# AUTOMATED CLEANING OF WINDOWS ON STANDARD FACADES

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**Abstract:** The aim is a cleaning robot which automatically cleans the outside of windows on a facade with vertical jambs and horizontal bars. The facade has to possess certain constructive properties. This "interface" enables the cleaning robot - which is detachable from the building and portable - to operate on any respectively designed facade on several buildings. A special cleaning-head keeps the water used for cleaning in a constant cycle. It is wielded through a filter and reused. The cleaning robot in operation is quicker, safer and cheaper than manual cleaning. Its use is environment-friendly and considerate with regard to resources.

**Keywords:** automatically cleaning facades, modular standard facade, cleaning robot

## 1. INTRODUCTION

The architecture of modern buildings reflects increasingly complicated and extravagant forms and materials. Often, a building's geometry is so complex that it is impossible to reach every corner of it for cleaning, maintenance and repairs with common means [2].

In particular, the cleaning of large glass facades is a very important task, which has to be carried out regularly.

Large, expensive and extravagant buildings more and more require the development and realization of special devices in order to reach and clean them properly. In addition to that, a survey made by Fraunhofer IPA [4] in 1998 shows that the personal costs for cleaning the facades (windows) of building are up to 70%. To reduce these expenses by using an automated facade cleaning robot will open huge economy savings.

The standard facade cleaning robot is a low-cost [1] and tough alternative for facades with vertical jambs and horizontal bars that means with regular repeating geometric forms (fig. 1).

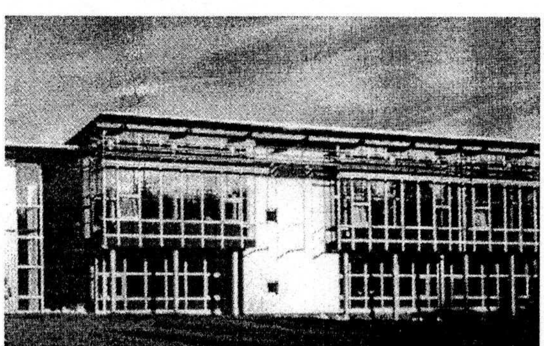


Figure 1. The front view of a facade with vertical jambs and horizontal bars

As the survey of the Fraunhofer IPA [2, 4] and market analyses have shown the most useful and economic relevant system would be a cleaning system for buildings with a height up to eight stories.

This development of a cleaning system for facades will confirm the change within the fields of research from the "regular" industrial use to the use in the fields of services with very high requirements to sensors and data processing [6, 3].

## 2. OTHER PRINCIPALS FOR CLEANING WINDOWS OF FACADES

Mainly there are three unique and to only one building bounded systems for an automated cleaning of the windows of facades [6]:

- The cleaning robot for the fair of Leipzig (Fraunhofer IFF, Germany)
- A prototype of Sirius$_c$ (IFF) shown at the HMI '99 in Hannover, Germany
- The cleaning robot for the Louvre in Paris, France (company: Comatec)

There are no automated systems which start from the ground and going up to clean the facades, without using any roof-bounded constructions and which are not fixed bounded to only one building. One of the most obviously advantages of such a system is, that there is no need for lifting the whole system on top of the roof of the buildings by man's help.

## 3. CONCEPTION AND DEVELOPMENT

At the beginning of concepting and developing the robot system, the general requirements, the guidelines and the customer requests and requirements are recorded. The determining of quality features and their importance takes place with the help of the QFD (Quality Function Deployment) method. One of the Houses of Quality (HoQ) is shown as an example in figure 2. The correlation of the quality features are to be determined and shown in this table.

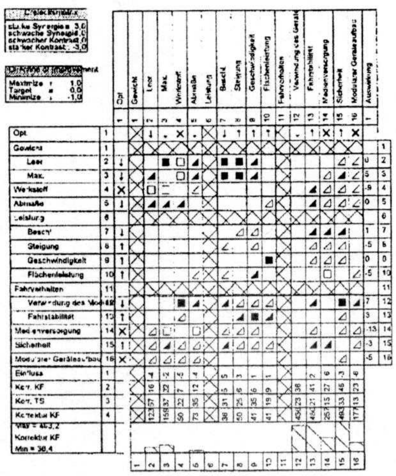


Figure 2. Sample table taken from the QFD method

As a result the table shows the sensitivity of the whole system, the critical components and the positive and negative correlation of the quality features. So in the ongoing research and development it is very easily possible to concentrate on these critical and sensitive components.

Afterwards, first ideas and various principles are developed and worked out (see some example sketches in fig. 3 to fig. 5).

The research and development was focused on a system for facades with regular repeating geometry and uncomplicated system of kinematics (fig. 3).

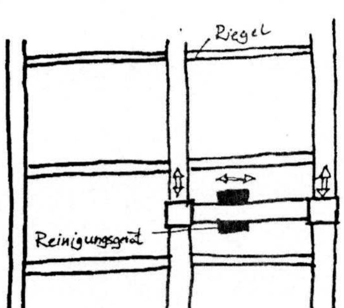



Figure 3. First ideas and drafts of the principles (I)

As the customer requirements asking for a system which is usable on several buildings and without the need to go on the roof of the buildings, the focus of the further project work is on the question how to connect and drive the robot to and on the facades (fig. 4).

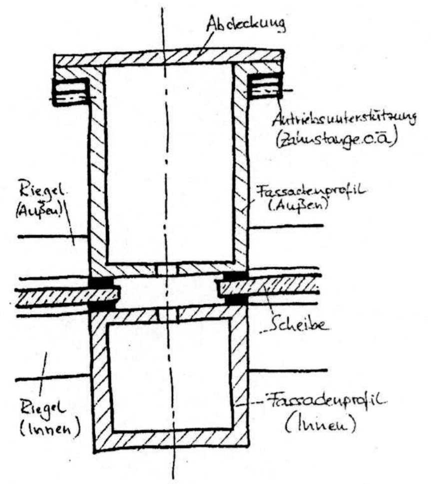



Figure 4. First ideas and drafts of the principles (II)

Not only the customer and technical requirements have to be met and fulfilled but also the needs of architects and the users of the building in future.

The derived requirements for the kinematics are: modular, easy to control, adjustable and robust. One idea is shown in figure 4.

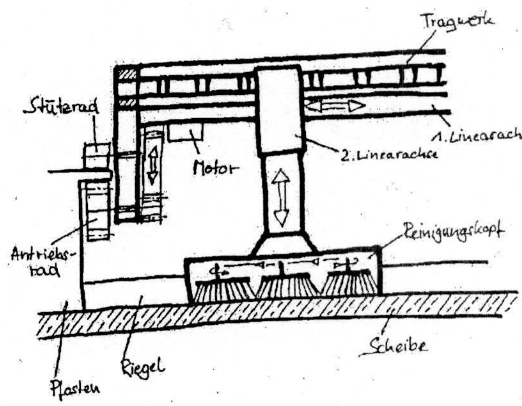



Figure 5. First ideas and drafts of the principles (III)

The various solutions for partial systems and complete systems are assessed according to what degree these solutions match the quality features which were determined beforehand. Then the choice is made. The chosen solution with the most advantages for the final users according to the requirements is now tested with a series of experiments in order to find out what its realization would like.

# 4. THE TECHNICAL IMPLEMENTATION

The first experimental set-up (fig. 6) of a prototype of the Standard Facade cleaning Robot (*SFR I*) serves the purpose of mechanical preexperiments and various cleaning experiments, as well as the exhibit at the IRW fair in Cologne, Germany.

Within this first prototype the kinematics are to be designed for cleaning one window with different cleaning methods (cleaning heads, end effectors) and different cleaning procedures (e.g.: linear, circular or randomized). The control and the supply unit (power and water) is designed as an external module (see behind the window of the facade element in figure 6).

The result of prototype SFR I is a knowledge of cleaning methods: data base, cleaning procedures: linear and first practices.

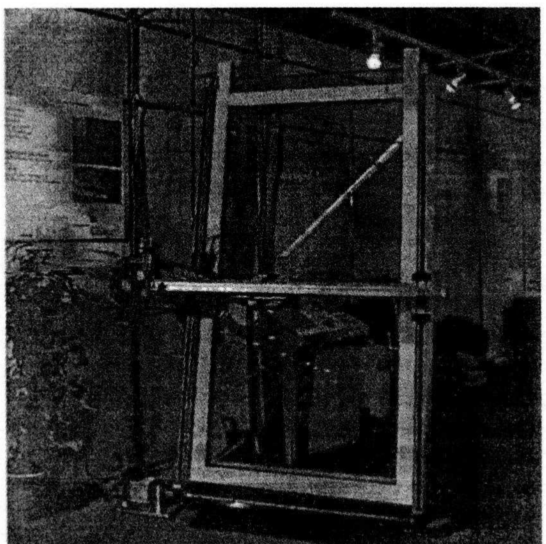


**Figure 6. The initial experimental set-up (*SFR I*)**

These results determine the further interpretation, the details and the design of the second robot (*SFR II*). A simulation is produced (fig. 7) first, in order to show and verify an entire cleaning cycle.

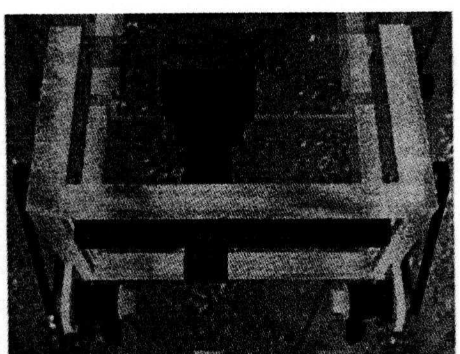


**Figure 7. Excerpt taken from the simulation for SFR II**

The facade has to be slightly modified in order to tie the cleaning robot to it.

Figure 8 shows in a total view all the components of the whole cleaning system for cleaning standard facades in its second experimental set-up: the robot system itself (1), the facade (2) built up in the lab of Fraunhofer IPA, the supply unit (3), the control unit (4) and the umbilical cord (5). Figure 9 and 10 will show details of the facade and the robot system.

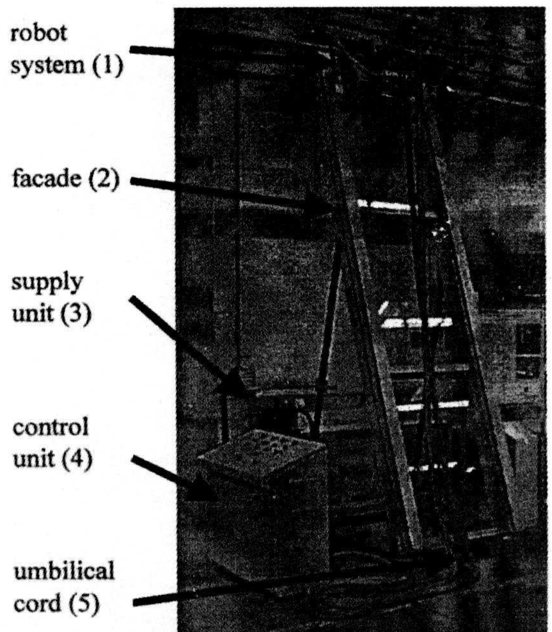



**Figure 8. Total view of the standard cleaning robot *SFR II***

The standard cleaning robot *SFR II* is put up at the joint interface on this modified facade. The control and supply unit is to be connected via the umbilical cord. After starting the system, the robot now fully automated cleans the three test windows. These are separated through horizontal bolts which stick out from the surface. These are to be overcome by the cleaning head during the cleaning process.

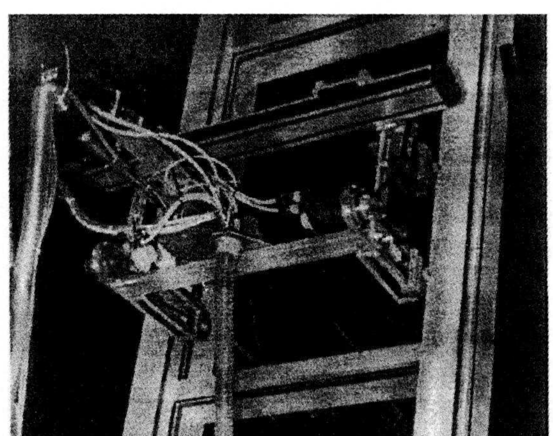


Figure 9. Top view of the standard cleaning robot *SFR II*

The cleaning robot is connected to a supply unit and a control unit through hoses and cables. It supplies the cleaning head with water and processes the sucked off used water. It consists of the pressure pump, the suction device, the filter and a tank. The control unit is in charge of the regulation and control of the entire system. It is connected with the sensors and the servo motors of the robot through information and performance cables. The computer will calculate in advance the necessary movements according to the facade which is to be cleaned.

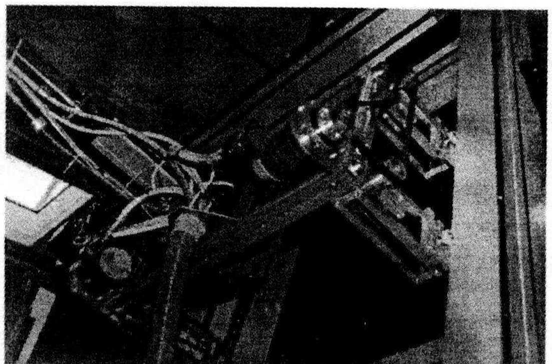


**Figure 10. Detailed view of the standard cleaning robot *SFR II***

During the experiment optimization potentials are worked out and collected for the further development of the facade cleaning robot.

The next step of development consists of minimizing the components, making the robot system suitable for manufacturing and assembly.

The user interface (MMI, Man-Machine-Interface) has to be designed simple and safe. Safety has to be ensured at all times for people, as well as the building itself.

## 5. THE CLEANING HEAD

The cleaning head is a special development of the Dornier-Technology GmbH and protected by copyright. Figure 11 shows the view of one of the first camouflage prototypes of a cleaning head through a window from the inside of a building.

The cleaning consists of a abrasive procedure with rotating brushes, water and cleansing agent, measured out according to the need and degree of dirt. The area of cleaning is watertight. The cleaning head floats on a thin surface of water and does not scratch the panes therefore. Since the water is sucked off at the outer edge, it is possible to reuse it again several times by recycling it through a filter. The cleaned windows are immediately dry and free of streaks.

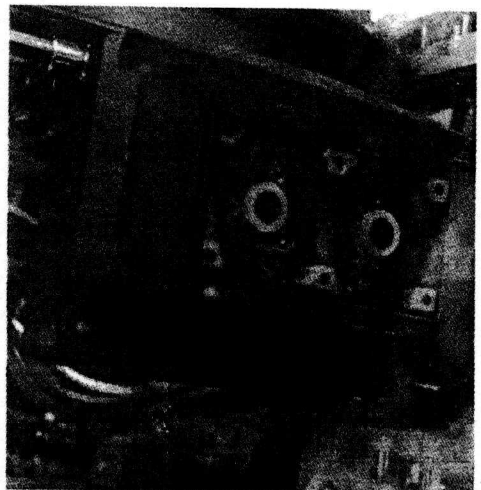


Figure 11. **A camouflage prototype of a cleaning head of the Dornier-Technology GmbH**

With that one and other cleaning heads all the various cleaning experiments are executed, taken down and analyzed: individual tests and endurance tests, varying kinds and degrees of dirt, varying panes and kinds of glass, varying stain-resistant or nonstick coatings.

## 6. RESULTS

The tests show that it is possible to realize the control, sensoring and kinematics but it needs more than using the current state-of-the-art. Last but not least the development in the technical fields is steadily going on, so the aim of minimization of the system's geometric extension will be reachable.

Business economic studies give clear evidence for the economic advantage of the standard cleaning robot as against the up to now manual cleaning.

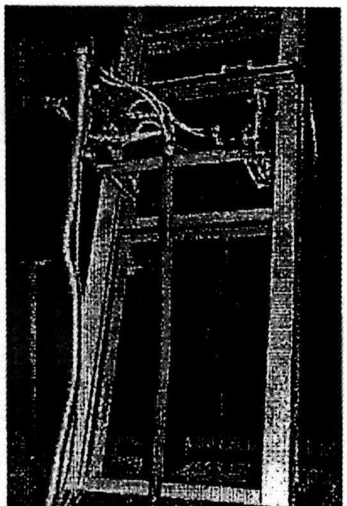
The quality level of our cleaning results by far exceed manual cleaning. In particular in the case of hard reachable spots or upside down cleaning. Automated cleaning ensures constantly well cleaning results.

The presentations of the test robots (*SFR I* and *SFR II*) as exhibits on fairs or at the research lab of the Fraunhofer IPA caused great interest with all potential users: architects, building contractors, building coordinators, cleaning suppliers, facade and cleaning device manufacturers.

## 7. SUMMARY

*SFR* is a short for Standard Facade cleaning Robot. It means a portable cleaning robot which can be used on various buildings and integrated in the facade. Simple control, flexible use, safe and reliable operation, as well as the attractive and robust design distinguish the solution of the Fraunhofer IPA in its later, final version.

Figure 12 shows the entire second prototype of *SFR II*, a standard facade cleaning robot.



12. Front view of *SFR II*

The operation of the standard facade cleaning robot functions as follows:

The cleaning service person or the janitor insert the robot downstairs, respectively the ground floor, on the accordingly prepared facade. The control and the supply unit are connected through simple plug connections. The robot is turned on. Now it receives the necessary and specific data in the form of transponders, code numbers, barcodes etc. about the facade to be cleaned. The computer calculates the control program. Right after the user's release, the robot starts the cleaning cycle and runs along a vertical row of windows all the way to the top. There, it begins to clean every single pane meanderingly downwards. The actual cleaning speed is now approximately 60sqm/hour. This value can be clearly improved by using a larger cleaning head and further measures of optimization. The user can work on something else while the cleaning system is in operation. A radio signal indicates the time when to switch the robot to the next row of windows. The following cleaning cycle is started. If necessary, the control shows the user whether the water or the cleansing agent have to be exchanged or renewed. Once all the windows of the building have been cleaned that way, the robot can be dismantled and driven to the next place of action.

The *SFR II* possesses three degrees of freedom. The robot runs up and down the row of windows with the y-axis. The x-axis ensures that the cleaning head moves on the pane from left to right. The z-axis enables the delivery to the pane, over and across the horizontal bars, any kind of sun blinds or other obstacles. Safety precautions or roadblocks and Emergency-Stop functions are provided and implemented.

## 8. FUTURE PERSPECTIVE AND CONCLUSION

The two prototypes have mastered their series of experiments successfully. The potentials of optimization are recognized and were or are transformed. Further development focuses now on the improvement and simplification of the tie to the building, weight reduction and increase of the flexibility as well as the cleaning performance of the robot. The next target are outdoor tests at a facade with vertical jambs and horizontal bars of an experimental building.

The response to the presentation of the robots at the fairs IRW (Cologne, Germany) and HMI '98 (Hannover, Germany) were outstandingly positive, and the further development of the standard facade cleaning robot is expected.

By switching the cleaning head for other effectors the robot is enabled to perform other important tasks, so it can broaden its field of operation. According to the chosen system, it can perform maintenance tasks, inspection or painting tasks, the renewal of sealing compounds or the cleaning of sun protection systems as well as bars or window seats.

Another possibility and with a huge demand [4] is to develop a system which can be mounted to existing buildings during renovations (fig. 13).

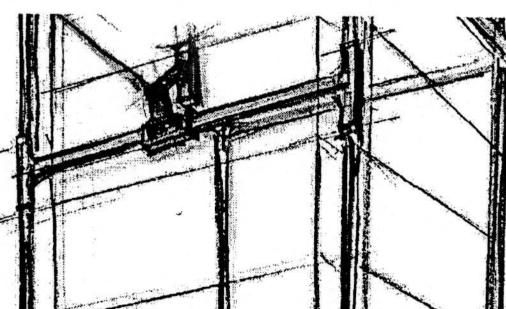


Figure 13. Vision of a cleaning system to be mounted to existing buildings during renovations

The possibility to offer a modular system that can be used with little changes on new and old (existing) buildings is the main concern of the further and ongoing research and development of the Fraunhofer IPA.

# 9. A DEDUCED SPECIAL SOLUTION

Based on those research results of the standard facade cleaning robot, it is possible to deduce quickly individual special solutions for new immediate employment with relative little effort of development.

So the future inside cleaning robot of the glass roofing of the train station "Lehrter Bahnhof" in Berlin, Germany (fig. 14) is developed by the Fraunhofer IPA and corresponds to the basic operational principle of the standard facade cleaning robot.

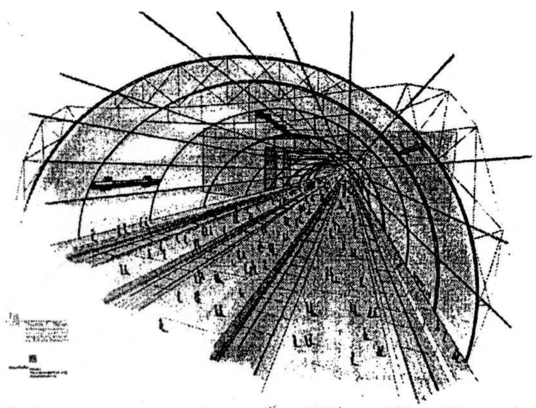


Figure 14. The vision of the cleaning robot "Lehrter Bahnhof, Berlin"

# 10. TECHNICAL DATA

Cleaning robot (total)

| | |
|---|---|
| dimensions: | 950·1430·450 mm (l·w·h) |
| handling weight: | 5,0 kg |
| position accuracy: | 5,0 mm |
| total weight: | 45,0 kg |
| cleaning speed: | effectively 60sqm per hour |
| umbilical: | electricity, air pressure, control signals |
| material: | aluminum |
| translatoric drives I: | Wittenstein Motion Control |
| translatoric drives II: | Control Techniques Dynamics |
| control unit: | Control Techniques Dynamics |
| cleaning head: | Dornier-Technologie GmbH |

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