Control System for a Semi-automatic Façade Cleaning Robot

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Abstract: In the last years, several robots for building façade cleaning have been designed and some prototypes have been developed. However, most of these robotics systems are too expensive to be introduced in the market or are only able to cope with very simple completely flat glass façades. Funded by the European Commission, a consortium formed by several European enterprises and research institutions has developed a semi-automatic low cost robotic system that is able to cope with the cleaning tasks of most of the existing large building façades. In this article, after a description of the robotic façade cleaning system we present the innovative control architecture that has been implemented.

Keywords: Automatic Façade Cleaning, Robot Control, Cleaning Robots.

1 INTRODUCTION

Nowadays the number of buildings with large glass or flat façades is increasing all over the World. These façades must be periodically cleaned with manual procedures that supposed high cost and risk for the workers which have to develop their work under heavy conditions. Although the cleaning cost depends a lot on several factors as the façade characteristics, the cleaning periodicity or the total surface to be cleaned, the average cost is € 8-9 per square meter. A typical building of 12.000 m^2 supposes a total façade cleaning cost of € 100.000 and this task is usually done every year. The use of an automatic or semi-automatic cleaning system can lead to around 60% savings over existing practice.

Automation and robotics technologies allow environmentally friendly façade cleaning, helping to reduce the cost of these tasks. Additionally, these systems overcome the current worker safety problems associated with difficult and dangerous access, contributing to a zero injury and fatality working practices [1].

Because of the increasing number of high-rise buildings and large glass façades and the resulting problem of safe and effective cleaning, a lot of effort has taken place in the last few years to develop automated cleaning systems. The majority of systems conceived and developed thus far are in Japan [2] and Europe [3]. The first automated cleaning systems for high-rise building were used in Japan in the middle of the 80's. These systems were mainly designed for use on specific buildings. For safety purposes or in order to guide the robot's movement on the façade, they often required additional construction such as guidance rails to the façade.

The practical application of the existing systems mostly failed because of either a weak safety concept, poor cleaning quality, required additional construction to the façade, or simply due to expensive initial or operating costs. At this time, there is only one known system that is in practical operation. That is the automatic system for the cleaning of the vaulted glass hall of the Leipzig Trade Fair, Germany (Figure 1), which was developed by the Fraunhofer Institute IFF, Germany [4]. It must also be added that this system is only applicable to this particular building.

Figure 1. Automatic Facade Cleaning System for the Vaulted Glass Hall of the Leipzig Trade Fair (Fraunhofer FhG)

Table 1 shows the different known robotic façade cleaning systems. Figures 2 to 4 show some of these systems.

Funded by the European Commission, a consortium formed by several European enterprises and research institutions has developed a semi-automatic low cost robotic system (CAFE) that is able to cope with the cleaning tasks of most of the existing large building façades.

This system is with minor changes adaptable to the largest possible number of buildings with homogeneously-designed façades. Additional constructions to the façade such as guide rails or scaffoldings are avoided or made unnecessary. The requirements for the control and sensor concepts are very specific, because the proposed robotic system is able to operate under adverse conditions such as changing weather conditions.

In this article, we present the description of the robotic façade cleaning system and, after that, the selected control architecture and the implementation of this concept in the real system.

Manufacturer	**Robot**	**Country**	**Application**	**Kinematics**	**Overcoming of obstacles**	**Facade type**
Taisei	Exterior Wall Painting Robot	Japan	Coating	rail guided	No	Vertical
Taisei	Tile Separation Detection Robot	Japan	Tile inspection	Tensed up with cables from roof to floor	No	Vertical
Kumagai Gumi Co. Ltd.	KFR-2	Japan	Coating	Cables, vacuum cups	No	Vertical
Shimizu Corporation	SB- Multi Coater	Japan	Coating	rail guided	No	Vertical
Kajima Corporation	Tile Separation Detection Robot	Japan	Tile inspection	Tensed up with cables from roof to floor	No	Vertical
Kumagai Gumi Co. Ltd.	Automatic Diagnosis System of Tiled Wall Surfaces	Japan	Tile inspection	Tensed up with cables from roof to floor, wheels	Yes	Vertical
Toshiba Cooperation	Vacuum Suction Self-Traveling Wall Washing Machine	Japan	Wall cleaning	Vacuum cups	No	Vertical
Obayashi Corporation	Wall Inspection Robot	Japan	Inspection	Vacuum cups, secured by cables	Yes	Vertical
Takenaka Komuten Co. Ltd.	SC 11-101	Japan	Tile inspection	Vacuum cups, secured by cables	No	Vertical
Tokyo Construction Co. Ltd.	Wall-Surface Operation Robot	Japan	Tile inspection	Vacuum cups, secured by cables	No	Vertical
Mitsubishi Electric Cooperation	Automatic Window Cleaning System	Japan	Façade cleaning	Rail guided	No	Vertical
Shimizu Corporation	Canadian Crab	Japan	Façade cleaning	Vacuum cups, secured by cables	Yes	Inclined
Fraunhofer-Institut IFF	Cleaning robot for the Glasshall Leipzig Trade fair	Germany	Façade cleaning	wheels, secured by cables	No	Convex
Comatec	-	France	Façade cleaning	Vacuum cups	No	Inclined
Robosoft	-	France	Façade cleaning	Rail guided	No	Horizontal
Robosoft	Autonomous Window Cleaner Robot for High Buildings (EC: AUTOWIND)	France	Façade cleaning	Rail guided	No	Vertical
Fraunhofer-Institut IFF, Dornier Technologie	SIRIUSc	Germany	Façade cleaning	Rail guided	Yes	Vertical
Newcastle University; OCS Group; Cradle Runways	Arcow	UK	Façade cleaning	Rail guided	No	Vertical
CSIC	Tito	Spain	Façade cleaning	Air suction	No	Vertical

Table 1. Façade Cleaning Robots

Figure 2. ARCOW Façade Cleaning System
(Newcastle University; OCS Group; Cradle Runways)

Figure 3. SIRIUSC – Automatic Facade Cleaning System
(Fraunhofer FhG, Dornier Techologie)

Figure 4. TITO – Automatic Facade Cleaning System
(CSIC)

3 CONCEPT OF THE CAFE ROBOTIC CLEANING SYSTEM

All the high buildings use commercial carrier systems that support a gondola that moves on the façade for manual cleaning. One or two operators are needed for this task. Based in the existence of the carrier system on the building roof, the CAFE robotic system uses it to reduce the costs of the vertical and horizontal movements. The system uses a commercial carrier with minor modifications for movements in axes X and Y (Figure 5).

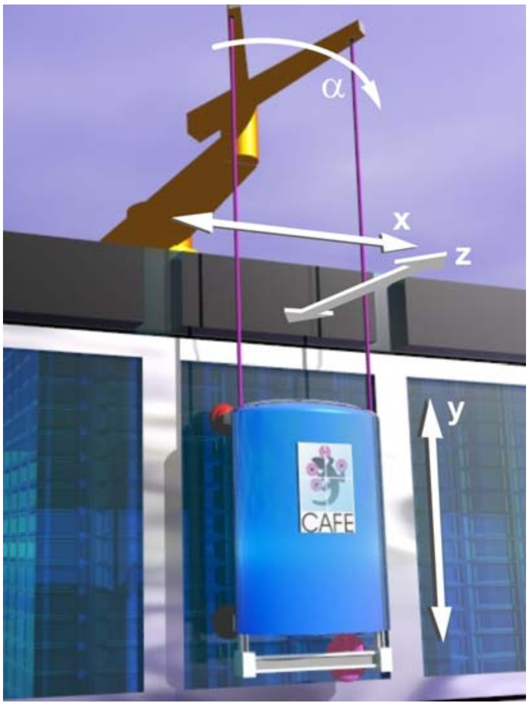

Figure 5. CAFE Façade Cleaning System Concept

Completely autonomous systems result too expensive for the market and the proposed system has been designed to perform the cleaning task in a semi-automatic way. This means that many of the tasks are performed in a completely autonomous way; however, because of security and economic considerations, a human operator permanently controls the robot operation.

The complete semi-automatic cleaning system is operated by a single person physically situated on the ground below the robot. However, most of the task can be performed in a completely automatic way.. The operator has to install the machine at put it in work giving periodical attendance when necessary (filling deposits, changing task, etc.). To achieve this, it is necessary to program the robot adapting it to the building's façade. This task is necessary only one time, previous to the work and it is not be very time consuming. Due to the low cost of the system, buildings with large façades can have dedicated machines.

The robot cleaning system has been decomposed in four different modules (Figure 6):

- Cleaning Module (CLM)
- Kinematics Module (KM)
- Carrier Module (CaM)
- Control Module

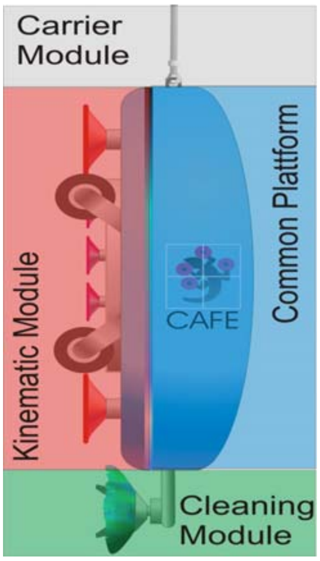

Figure 6. Arrangement and interconnections of the hardware modules

The Cleaning Module is in charge of the actual façade cleaning. It mainly consists in a cleaning mechanism and a positioning system. The most important features of the cleaning module include:

- Cleaning with brushes and water (environmentally-friendly)
- Water recycling system (low water use)
- All actuators pneumatic (compliant motion, simple control structures, robust)
- Passive degrees of freedom in kinematics to account for unevenness in façade surface and to protect against hard collision with framework when moving up and down the façade (braking distance)
- Sensors for detecting glass framework and overseeing the condition of the cleaning module

The cleaning system is able to clean up to between 3-10mm away from a window pane. The cleaning Module is shown in Figure 7.

The carrier is the part of the façade cleaning system that safely holds and provides horizontal, vertical and transversal motion to the kinematics and cleaning modules. It is installed on the building rooftop and moves over rails or on a concrete path (guided along the parapet), holding and providing motion to the cleaning and kinematics modules by means of cables. While the cleaning robot might be moved from one building to another, the carrier system will generally stay on the building rooftop.

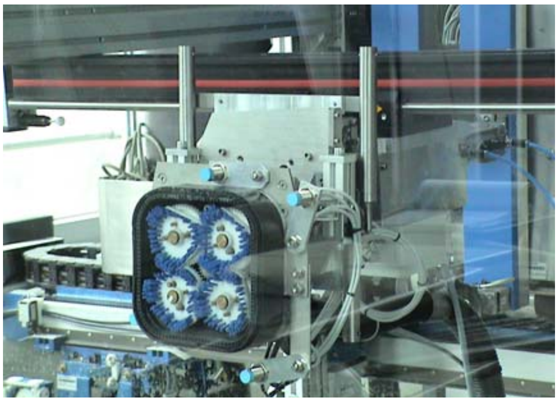

Figure 7. CAFE Cleaning Module

The carrier must position the kinematics and cleaning modules on the façade at the beginning and between cleaning operations. The carrier positions the cleaning and kinematics modules in the x axis through its movement along the rooftop. The vertical motion and positioning in the y axis is transmitted by the winding or unwinding of the cables. The adjustment of the distance to the wall z is obtained by controlling the angle a (see figure 5).

The carrier must also be able to bring the kinematics and cleaning modules down to the floor or hoist and deposit them on the rooftop in order to perform maintenance operations, refill cleaning water or even lay those on a vehicle on ground to be transported somewhere else.

The Kinematics Module establishes contact between the cleaning head and the window pane. This contact is necessary for generating a reaction force of the cleaning head against the window pane. The presence or absence of the contact is controlled by the system controller accordingly to nominal and non-nominal situations.

In nominal situations the contact must be established during the entire cleaning task and hoisting operation. The break of contact can induce serious problems like bumps towards the facade caused by oscillations of the carrier. In case of this non-nominal situation a safety module must be activated in order to avoid oscillations.

4 CAFE ROBOT CONTROL SYSTEM

The term Control Module refers to the general architecture of the control systems of al the modules, and encompasses the concept for controlling each individual system. The cleaning task has been decomposed into different actions that must be performed simultaneously by the different robot modules. The control module is in charge of the synchronization of all this tasks. The control scheme has been implemented using a hardware decentralized and a software centralized control architecture. This architecture is considered more appropriate for the control system than a decentralized one (Figure 8).

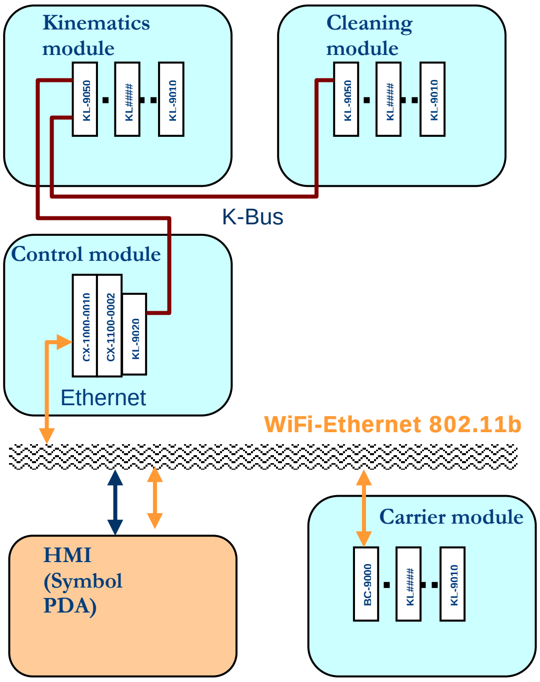

Figure 8. Control System Architecture

A wireless connection (Ethernet WIFI 802.11b) is used for the connection between the Control Module and the operator interface, and between the Control Module and the carrier. For safety reasons and for control purposes a simple PLC system is included on the Carrier Module. This configuration reduces the total cost of the system and simplifies the integration. The Control Module, the Carrier Module (for safety reasons) and the Operator Interface, include their own microprocessor based computer. The safety of this communication is critical and it has been guaranteed by a watchdog system. In case of failure of the wireless communication, all the system adopts a safety position and can be recovered manually from the Carrier Module Control. The communication scheme is shown in Figure 9.

For the operator interface a pocket-PC (windows CE) system was selected (Figures 10, 11 and 12). This system allows intuitive and easy interface via wireless connection. The exchange of information between the Control Module and the Operator Module is based on a wireless WIFI-802.11b compliant connection. The communication can be encrypted under WEP protocol and the access point allows configuring specific IP directions to connect.

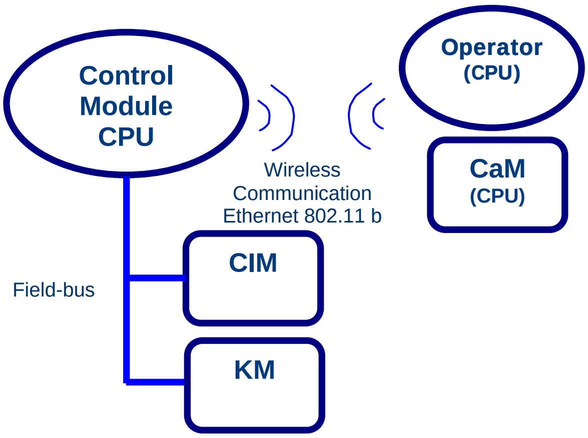

Figure 9. Communication scheme of the control system

Figure 10. Operator Interface Device

The Server-side is included in the Control Module whereas the Client-side is in the Operator Interface. Both the Client and the Server are programmed with C# and compiled for the Microsoft .NET platform (so .NET Compact Framework is required).

The communication is established after accepting the Server a request from the Client. No hand-shake protocol is implemented. The Server is able to detect both when the connection is fortuitously cut and when it has not been recently used and reinitiates its state to a new connection. The Client will receive the data and will only send Operator orders when produced.

At each cycle of the PLC program, the wireless connection is checked. If a lack in the communications is detected, an emergency process is started in both the control module and the carrier module. In the control module the emergency process commands the kinematics and cleaning module to adopt a safe configuration. In the same way of working, the CX1000 of the carrier will stop any movement of the carrier and enables the manual control of the system.

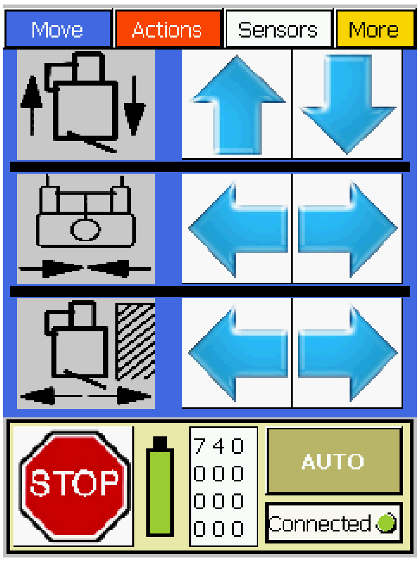

Figure 11. Operator Interface Screen for manual control

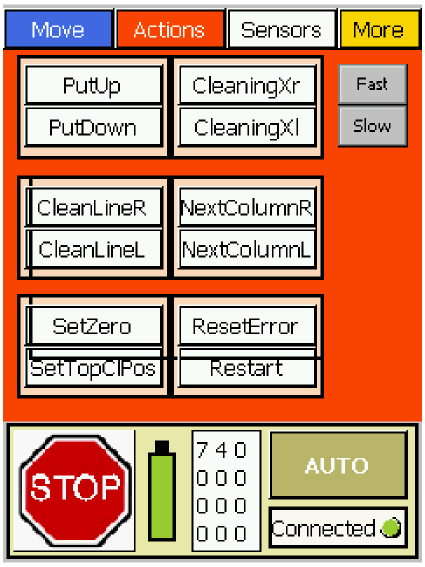

Figure 12. Operator Interface Screen for automatic control

5 RESULTS

After the development of the prototypes of the different modules, the complete cleaning system was merged. Some systems were refined and several parts of the control Software were modified. The performance tests were successfully accomplished in automatic way .

From the test operation the following was concluded:

- The overall cost of the system can be under 50 T€ on sale
- The operating costs are under 3 T€ per annum
- The cleaning speed in total is above 200 m2 per hour
- The system is usable at facade areas of under 7000 m2
- The cost saving is of up to 5 € / m2
- The roof car costs (depending from comfort) is around 20 T€ on sale
- The robotic system is able to serve more building of the owners
- The interface set cost for changeable operation on existing BMU s is under 15 T€

Figure 13 shows a real image of the CAFE prototype.

Figure 13. CAFE Robotic Façade Cleaning System

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