Facade Cleaning by Service Robots

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Abstract

The paper describes a service robot which has been developed and realized for glass facade cleaning. It is the world-wide first fully automatic system for cleaning vaulted glass facades. The shape of the building which has to be cleaned is a special semi cylinder of glass and steel. The robot moves through the facade-side mechanical construction of the building and cleans the facade outside. The design, the mode of robot operation and the control concept are described.

1 Introduction

A new generation of service robots is conquering the service sector market. Now that robots have revolutionized industrial production, they are also beginning to prevail in the service sector. Wherever monotonous, dirty and dangerous work must be done, service robots are being used more and more.
The Fraunhofer Institute for Factory Operation and Automation (IFF) in Magdeburg, Germany, is intensively exploring facade cleaning robot systems. Interest in this area is generated by the fact that big buildings with homogenous designed facades with relatively flat surfaces are ideal for automated cleaning. These surfaces are also often difficult to access by people, and personnel costs are high. Moreover the automatic facade cleaning systems have the advantage, that the robot fits in the architecture more than conventional gantries. If the task of cleaning a facade is given to a service robot system, the robot could reduce expensive personal costs.
A facade cleaning robot gives important benefits compared with personal cleaning:

- short cleaning times for large surfaces
- low operating costs, no personnel costs
- cleaning of difficult-to-access areas
- flexible cleaning cycles, cleaning of especially dirty facade areas or cleaning on demand
- consistent value and aesthetic appeal through ease of regular cleaning
- ecologically friendly cleaning

Another interesting benefit may be publicity and the message of a modern enterprise or building which is given to tenants, visitors and customers by such an automatic cleaning robot system.

2 Task Description

The kinematics of the robot and the cleaning procedure depend on different conditions. The most important point is the architectural design. Now the cleaning robots have to be developed especially for any building, there exists no 'allround' system yet. Of course, a modular system for different facade types must be used in future. Facade cleaning robots could work at any building with a large glass facade and with a homogenous shape.

2.1 The Building at the Leipzig Trade Fair

The building the cleaning robot was developed for is the central building of Leipzig Trade Fair, Germany. This building is completely built with glass and steel. The vaulted glass hall, jewel of the new Leipzig Trade Fair, is 243 meters long, 80 meters wide, and has a central height of 28 meters. A surface area of 25,000 square meters is covered by glass.

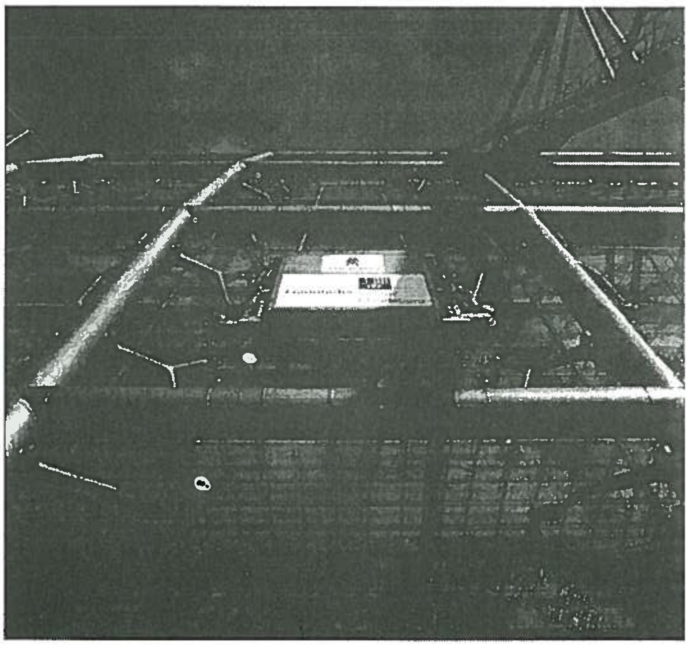

Figure 1. The glass building and the robot

The carrying steel construction is located at the outer side of the glass facade. Glass panes are hanging under suspensions of the steel construction. The hall has an external steel support structure with the glass panes attached under the steel at a distance of 0.35m. The steel construction is organised as a grid with quadratic segments with a side length of 3.12m. The number of segments from the top of the hall to the bottom is 15. 80 stripes of such segments are located on each side of the hall, about 4.800 glass panes (1.56m x 3.12m) are hanging under the construction. Due to architectural restrictions no changes at the facade or the steel carrying construction were allowed.

2.2 Robot dimensions

The robot dimensions are strictly fixed according to the building construction:

- Maximum height: moving through the tunnel of the steel construction and the glass the height of the robot is limited to the working space of 38cm. Due to mechanical tolerances and the convex facade surface a height of 30cm is possible.
- Maximum width: the tunnel width dimension is limited by the glass suspensions. To serve tolerances of the building construction a maximum width of 1.5m is possible
- Maximum length: the length is also limited by the steel construction. To put the robot down to the glass surface by a lift-construction the robot has to be moved down through the steel construction.
- Maximum weight: the glass panes allow a maximum robot weight of 250 kg. Also a optimal force-distribution is needed to avoid any overload on the glass surface.

The robot moves through the small tunnel on the glass. The robot itself has a very flat shape to match the tunnel geometry.

3 Solution of the Cleaning Robots

The development of the robot shared in following tasks:
- automatic positioning of the robots at the segments
- construction of the robot, the maximum dimensions of the robot are fixed, all drives and electrical elements, the rope, water and cable drums and the cleaning units must be mounted on the robot
- kinematics of the robot
- navigation of the robot, control algorithms
- multisensory system
- user-friendly operator surface

3.1 Principal description of the automatic cleaning robot

At the apex of the roof, a trolley has been installed to position the robot which can then ride the entire length of the ceiling. On both sides of the trolley there are elevators to lower the robots down the glass surface and lift them back up again.

The cleaning itself happens during the downward pass of the robots. They are navigated by the use of two kevlar ropes which are attached to the trolley. In this way minimal deviations in their movement can be balanced. The robots move on specially coated wheels enabling minimal friction over the glass, and therefore avoiding even the smallest scratches. In the upper flat area of the roof, the robot is powered by a fifth wheel; in the under section gravity is sufficient. In this way, it is insured that both robots can ride down the 45 meter length of the hall with a maximum angle of exactly 70 degrees.

Piping for water and power for electricity and data transfer are hooked up from the inside of the hall directly to the trolley at the top of the roof. Both of the cleaning machines are supplied through the respective tubes and cables with the necessary input required. All rope, piping and cable drums are mounted right on the robot. Therefore they do not have to be pulled over the surface of the glass, but laid on top of the glass panels and silicon seals without risking damage to the surface.

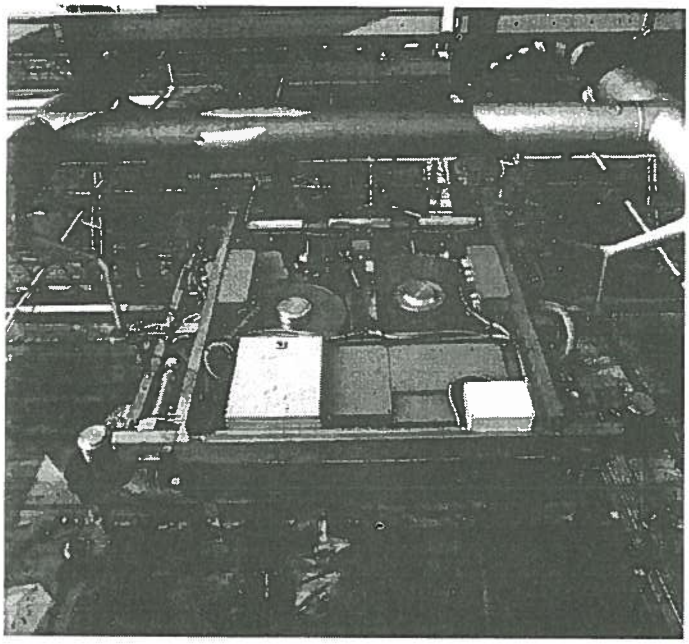

Figure 2. A view inside the robot

3.2 Cleaning procedure

The glass panels are cleaned with roller brushes at the track the robot moves and extendible, adjustable rotating plate brushes at the side glass surface. In this way, all fixtures and glass areas covered by the fixtures can be cleaned. Cleaning is done exclusively with warm water – without detergents – and an optimized brush system.
The cleaning procedure for washing around the suspensions is performed in two steps: First the arms are driven out by linear axes and the brush heads swing to the rear side. When an arm is completely driven out the second step begins. The plate brush swings to the front and the arm retracts until a suspension or the robot itself is reached. The brush swings into the middle position and the arm retracts completely. For environment protection only clear, warm water is used for cleaning. Due to ecological restrictions no chemical agents are used. To avoid water stains the cleaning water is deionized.

4 Mechanics and Control

4.1 Navigation requirements

When the robot was set down a complete track with a length of 45 meters has to be cleaned. The sensor system of the robot partly uses the glass suspensions for navigation. On the one hand the effect of thermal extension of the whole steel-glass-construction is problematical with regard to the long distance. On the other hand, the tolerances of the steel construction are rather coarse. Therefore the navigation system must be able to work despite these problems correctly. In addition the sensor system is able to detect sensor problems and sensor errors while using the sensors to navigate (self checks).

4.2 Control

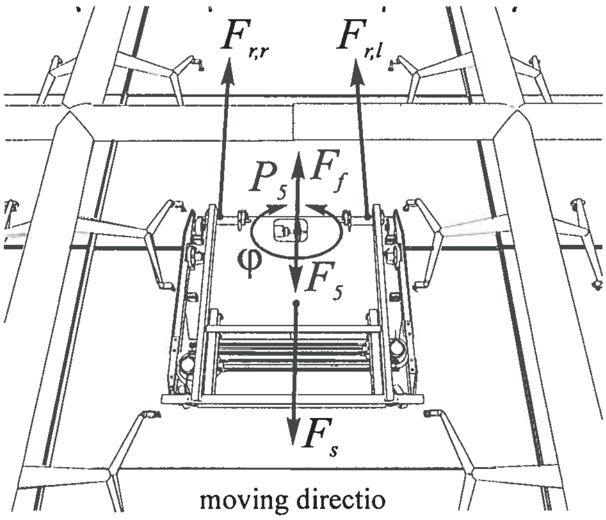

Figure 3. Robot scheme

The robot is driven in two ways. The first driving force is the slope-force F_s. If the slope-force F_s is greater than the friction-force F_f the robot can be driven only by unwinding the ropes. At the first few meters the slope-force is smaller than the friction-force. In this case it was necessary to raise up a new force. A 5th wheel (P_5 in fig. 3) was implemented to drive the robot. On this wheel a special coating was applied to increase the friction between glass and wheel.
Fig. 4 describes the control scheme for the 5th wheel. If the value of the smaller rope force F_{min} falls below the value F_{rp} then the 5th wheel is put on the glass. By u_5 the necessary rate of the 5th wheel is given.

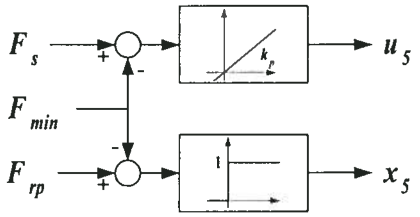

Figure 4. Control scheme of the 5th wheel

The navigation between the suspensions is performed by controlled unwinding of the two ropes. If the unwinding of the left rope is different from the right rope a steering torque arises around point P_5 (fig.3) and causes a rotation motion. The passively steered wheels in front of the robot make it possible to follow this motion. Because the centre of gravity lies lower to P_5 a resulting torque acts contrary to the steering torque.

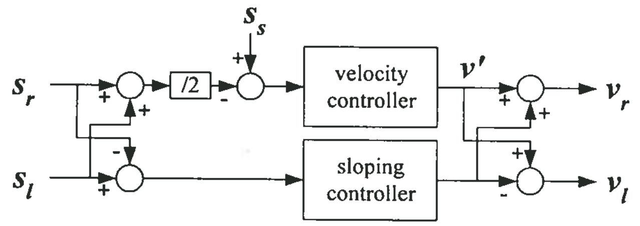

Figure 5. Motion control

The information about position and angle of the robot is detected by two wheels equipped with incremental sensors. The average of left and right position is used for setting the velocity of the robot. The difference between both values is used for correction of the moving direction. A scheme of this control algorithm is shown in fig.5. To avoid larger differences between real position and measured position two optical sensors detect the suspensions. Along a distance of 0,7-1m the measurement system is referenced. To prevent a parallel shift along the path two guide rails were constructed. These rails have the function to lead the robot motion. It is also possible to exert a force on the suspensions. The robot automatically pushes itself away from the suspensions to the middle of its path. To avoid any damaging of the panes and the sealing of joints a passive control algorithm was implemented (figure 6). By the use of a hardware control the cable and the water hose are putting down the glass. By i_{dr} the motor-current for driving the both drums is set by the IPC.

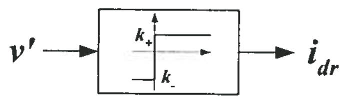

Figure 6. Control scheme of the motor-current for the cable drum

Due to the proportional reaction between motor-current and driving-torque the tensile force is nearly constant while laying down the cable. Due to the occurring traction power the driving-torque has to be smaller during the downward motion than during the upward motion. Additionally the driving torque has to be higher than the static friction.

5 A look ahead

The areas for application for automated cleaning systems will expand considerably. The simplification of the cleaning process will support the trend for glass construction. It makes sense to include the concept of cleaning systems into the planning and design stage of a building. In this way, the architect has the opportunity to address early the concerns cleaning of difficult-to-access facade areas.

The Fraunhofer IFF is currently developing customized solution concepts of automated cleaning systems for different types of buildings. At this time, their focus is on slanted and vertical facades.

The focal points of development are in the:

- adaptation of cleaning robots to gantries
- robot kinetic systems for different facade types
- sensor and control techniques
- development of ecologically friendly cleaning techniques with high cleaning performance
- implementation of additional functions for inspection

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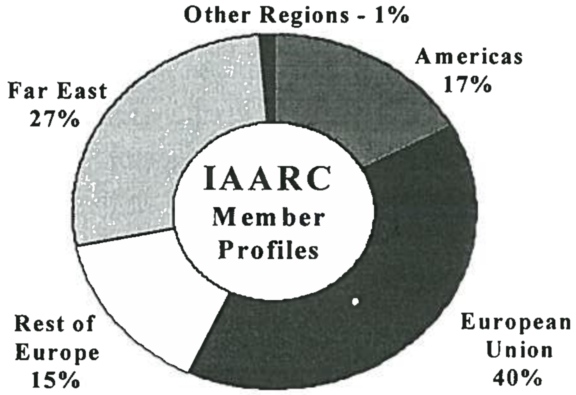

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