhesion principle 3. This concept was selected because a fast continuous motions should be achieved and the mechanical construction (which influences strongly the price of the machine) should be as simple as possible. As result a vehicles was designed which consist of 7 vacuum chambers (Fig. 2). The chambers are moving over the concrete without losing contact. The choice of a large area of about  $0,64 \text{ m}^2$ , where the vacuum has an effect, needs a small vacuum of about 50 mbar to hold the robot at the surface. Theoretically the possible adhesion is about 3000 N. An electrical blower is evacuating the air out of each chamber controlled pressure sensors and by fast valves. The aim of this concept is that the system can react on leakage on different parts of the seal, without losing the complete adhesion.



**Fig. 2 The concept of a 7 chamber system with three omni-directional driven wheels**

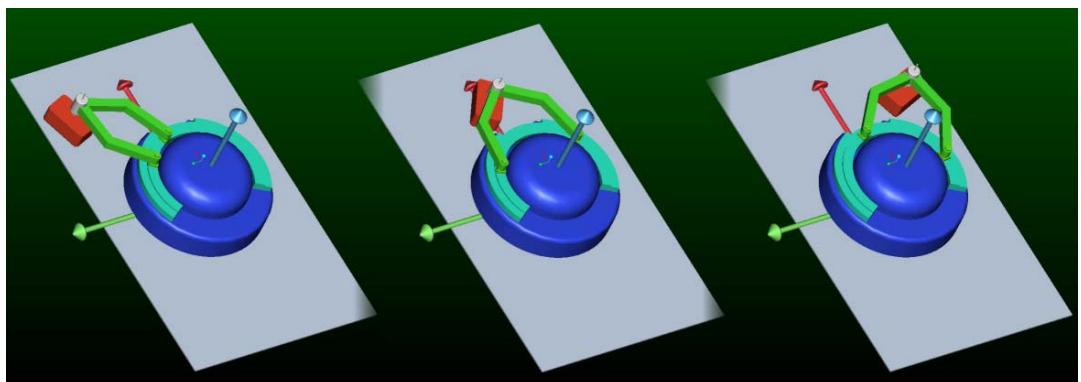
To hold the vehicle on the surface, the frictions of the driven wheels are responsible and any passive wheels can't be used for it. Also undesirable is the fiction of the seal, which slows down the motion. The concept comprise that the robot has only omni-directional driven wheel no passive ones and exactly three of them. By using two driven wheels small rotations around the axes of the driven wheels cause forces to the seal, which leads to high friction forces. If the robot is using four or more wheels the vehicle needs a spring/dumper mechanism to guarantee the contact of each wheel to the surface. But this would cause the same problem described above. The only solution, when using four-wheel is an active compliance control mechanism. To avoid this high construction effort a locomotion system with 3 omni-directional wheels was constructed.

The most critical item for building the robot is the seal. The seal system must be designed in a way that in operation low-pressure force and low friction with the concrete exist. Additional to that the seal must be able to adapt bended surfaces and overcome steps of 2cm height. At the same time the seal must be robust enough to tolerate the air pressure difference without absorbing to the vacuum. This can only be achieved by a special assembly.

At the moment a close-loop control system is under development which is able to find a stable state. Therefore one must consider that one on hand side the vacuum is not to high so that the seals is not pushing to hard to the surface and the robot can not move. On the other hand side the robot should not lose the adhesion in a way the it fall or slip down.

#### 4.2 Manipulator system for the Inspection

For inspection tasks the locomotion system is not exact enough to fulfil precise scanning of small areas. Therefore a manipulator is necessary. Because of the adhesion problem the manipulator must be designed in a way that its center of gravity is closed to the surface and that the manipulator arm is closed to the center of the vehicle to avoid undesirable torques

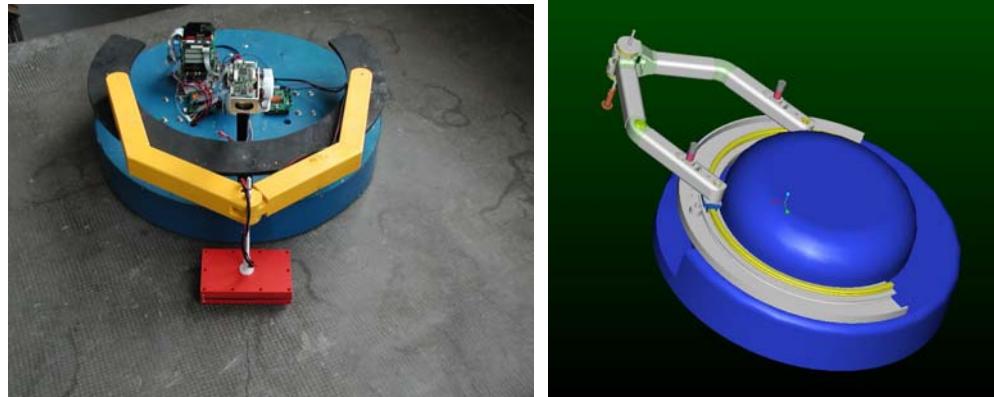


**Fig. 3 The motions of the manipulator with four degrees of freedom**

As a solution a construction was designed with 4 DOF (two coupled arms which are move on a round guide, a rotation and a up/down unit for the inspection payload) (Figure 3). For this arm 3 sensors systems are adapted which can be directly mounted on the robot arm (covermeter, radar and impact echo).

In parallel to the development of the climbing machine a platform with the same dimension is build to test all subsystems like the manipulator, the inspection system, the overview camera and the navigation system. The system integration (hardware, sensor system, software) is done in a way that it can be directly integrated into the new climbing machine. All behaviours which are necessary to navigate the climbing machine on the concrete wall, to perform inspection task and to record the results are successfully tested.

At the moment the final climber with all subsystems will be assembled.



**Fig. 4 Left the integration on a floor vehicle – Right the concept of the final robot**

The technical data of the climbing robot is listed in the table below.

Dimension		Capacity		Mobility		Energy supply	
Diameter	0,8m	Max. Speed	10m/min	Wheels	3	Energy supply	External
Height	0,3m	Weight	15kg	Active degrees	6	Power supply	220 V
Workspace of the manipulator	0,3 m around the vehicle	Load	10kg	Passive degrees	0	Power consumption Including vacuum pump	1400Watt

## CONCLUSION

In the paper a classification of climbing machines is presented which considers the type of locomotion as well as the adhesion principle. Based on the requirements of an application several prototype machines exist which show the huge application potential of these kind of machines. The inspection of the big concrete walls which is frequently necessary by law for stacks, bridges or dams etc. is the application area for our climbing robot. The climbing principle and the inspection subsystem was successfully tested. Field test of the robot on a pillar of a bridge will be performed in the next mouth.

## REFERENCES

- [1] <http://141.18.3.35/roboterlabor/kletterroboter.html>
- [2] A. Gimenez, M. Abderrahim, C. Balaguer – „Lessons from the Roma I inspection robot development experience“, Proceedings of the 5th International Conference on Climbing and Walking Robots, pp. 913-920, Karlsruhe, Germany 2001
- [3] J.C. Grieco and M. Prieto and M. Armada and P. Gonzales de Santos, A Six-Legged Climbing Robot for High Payloads, Proceeding of the 1998 IEEE International Conference on Control Applications, 1998
- [4] K. Berns, C. Hillenbrand – “A Climbing Robot for Inspection Tasks in Civil Engineering” – FZI Research Center for Information Technologies at the University of Karlsruhe – 1<sup>st</sup> International Workshop on Advances in Serves Robotics (ASCER) 2003 – Bardolino, Italy
- [5] F. Weise, J. Köhnen, H. Wiggenhauser, C. Hillenbrand, K. Berns – „Non Destructive Sensors for Inspection of Concrete Structures with a Climbing Robot“ – BAM Federal Institute for Materials Research and Testing, Devision IV.4, Berlin, Germany and FZI Research Center for Information Technologies at the University of Karlsruhe, Germany – Clawar 2001 – Karlsruhe, Germany